Evaluation of Cast-in-Situ Pile Condition Using Pile Integrity Test

Mohammad I. Hossain, Omar F. Hamim

***Abstract*—**This paper presents a case study on a pile integrity test for assessing the integrity of piles as well as a physical dimension (e.g., cross-sectional area, length), continuity, and consistency of the pile materials. The recent boom in the socio-economic condition of Bangladesh has given rise to the building of high-rise commercial and residential infrastructures. The advantage of the pile integrity test lies in the fact that it is possible to get an approximate indication regarding the quality of the sub-structure before commencing the construction of the super-structure. This paper aims at providing a classification of cast-in-situ piles based on characteristic reflectograms obtained using the Sonic Integrity Testing program for the sub-soil condition of Narayanganj, Bangladesh. The piles have been classified as 'Pile Type-1', 'Pile Type-2', 'Pile Type-3', 'Pile type-4', 'Pile Type-5' or 'Pile Type-6' from the visual observations of reflections from the generated stress waves by striking the pile head with a handheld hammer. With respect to construction quality and integrity, piles have been further classified into three distinct categories, i.e., satisfactory, may be satisfactory, and unsatisfactory.

***Keywords*—**Cast-in-situ piles, characteristic reflectograms, pile integrity test, sonic integrity testing program.

I. Introduction

PILE foundations are being extensively used for constructing high-rise residential and public buildings in Bangladesh. Being a developing country, most of the infrastructures are being built in filled lands requiring deep foundations such as pile foundations.

Pile foundations are being extensively used for constructing high-rise residential and public buildings in Bangladesh. For piles being a sub-structural element, the length of pile and quality of concrete has been a concern for the engineers. Also, in order to ensure satisfactory long term performance, continuity in the geometry of the pile foundation during construction needs to be ensured. Direct relation between load capacity and quality of piles makes the quality essential in terms of serviceability and sustainability. Although it is a usual practice to inspect the concreting of piles during construction to ensure the highest quality, it is impossible to determine if the pile is constructed as per intended quality or not without testing.

Low strain integrity tests have been successfully used to ensure the length, discontinuity in geometry of pile (e.g. necking, cracking and void) and quality assessment of concrete for existing or in-service piles [1], [2]. Paikowsky and Chernauskas [3] applied different non-destructive tests to determine the defects and exact length of the piles after reviewing advantages and disadvantages of these methods. Prakash et al. [4] applied low strain pile integrity test to determine the concrete quality, geometric properties (e.g. shape and length) of existing pile below transmission line tower.

In our research work, pile integrity tests have been performed on 387 cast-in-situ reinforced cement concrete (RCC) piles installed for construction of pumping station in the vicinity of Narayanganj, Bangladesh. Based on the results of pile integrity tests, the as-built length and condition of the piles were assessed. The present study discusses the observations made on the reflectograms extracted from the pile integrity tests and aims at classifying piles for identifying possible defective piles and recommending further investigation.

II. Methodology

Pulse Echo Method was followed for this study using SIT32 (Sonic Integrity Testing) program, ver.7.42 and pile integrity testing device made by TNO Profound of Netherlands [5]. Following this method, firstly, the pile head is struck with a small hammer while a small accelerometer is placed on the pile top (Fig. 1). The generated stress waves travel along the pile shaft towards the toe and get reflected which are registered by the accelerometer. By integrating the accelerations, the pile head velocity is obtained. Apparent reflections occurring prior to toe response of the same sign as the input occur due to a relative decrease of impedance whereas, reflections of the opposite sign happen due to a relative increase of impedance. In this method, the pile head is struck with a small hammer while placing a small accelerometer on top of the pile in order to generate a stress wave travelling down the pile shaft and getting reflected at the toe of the pile. Such reflections are registered by the accelerometer and then integrated to obtain the pile head velocity. A relative decrease of impedance is represented by reflections of the same sign as the input whereas a relative increase of impedance is denoted by reflections of the opposite signs. Pile impedance is denoted by Z which is defined by:

$$Z = EA/c \quad (1)$$

where, E = elastic modulus (Young's modulus) of pile material; A = cross-sectional area; c = stress-wave velocity.

