High strain dynamic pile testing on rock socketed reinforced concrete piles – Mumbai experience

Vaidya, R.
Geo Dynamics, India

Keywords: HSDPT, CAPWAP, pre-cast prebored, r.c. bored, load test

ABSTRACT: Construction of cast-in-place and pre-cast prebored piles is very common in Mumbai in India. Most of the piles are cast-in-place concrete bored piles with diameter ranging from 400 mm to 1500 mm. In some cases where chloride or sulphate content in soil is high, prebored and pre-cast piles are also used. The type of strata where the piles are embedded is mostly rock that could be breccia or basalt and maybe compact or weathered. Pile foundations are hence designed as toe bearing piles with capacity either due to toe bearing or combination of rock socket friction and toe bearing. High strain dynamic pile testing is now accepted in Mumbai as many reliability studies with conventional static tests have been done for various flyover projects and published literature available. Although there has been some concern about use of HSDPT for rock socketed piles, it is now commonly used in Mumbai which is mostly founded on rock. The paper describes the types of pile foundations that are used in Mumbai, includes case studies, reliability study and findings for prebored and pre-cast piles.

1 INTRODUCTION

High Strain Dynamic Pile Testing (HSDPT) is now routinely used in Mumbai where buildings, flyovers are mostly founded on pile foundations. The acceptance of this method is due to reliability studies done between HSDPT and conventional static load tests and published literature available (Nayak, N.V. et al, 2000). Similar work for rock socketed piles across the world is also available (Rausche, F., & Siedel, J., 1984). These literatures demonstrate the acceptability of HSDPT for rock socketed piles. Most of the piles in Mumbai are founded on breccia or basalt that maybe weathered or hard rock. The pile depths mostly range from 6 m to 20 m. These piles are either cast-in-place r.c. bored piles or pre-cast reinforced concrete piles placed in prebored holes. Both the pile types are briefly described.

The paper describes case studies to demonstrate that high strain dynamic pile testing is possible for rock-socketed bored piles although there have been concerns about damage to such piles during testing. The paper describes testing of pre-cast prebored piles with reliability study and also mentions about hammer weight that can be used for rock-socketed concrete bored piles.

2 TYPES OF PILE FOUNDATIONS

2.1 *Cast-in-place reinforced concrete bored piles*

Pile Foundations in Mumbai are mostly cast-in-place reinforced concrete bored piles. These range from 400 mm to 1500 mm diameter and are installed using rotary piling rigs in a method and procedure that is similar worldwide. Smaller diameter piles up to 750 mm are also routinely installed with a conventional winch and tripod with bailer and chisel method.

2.2 *Pre-cast prebored piles*

Pre-cast prebored piles are 400 mm or 500 mm diameter pre-cast piles with a 39 mm tube at the centre for injecting grout material. These are installed by first boring in a conventional manner using a rotary piling machine or a winch and tripod. After boring is completed, the pre-cast pile is lowered down the borehole using a crane. Grout is then injected through the 39 mm central tube generally at 3 bar pressure and is continued till the time it reaches the tip of the pile and then starts filling the gap between the pile and the soil / rock. Grouting is continued till clean grout starts flowing from the sides of the pile. The grout is allowed to set to its

