Application of Wave Propagation with Low Strain Pile Integrity Test—A Case Study

J. Prakashvel, S. Harishkumaran, P. Vasudevan, and K. Sathishkumar

Abstract Piles should possess the structural integrity to carry the design load and transfer to the soil/rock below. As per Indian standard IS 14893:2001, in general following defects are observed in the pile, which may lead to catastrophic failure. (a) Pile shaft necking, (b) Discontinuity of concrete, (c) Intrusion of foreign matter, (d) Improper toe formation due to contamination of concrete at the base with soil particles, (e) Washing of concrete due to high water current, and (f) Poor quality control with improper construction methods. NDT-based low strain pile integrity testing can be effectively used for evaluation of quality and acceptance of pile foundations. Low strain pile integrity test is based on pulse echo method. Pile integrity tester gives the velocity plot versus time. The plot is observed for the reflections, which indicate the change in the property of wave passing medium. The reflections may be due to soil resistance (stiffness) effects, cross-sectional changes, and soil property changes. In this study, bored cast-in-situ piles are evaluated for its integrity.

Keywords Pile integrity · Wave propagation · Pile shaft

1 Introduction

NDT-based low strain pile integrity testing can be effectively used for evaluation of quality and acceptance of pile foundations. Piles should possess the structural integrity to carry the design load and transfer to the soil/rock below. As per Indian standard IS 14893:2001 [4], in general following defects are observed in the pile, which may lead to catastrophic failure. (a) Pile shaft necking, (b) Discontinuity of concrete, (c) Intrusion of foreign matter, (d) Improper toe formation due to contamination of concrete at the base with soil particles, (e) Washing of concrete due to high water current, and f)Poor quality control with improper construction methods. This is economical method to test all the piles in the site compared to the cost of doing load tests for 0.5 to 2% of total no of piles at site. Low strain pile integrity test is based on

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pulse echo method. The test is termed as low strain method because a small hammer is used to generate a short wave of appreciable acceleration with low strain levels. Many numbers of piles can be tested at the site with this method. Pile integrity tester gives the velocity plot versus time. The plot is observed for the reflections, which indicate the change in the property of wave passing medium. The reflections may be due to soil resistance (stiffness) effects, cross-sectional changes, and soil property changes. In this study, the details of investigations and the inferences drawn on bored cast-in-situ piles for its integrity carried out at site by way of performing low strain pile integrity tests on 160 piles of TG foundation at Thermal power plant are presented. Thilakasiri [1] have modeled the wave propagation through the pile using the Wave Equation Method. He has divided the pile into 200 elements with varying soil stiffness along the pile shaft. With an artificial velocity pulse, velocity of the same element for varying ground conditions and the defects commonly encountered in Sri Lanka is determined and the location of the defects and its appearance in the velocity plot is investigated. Surya J Varma et al have evaluated the structural integrity of pile foundations by Pile Integrity Testing at bridge construction site in Tamil Nadu [5].

2 Motivation and Objective(s)

To study the wave propagation in the piles to evaluate the integrity and depth of piles.

3 Methodology

We performed low strain pile integrity tests on all 160 piles of the Turbo Generator (TG) foundation of Unit-1 at 2 × 660 MW Super thermal Power Plant. The diameter of the pile is 760 mm. The piles are laid below the raft concrete block. The columns will be constructed from the raft concrete. The soil in the site is of clay and the site is ash dyke of a thermal power plant. They have consolidated the soil with the sand piles near all the concrete piles. This has increased the soil stiffness to significant level and hence in some cases we could not get the toe reflections. The subsoil is characterized by a filled up soil with fly-ash disposed from the nearby thermal power plant. The initial layer consists of very soft silty clay. Below this medium silty clay to stiff clay layer is observed. Near 40 meters level below the ground, dense silty sand and hard silty clay layer is found.

The pile topping may be prepared with Cement mortar 1:3 or Conbextra GP grout material with 50 mm thickness. The topping has to be prepared 7 days prior to integrity test. Sufficient time should be allowed for topping material to attain sufficient strength for integrity test. Ultrasonic pulse velocity in the piles to be tested for integrity is evaluated using PUNDIT Ultrasonic equipment. This is the required input to be given to the Pile Integrity Tester for the reliable integrity assessment. The average wave velocity in concrete evaluated from Ultrasonic pulse velocity test measurements is 4173 m/s. Impact with less energy is imparted to the pile top. Accelerometer is fixed on the top of the pile surface after necessary preparations to get the response in time domain.

