INTRODUCTION TO HIGH STRAIN DYNAMIC PILE TESTING AND RELIABILITY STUDIES IN SOUTHERN INDIA

Ravikiran Vaidya
Geo Dynamics, Vadodara
geodynamics@satyam.net.in

ABSTRACT: High Strain Dynamic Pile Testing is increasingly used as a tool to evaluate pile capacity and integrity for pile foundations and its need has also increased due to increased usage of large diameter piles and consequently heavier loads. However, there is limited information published about the reliability of these tests in the Indian context and with particular reference to Southern India. The present paper describes introduction to High Strain Dynamic Pile Testing, basic principles and applications, limitations etc. including CAPWAP analysis program which is a mandatory requirement for proper capacity evaluation after the PDA field test is completed. The paper also describes five such co-relation studies between static and high strain dynamic test results for 1000mm and 1200mm bored piles in Bangalore, Chennai & Cochin. These co-relations prove the reliability of the test methods as well and the expertise of the engineer in such testing.

1. INTRODUCTION

The significant thrust on infrastructure projects like flyovers, bridges, metro rails, multi storey towers etc., has made large diameter bored more common and these carry heavy loads. With emphasis on time bound projects, there is a need to introduce technologies that cut down construction time without compromising the safety or durability of the structure. High Strain Dynamic Pile Testing or HSDPT and Pile Integrity Testing are two such powerful tools to evaluate the capacity and the integrity of the pile shafts in quick time. These technologies are standardized in USA, Europe and most of Asia since very long. They have been in use in India since 1988. However, their use has been limited till 1998 as not enough data was available and work done to justify its use and application on major infrastructure and real estate projects. Recently, numerous data has been published for work done by the author in Western India, however there is limited information on the use of this method in Southern India.

The method is now getting increased acceptance in Southern India also as reliability studies have been conducted by the author for large diameter friction and end bearing piles with loads upto 875 tons. The paper describes few such case studies as well as the test procedure, principle, applications and limitations of the high strain test method. For all these tests the Pile Driving Analyzer (PDA)TM was used in conjunction with CAse Pile Wave Analysis Program (CAPWAP)TM to evaluate the static pile capacity using dynamic impact.

2. PRINCIPLE OF HIGH STRAIN DYNAMIC PILE TESTING

The basic purpose of dynamic testing is to evaluate pile capacity and structural integrity of the pile and the total settlement under the measured capacity. Strains are recorded by the Pile Driving AnalyzerTM with the help of strain transducers attached to the pile, whereas accelerometers record the accelerations generated in the pile caused due to the impact of a heavy hammer falling from a pre determined height. The PDA converts strain to force, and acceleration records are converted to velocities. The resistance developed by the pile is then 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 CAPWAP analysis conducted on field data. Further discussion is beyond the scope of the paper. Field results usually includes capacity of the pile, based on an assumed damping value, stresses in the pile, net settlement and total settlement of the pile, skin friction, end bearing, etc., although 30 different parameters are evaluated.

3. CAPWAP ANALYSIS

The CAPWAP program is an analytical method that combines measured field data with pile wave equation type procedures, to predict the pile's static bearing capacity and soil resistance distribution. Measured force and velocity data is directly input from the PDA. Based on the measured velocity data, the program computes the force required to induce the imposed velocity. Both measured and computed forces are plotted as a function of time and the iterative analysis is continued till there is good agreement between both the curves. If the agreement is not satisfactory, the soil resistances at the pile point and along the pile are adjusted until a good match is obtained. This gives the frictional distribution along the sides, the end bearing component of the pile, as well as better estimates of the actual static pile capacity measured during field testing.

4. METHOD OF TESTING

The method involves attaching strain transducers and accelerometers to the sides of the pile approximately 1.5 times pile dia. below the pile top. A pair of transducers is fixed onto opposite sides of the pile so as to detect bending in the pile if any during testing. These transducers are then connected through the main cable to a Pile Driving Analyzer (Model PAK or PAL), which is a State of Art Pentium Computer System with ability to record strain and acceleration measurements and convert them from analog to digital form. The signals are then triggered by the impact of a ram falling from a pre-determined height. The ram weight and fall height is determined in advance. As a thumb rule, the ram weight shall be 1-2% of the testing capacity of the pile. For case histories described below, hammer weight equal to 1% of test capacity was used and the drop height varied from 1m to 4.5m, although Wave Equation Analysis Program (GRLWEAP) can be used to know the weight of the hammer and its fall height prior to testing. A 50mm thick plywood cushion and 50mm thick steel plate were placed on the pile top to avoid any damage to the pile during testing. The tests were generally conducted as per ASTM D4945-96. The following describes in brief individual case studies on each flyover / bridge.