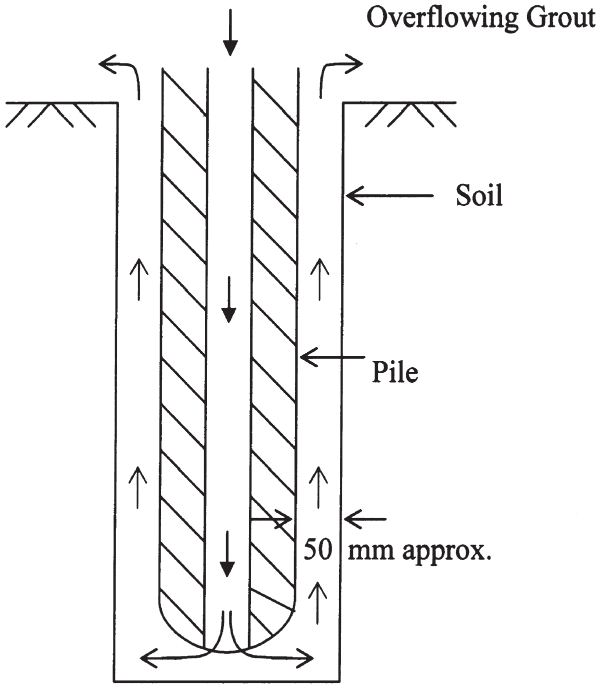

Figure 1. Typical pre-cast & prebored pile installation.

required strength (typically Grade 25–35). This according to the local industry ensures tip zone flushing and since boring is done using conventional method, the piles can be installed into rock unlike pre-cast driven piles that maybe damaged if they are driven into hard rock. Refer to Fig. 1 for the installation procedure of the piles.

Pre-cast prebored piles are selected in Mumbai at sites where there is presence of chlorides or sulphates and chances of side collapse of soil are possible. It is claimed that these piles are economical compared to bored piles with permanent liners and since they are pre-cast, they offer similar protection against contaminated soils.

3 CASE STUDIES

3.1 Case study: 1

For a multi-storey tower in Mumbai 500 mm pre-cast and prebored piles were used as a foundation. Approximately 200 such piles were installed at the project site. The piles were 8.5 m – 9.5 m deep and terminated into highly weathered grayish black basalt rock. The borehole log is shown in Fig. 2 for reference. The piles were designed for a test load of 2250 kN (design load was 1500 kN).

High Strain Dynamic Pile Tests were conducted on 30 piles at the project site. The tests were conducted using a 22 kN hammer falling from 1 m to 3 m drop height. These piles showed capacity ranging from 750 kN to 2000 kN only.

Most of the piles showed very high permanent settlement ranging from 10 mm to 200 mm during repetitive blows of the hammer and this was significantly higher than the permissible values.

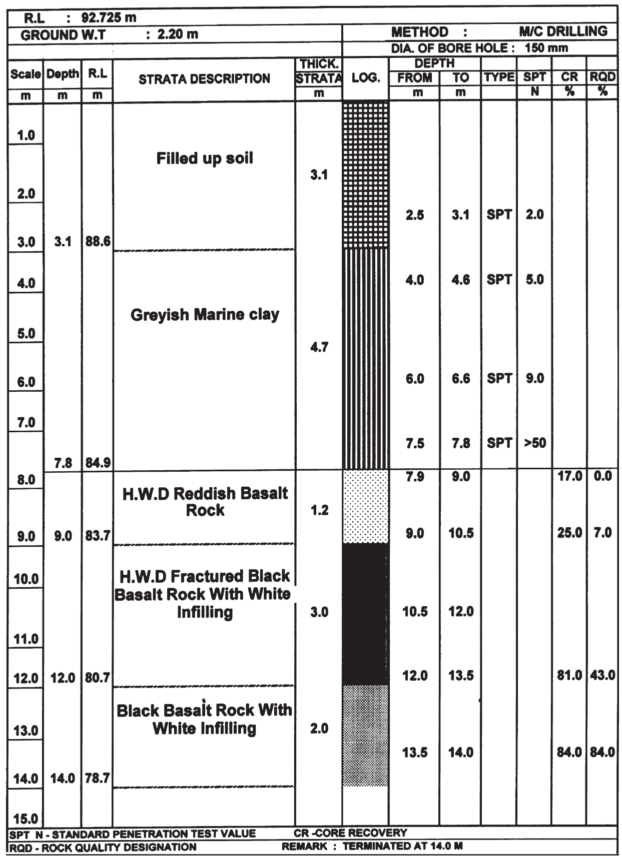

Figure 2. Soil borelog for case study: 1 & 2.

Static testing was also done on a pile adjoining to one of the piles that were dynamically tested. The purpose of selecting an adjoining pile was to ensure that the geotechnical parameters remain the same.