Pile Integrity Tests (PIT) are performed as per Indian Standard for Non-Destructive Integrity Testing of Piles (NDT)—Guidelines (IS 14893:2001 reaffirmed 2006) [4]; on all the 160 piles of the TG foundation using Pile Integrity Tester equipment (Make: Pile Dynamics Inc., USA; Model No.: PIT-FV). During the test, ASTM D5882—07 Standard Test Method for Low Strain Impact Integrity Testing of Deep Foundations [2] is also referred for guidelines of the test. The piles are constructed with M35 grade concrete. Prior to these PIT tests Ultrasonic Pulse Velocity (UPV) tests are performed as per Indian Standard for Non-Destructive Testing of Concrete—Methods of Test: Part 1 Ultrasonic Pulse velocity (IS 13311—Part 1: 1992; reaffirmed 2004) [3] on randomly selected 20 piles of the TG foundation from top concrete of 0.75 m depth from the cut-off level. In each of the selected pile, two sets of direct measurements along the diameter of the pile are taken at two different pile depths, namely 0.25 m and 0.75 m. For performing the UPV tests, a Portable Ultrasonic Non-destructive Digital Indicating Testing (PUNDIT) equipment (Make: Proceq, Switzerland; Model: PUNDIT Lab) is used. These UPV tests are performed to arrive at the representative stress wave velocity (C) of the pile concrete medium required for estimating the pile depth using PIT analysis software. In the present study, a mean stress wave velocity of 4173 m/s evaluated from UPV tests performed on the randomly selected 20 piles of the TG foundation is used in the PIT analysis to estimate the pile depth. The following aspects can be evaluated using pile integrity tester. Impedance change, Effects of surrounding soil and pile material in wave propagation, Maximum impact force given by the hammer. The wave reflections occur by change in the pile's impedance due to changes in either the cross-section or the material. Decreasing impedance shows tensile reflection, leading to wave velocity in the same direction as the impact. Increasing impedance leads to compressive reflection and velocity wave occurs in the direction opposite to the impact. For a stiff concrete pile in relatively weak soil (strength compared to the concrete), the toe reflection will have the same sign (positive) as the velocity input. For a pile with a fixed end (such as a rock socket), the toe reflection may be of the opposite sign (negative) as the velocity input. Other reflections, observed only in the velocity record, are caused by changes in the pile's impedance, ($E \times A \div c$,) where E is the elastic modulus, A is the cross-sectional area, and c is the stress wave speed. A local decrease (neck) would have a positive reflection followed by a negative reflection (positive negative cycle). A local increase (bulb) would have a negative reflection followed by a positive reflection (negative positive cycle). The reflections must be interpreted to determine whether the associated changes are normal or of major concern to the integrity of the shaft. ASTM D5882—07 [2] Standard Test Method for Low Strain Impact Integrity Testing of Deep Foundations have been referred in addition to the BIS code for conducting the test and analysis.

4 Results and Discussion

PIT tests involve low strain, stress wave propagation in the pile shaft. Non-uniformities observed in the cross-section of the pile shaft along the depth estimated from PIT analysis are discussed in this paper. UPV testing and pile integrity testing on a typical pile are shown in Fig. 1. Results of PIT in the form of wave velocity vs pile depth plots are analyzed using PIT software for all the 160 piles. These plots give the estimate of pile depth and pile depth locations where non-uniformity in the pile cross-section is likely to be present for each pile. The depth of the pile is estimated and uniformity of the cross-section is observed. Velocity time history of a pile with non-uniform cross-section and uniform cross-section are plotted. Higher soil stiffness is observed in some of the piles, which do not have well-defined toe reflection. Figure 2 shows the typical velocity profile of pile with uniform cross-section.

Most of the piles tested at site exhibits non-uniformity in the cross-section between 5 and 10 m. Due to the soil stiffness, many of the piles tested have shown early reflections rather than reflections at the toe and defects of the pile. From Fig. 3, it is inferred that due to the higher soil stiffness, there is no definite toe reflection. Due to the non-uniformity in the pile, between 7.5 m and 12.5 m there is additional reflections in the plot as shown in Fig. 3. In Fig. 4, it is noted that there is a non-uniformity in the cross-section near 7.5 m depth and toe reflection at 25.02 m.