5. CASE STUDIES

5.1 Highway Project near Chennai

It was proposed to test three initial piles both statically and using PDA to establish a co-relation between both the forms of testing & evaluate the reliability of the high strain dynamic pile test method. For two piles TP1 and TP2, static testing was done first followed by dynamic testing since this is the normal practice. However, for Pile No. TP3, HSDPT was conducted first followed by static testing so that the results of static testing are not known in advance. All the piles were 1200mm diameter with an approximate depth of 23m. The design load was 350 tons and they were to be tested for an ultimate capacity of 875 tons. The piles were friction piles and the soil was dense to very dense silty sand followed by moderately weathered sandstone. For PDA testing, a 9-ton hammer fabricated specifically on site was used. A guide with a fall of upto 4.5m was also provided to ensure concentric fall of the hammer. The setup arrangement is as shown in Fig.1.

Fig. 1 Site Arrangements for HSDPT for Chennai Project

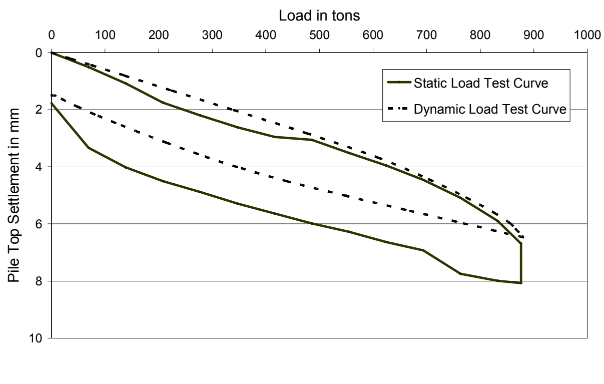

Fig. 2 Static Vs. PDA Test Match for TP1 at Chennai

Refer to Fig.2 & Fig.3 for co-relations conducted on Pile Nos. TP1 and TP2 at the project, the results of both static and HSDPT match exceedingly well. In both the cases, HSDPT was conducted approximately 33 days and 21 days after static testing. There was no major change in soil conditions during the times for both the tests. During both the tests, the piles were not loaded to failure indicating that they still had some capacity that was not measured.

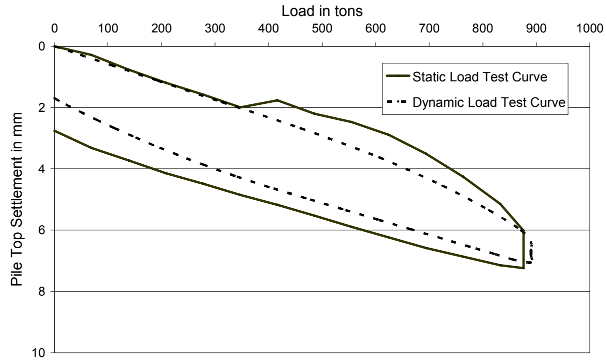

Fig. 3 Static Vs. PDA Test Match for TP2 at Chennai

Pile No. TP3 was tested dynamically first so that results are not known in advance and to remove any doubts regarding the test method and expertise of the agency. The PDA test results with CAPWAP evaluated the pile capacity as 890 tons at which the pile was observed to settle 3mm per blow indicating ultimate capacity for the pile. Static testing on the same pile showed a capacity of 840 tons (capacity at 12mm as per IS: 2911), although the curve shows onset of failure at 770 tons (Fig. 4). Considering static ultimate capacity as per IS: 2911 a comparison of both the test results showed that HSPDT over predicted by only 6% compared to static testing. Also that upto 770 tons the results of both the tests are almost the same. On the basis of these three case studies, static testing has been substituted by high strain dynamic testing for 40 routine piles at the project site.

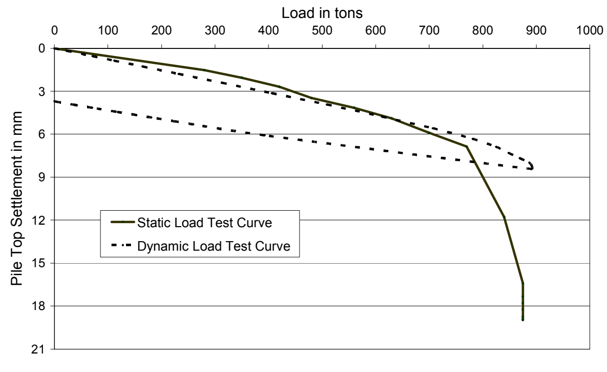

Fig. 4 Static Vs. PDA Test Match for TP3 at Chennai

It maybe noted here that there was a gap of almost 3 months between both the tests for Pile No. TP3. HSDPT was conducted before monsoon whereas static testing was conducted after monsoon and that there were heavy floods in the area causing changes in water table & soil properties and maybe a reason for small variation in the test results although very much with normal limits. Thus it is very important that the time gap between both the tests should be as minimal as possible to ensure a better comparison.