Fig. 3 shows the reliability study between static and HSDPT results. It can be inferred that both the tests show similar load bearing capacity and high net settlement. It was concluded that this was primarily due to two reasons.

a) The grout was not injected under adequate pressure and this resulted in grout or debris remaining below the pile, also described as soft toe condition. This caused excessive net settlement. b) The rock socket was inadequate and hence these piles could not reach the respective test loads. Refer to PDA data in Fig. 4 and Fig. 5 which show that either of these findings is a possibility.

As a remedial action, it was decided to tap the piles by successive blows of the hammer with a

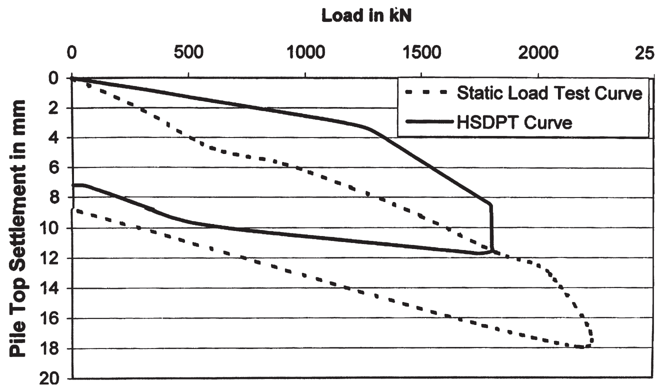

Figure 3. Reliability study for pre-cast & prebored pile.

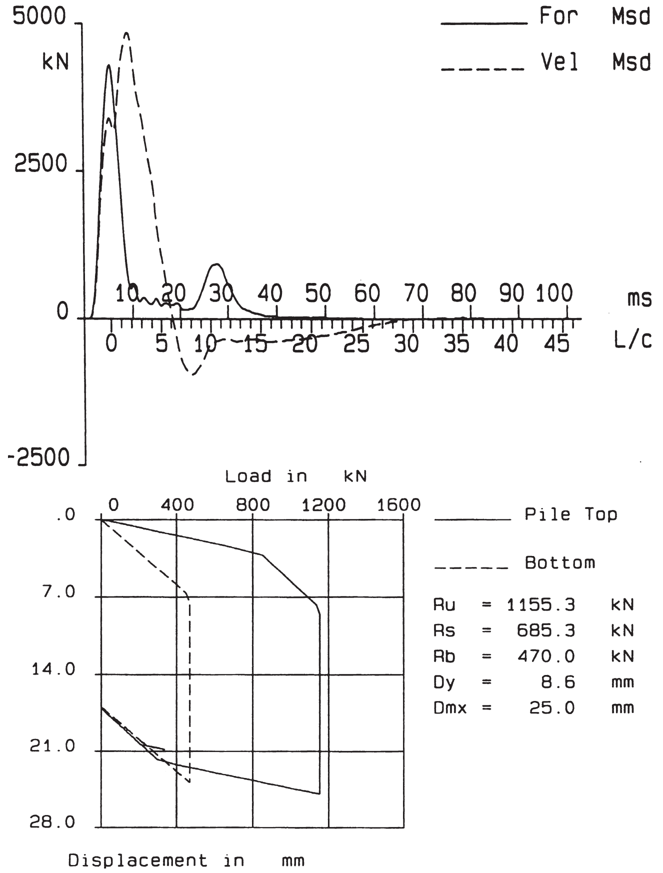

Figure 4. Toe bearing pile with high settlement.