It is observed from the PIT analysis performed, the estimated pile depths of 101 piles (out of 160 piles) are found to be higher than the 23.4 m (90% of the design depth of 26 m). 10 piles are found to be with estimated depth lower than 90% of

Fig. 1 UPV testing and pile integrity testing on a typical pile

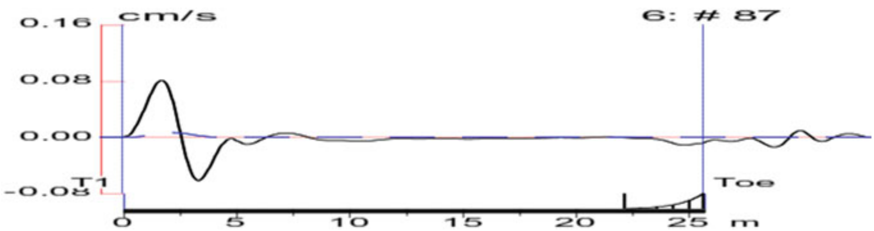

Fig. 2 Typical velocity profile of pile with uniform cross-section (Estimated depth is 25.69 m)

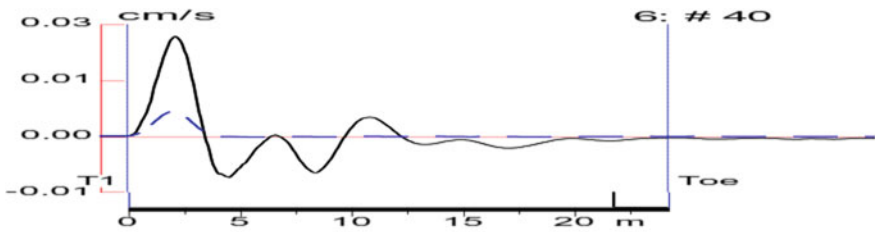

Fig. 3 Typical velocity profile of pile with non-uniformity in the cross-section between 7.5 m and 12.5 m depth

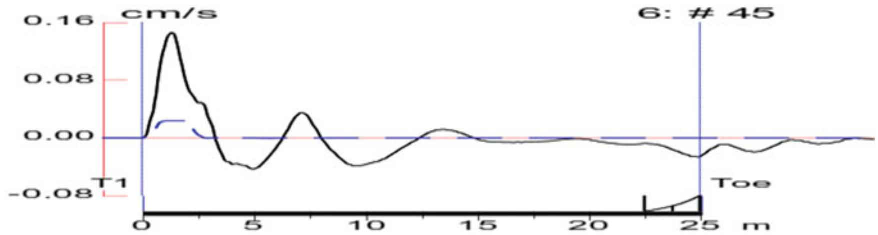

Fig. 4 Typical velocity profile of pile with non-uniformity in the cross-section near 7.5 m depth and the toe reflection at 25.02 m

design depth (i.e., 23.4 m). This could be due any one of the reasons stated above. 49 piles found to be with inconclusive depth due to the absence of well-defined wave reflection.

5 Conclusions

Pile integrity tester is a compact equipment, which also reflects the soil stiffness, in addition to abnormalities in the pile, which are tested. During the study, it is observed that few piles have the depth less than the design depth. The pile depth is estimated using PIT software based on the first reflection observed in the wave velocity profile beyond 20 m depth adopting a pile depth estimate of 26 m, 0.76 m pile diameter, and an average stress wave velocity of 4173 m/sec evaluated from UPV tests. This first wave reflection observed is mainly attributed to sudden variation of impedance (Z) ($Z = EA/C$, where E is the elastic modulus of the medium, A is the area of cross-section, and C is the stress wave velocity of the pile shaft) in the pile shaft through which the stress wave travels and could be due to any one of the following reasons. (a) Toe of the pile. In this case, the first reflection shows the end of the pile shaft. (b) Major reduction in the cross-section of the pile shaft in the form of necking or defect (crack). In this case, possibility of pile shaft material beyond this depth also exists. (c) Major non-homogeneity. In this case, possibility of mixing of concrete and soil at this depth exists. The absence of well-defined wave reflection beyond 20 m depth shows that the low strain, stress wave generated at the top of the pile due to hammer impact gets attenuated fast and do not travel beyond this depth and could be due to any one of the following reasons. High soil stiffness is due to closely spaced piles within the group. Heterogeneity in the pile shaft material is due to poor concrete quality (like honeycombing and low grade concrete).

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