5.2 Bangalore Flyover

HSDPT was proposed at one of the longest grade separators in the country and again co-relations were required to justify the method and expertise in interpretation. Co-relations were conducted on three piles and a typical co-relation study for one of the routine piles is presented here. The piles were 1000mm diameter with a working load of 225 tons and a test load of 340 tons. The piles were installed in murum for 7m-8m with N value of 30-40 followed by embedment in soft rock with N values ≈ 100. The piles were mostly end bearing piles with significant capacity contribution expected from rock socket friction. A comparison between both the test results is as shown in Fig. 5. As evident both the results matched well. Since it was an end bearing pile and the pile had already undergone a net settlement during the static testing, hence there was very little set during dynamic testing conducted afterwards.

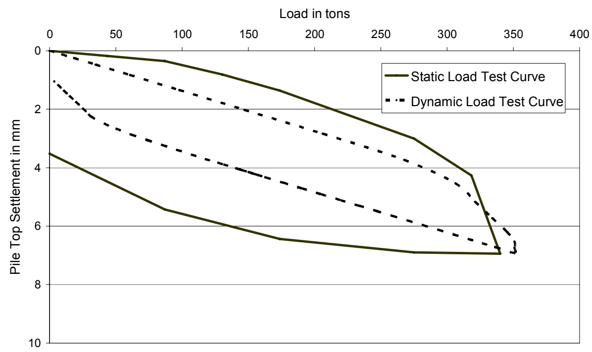

Fig. 5 Static Vs. PDA Test Match at Bangalore

Hence generally a comparison is done between both the tests only for the loading curve as the unloading curve will never be the same for tests conducted twice on the same pile. This is also true if static testing is conducted twice on the same pile. Two other comparisons also conducted at the same project also showed a good match. On that basis 25 piles were tested dynamically instead of static testing at the project site resulting in huge savings in time and cost. HSDPT also required much lesser space for the grade separator that was as at a busy intersection and thus helped avoid traffic problems.

5.3 Cochin Highway Project

HSDPT was also adopted at this major highway widening project on the basis of co-relation study conducted on one pile of 1200mm diameter and 47m depth. The pile was a friction pile with medium to stiff clay upto 39m followed by dense silty sand till pile toe and beyond. The pile design load was 150 tons and was statically tested to 300 tons whereas it was proposed to test the pile to 450 tons during the PDA test. The PDA test was conducted using a 5.5 ton hammer falling from a height of 2m. The results of both the tests are as shown in Fig. 6. Based on a reasonable match between both the test results, HSDPT was adopted on all the remaining initial and routine tests for the project.

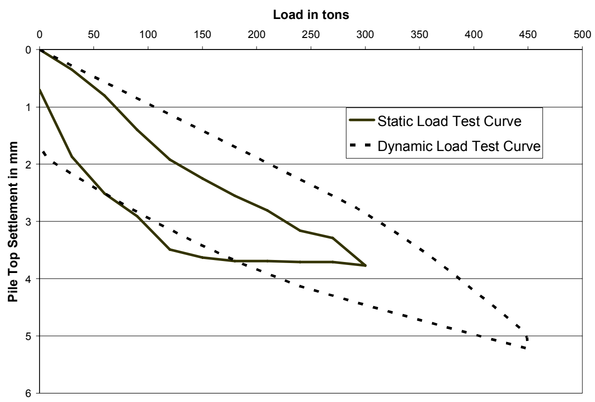

Fig. 6 Static Vs. PDA Test Match at Cochin

6. GENERAL COMMENTS

Co-relations help establish confidence in the test method and confirm the expertise of test engineer and should always be encouraged at big sites.

Both the static and PDA test give information on the capacity of the pile at the time of testing. It is therefore desirable that there is minimum time gap between both the tests when doing co-relation study to ensure that there is no change in soil conditions, water table etc. during the intervening period.

Conducting co-relation study on adjoining piles is not preferred especially for bored piles due to the fact that no two piles are having exactly the same properties and profile. Hence the trend is always to test the same pile for comparison purposes.

It has also been observed by the author during the many co-relations conducted other than those listed above, errors also happen during static testing and thus proper and equal care need to be exercised during both the test methods, else it leads to lot of confusions and time loss in discussions.

CAPWAP was done on all the PDA data to obtain the simulated static test curve for comparison with the conventional test results. CAPWAP is normally mandatory particularly for bored piles to correctly evaluate soil parameters, pile profile etc.

In all the cases structural integrity of the piles was also verified. Additional information about skin friction along the length of the pile and end bearing was also obtained from CAPWAP and the stress in the pile was also monitored during testing ensuring no damage during successive impacts of the hammers. Thus both durability and capacity could be ascertained resulting in better quality assurance.

At all the above sites, static testing was to a large extent replaced by dynamic testing that resulted in major savings in time and avoided use of concrete blocks, kentledge, etc which was very cumbersome. This also ensured early completion of the activity for the project.

Based on co-relations, several routine & sometimes initial piles were tested at the projects. Due to simplicity of arrangements, suspect piles or piles that had limited access, close to road traffic could also be selected, which otherwise would have been impossible with a static test.

7. REFERENCES

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