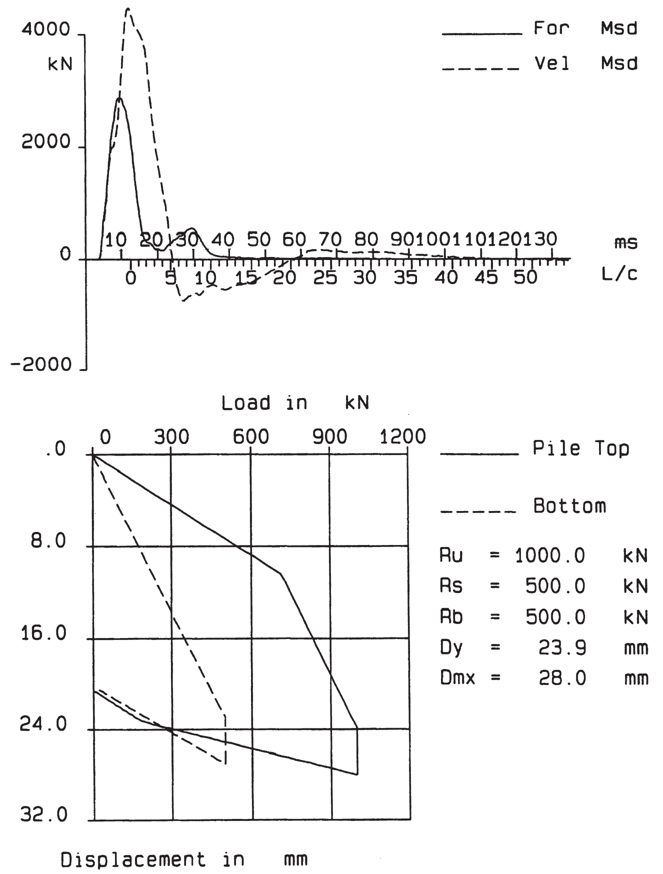

Figure 5. Toe bearing pile with high settlement.

pre-determined drop and treat them like pre-cast driven piles. The purpose was to check that whether there was grout or debris and if they can be removed by driving the piles. Most piles still showed high permanent settlement up to 200 mm and yet could not achieve the required capacity. It was then decided to reject all the piles due to the mentioned reasons.

3.2 Case study: 2

For the same project, it was then decided to install new cast-in-place reinforced concrete bored piles with permanent liners. The piles were 600 mm diameter with a depth of 11.5 m – 13.0 m and the expected test load was 6300 kN (design load of 4200 kN). These piles were installed in fresh grayish black basalt and they were socketed for a depth of 2 m into the stratum. This was at least 3 m more than the previous piles. Refer to Fig. 2 for soil details.

Concrete Grade 60 was used for these piles to ensure that they are able to take the heavy load.

These piles were tested using a 38 kN hammer falling from a height of up to 3.5 m. All the piles achieved the required test load and there was hardly any net settlement recorded by the piles.

The pile integrity was found to be acceptable and there was no sign of crushing of pile toe in the records. The maximum compressive stress at the pile head and at the pile toe never exceeded 35 MPa. Thus the tests demonstrate that toe bearing piles installed into hard stratum or with rock socket can be tested by HSDPT.

Since the pile shows negligible net settlement due to being installed in hard stratum, it was inferred that it may achieve ultimate capacity only due to maximum stress in concrete.

As only a 38 kN hammer was used to test the pile up to 6300 kN (hammer weight is 0.6% of test load), it can be said that lighter hammer can be used to measure heavier loads for rock socketed piles. A hammer weight of 1%–2% of the test load may not be required all the times. However, this depends on experience in the region and should be used with precaution.

Fig. 6 demonstrates the field data and simulated load test curve after CAPWAP analysis for one such pile.

3.3 Case Study: 3

Pre-cast prebored piles as explained earlier are installed by injecting grout through the central tube which then flows through the sides of the pile. In the process the grout acts as a bond between concrete and soil.

Although these piles are designed as toe bearing piles, it is expected that the grout will generate additional friction on the pile sides.

Fig. 7 shows data for a pre-cast prebored pile of 500 mm that was tested using a 20 kN hammer falling from a drop of 1.5 m. The test load for the pile was 2250 kN. As evident from the CAPWAP analysis, the pile can take the required test load and the contribution is both due to friction and toe bearing.

It can hence be said that grout also provides frictional capacity depending on the type of soil / rock.

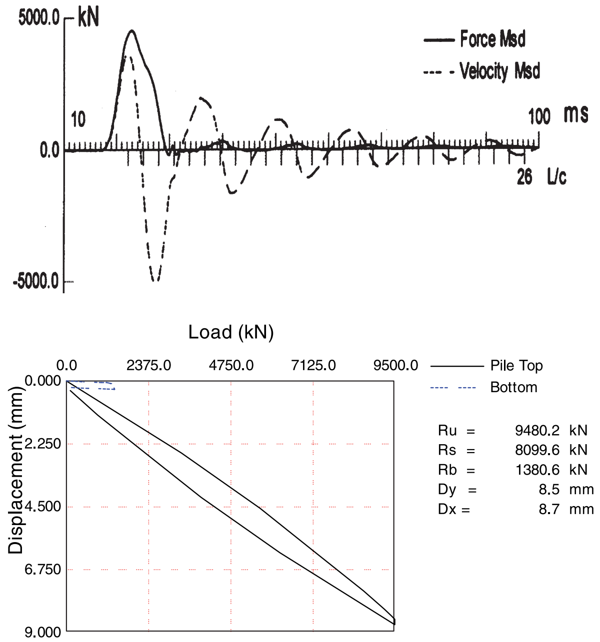

Figure 6. PDA Field Data for rock socketed pile.

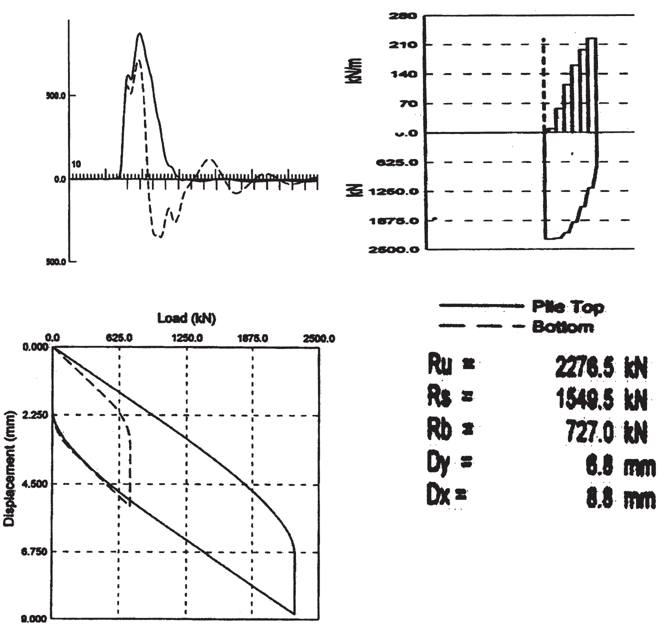

Figure 7. Friction distribution for pre-cast prebored pile.

3.4 *Case study: 4*

For a multi-storey building in Mumbai, a 1.0 m diameter pile with permanent liner was suspected to have soft toe condition during low strain integrity testing. The pile was installed in fresh rock and socketed to one times the pile diameter. The required test load for the pile was 3600 kN. HSDPT conducted on the pile with a 40 kN hammer and 1.5 m drop showed much lower capacity for the 1st blow at only 2100 kN.

The pile was then subjected to 14 blows to check if weak material beneath the pile can be removed so that more toe bearing can eventually be mobilized. It was observed that the pile permanently settled by 70 mm during the blows and then was able to take the required load. Although, theoretically the pile fails to achieve the required load within permissible settlement values,

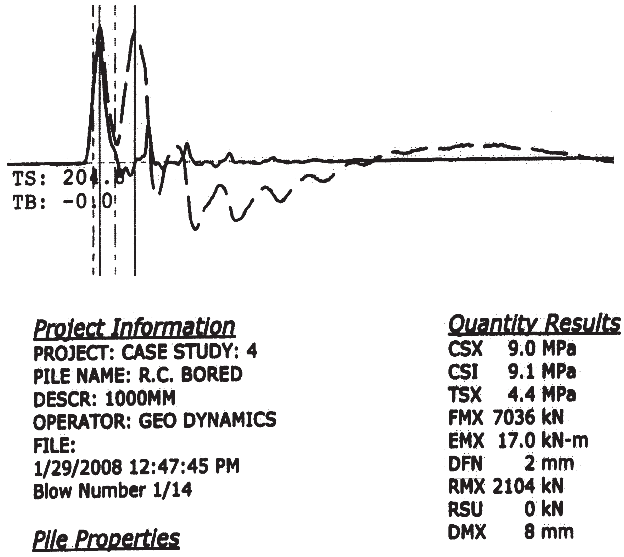

Figure 8. PDA field output for 1st blow.

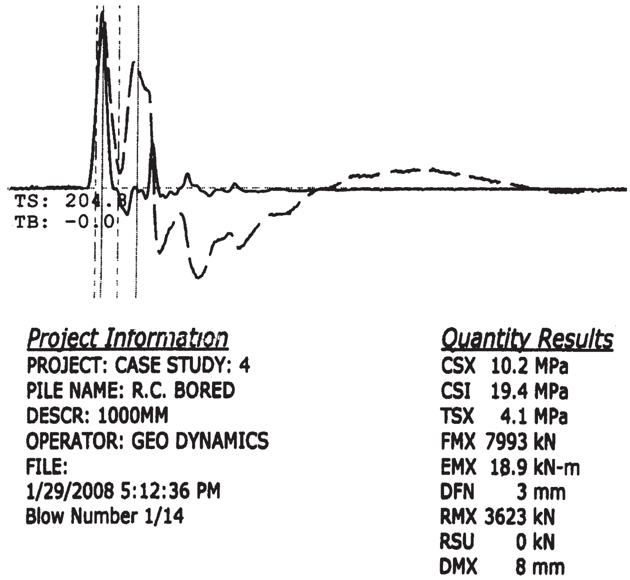

Figure 9. PDA field output after 14 blows.

no further remedial action was required. Refer to PDA field data in Fig. 8 that shows capacity lower than test load.

Fig. 9 shows the PDA data for the blow that achieved the required test load. Capacity was later confirmed by CAPWAP analysis.

4 CONCLUSIONS

High Strain Dynamic Testing is applicable for rock socketed piles. For piles in hard rock or socketed very deep into weathered rock and which may not undergo a measurable net displacement, the ultimate capacity will mostly be defined by the permissible stress in concrete.

It is possible to test rock-socketed piles with hammer weights up to 0.7% of the test load considering a drop of 1 m – 3 m and where dead weight of the pile is not a governing criterion. However, this must be used where there is past local experience or soil stratum is reasonably known.

The quality and strength of grout plays an important role in case of pre-cast prebored piles. If grout is pumped properly and achieves the required strength, it also provides for side friction.

For piles with moderate soft toe condition, it may be possible to reach the required test load by impacting few additional blows to the pile, although theoretically the pile fails the load test.

REFERENCES

Goble G. G., Likins G.E. (1996), ''On the Application of PDA Dynamic Pile Testing'', Fifth International Conference on the Application of Stress Wave Theory to Piles, Orlando, Fl, USA.

Nayak, N.V. et al (2000), ''Static and High Strain Dynamic Test Co-Relation Studies on Cast-In-Situ Concrete Bored Piles'', Proceedings of DFI 2000, New York, USA.

Rausche, F., et al (1988), ''Pile Integrity by Low Strain and High Strain Impacts'', Proceedings of the Third International Conference on Stress Wave Theory on Piles, Ottawa, Canada.

Siedel, J., Rausche, F. (1984), ''Correlation of static and dynamic pile tests on large diameter drilled shafts'', Second International Conference on the Application of Stress Wave Theory on Piles, Stockholm, Sweden.

Vaidya, R. (2004), ''Low Strain Integrity and High Strain Dynamic Testing of Piles – An Indian Overview'', Proceedings of the 7th International Conference on Application of Stress Wave Theory to Piles, Kuala Lumpur, Malaysia.