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Stress-wave velocity (c) can be calculated according to one-dimensional stress-wave theory using:

$$c = \sqrt{E/\rho} \quad (2)$$

where, ρ refers to the mass density of pile material.

A combination of (1) and (2) can be used to express pile impedance (Z) as:

$$Z = A\sqrt{E}\ \rho \quad (3)$$

Thus a decrease in area A, modulus, E or density, ρ certainly causes reduction in impedance. It can be inferred that, a change in impedance is related to a change in cross-sectional area or concrete quality since both E and ρ are related to concrete strength.

The pile length (L) is affected by the time of toe reflection (T) and the velocity of wave propagation through concrete (c). So, an equation expressing the pile length (L) will be:

$$L = c.T/2 \quad (4)$$

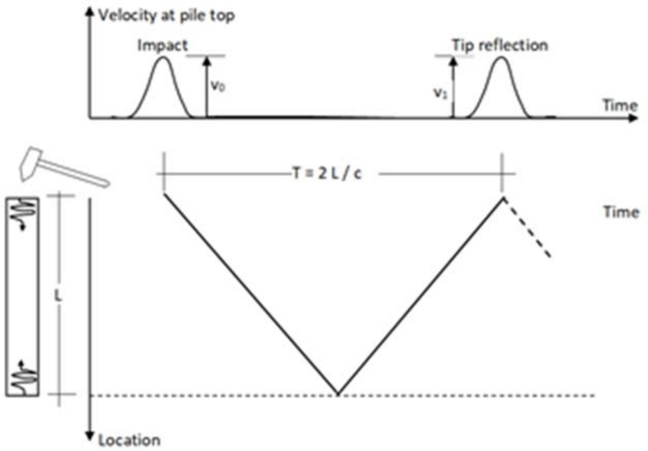

Fig. 1 Basic principle of low strain integrity

III. Testing Procedure

We made multiple visits to the site to perform pile integrity tests on 387 piles accompanied by experienced technicians. First the pile locations for testing the piles were identified from the pile layout drawing of the under construction pumping station. The piles were divided into three segments (e.g. A, B and C) and were identified by the Pile ID number. The test was carried out by pressing a transducer onto a pile top while striking the pile head with a handheld hammer. A photograph displaying the prepared pile head for performing the pile integrity test is presented in Fig. 2. The impact of the hammer is registered by the SIT-system followed the response of the pile and is shown on the display. The test procedure mentioned in ASTM D 5882-00 has been followed for carrying out this research work [6].

Fig. 2 Condition of prepared pile head

The minimum 28 days cylinder strength of the concrete used for piles is 22 MPa (3190 psi) and the diameter of the piles is 600 mm. The design length of the piles at Segment A (Pile ID: 1 to 113) is 25.45 m, Segment B (Pile ID: 114 to 249) is 24.45 m and Segment C (Pile ID: 250 to 387) is 26.45 m. A stress-wave velocity of 3000 m/sec through the pile material has been assumed for the integrity tests. For each pile location, three hammer blows were applied on top of the piles and recordings were obtained. The reflectogram records were later studied using various amplification, smoothening, averaging and data correction techniques to assess the length of the piles, integrity of the shaft and quality of concrete.

IV. Analysis and Discussion of Results

In this study, reflectograms of 387 piles under selected site have been interpreted considering the sub-soil condition. For mature concrete, the compression wave velocity usually ranges from 3000 m/s to 4000 m/s. The wave velocity depends on several factors such as concrete strength, density, type of aggregate, mix ratio etc. For the piles at the site, a stress-wave velocity of 3000 m/s through the pile material has been considered to be appropriate since the concrete strength was 3190 psi. As these were cast-in-situ piles, continuity of the shaft is of prime concern rather than quality of concrete, change in cross-section or length of pile.

From visual observation and interpretation of the reflectograms of a pile, the piles may be reported as “Pile Type-1”, “Pile Type-2”, “Pile Type-3”, “Pile type-4”, “Pile Type-5”, or “Pile Type-6”. A brief description of these pile types follows:

Pile Type-1: A pile is reported as “Pile Type-1” if the signal is assessed to have reasonably good quality concrete over the whole length, almost free from cracks or reduction in cross-section and conform to design length as shown in Fig. 3.

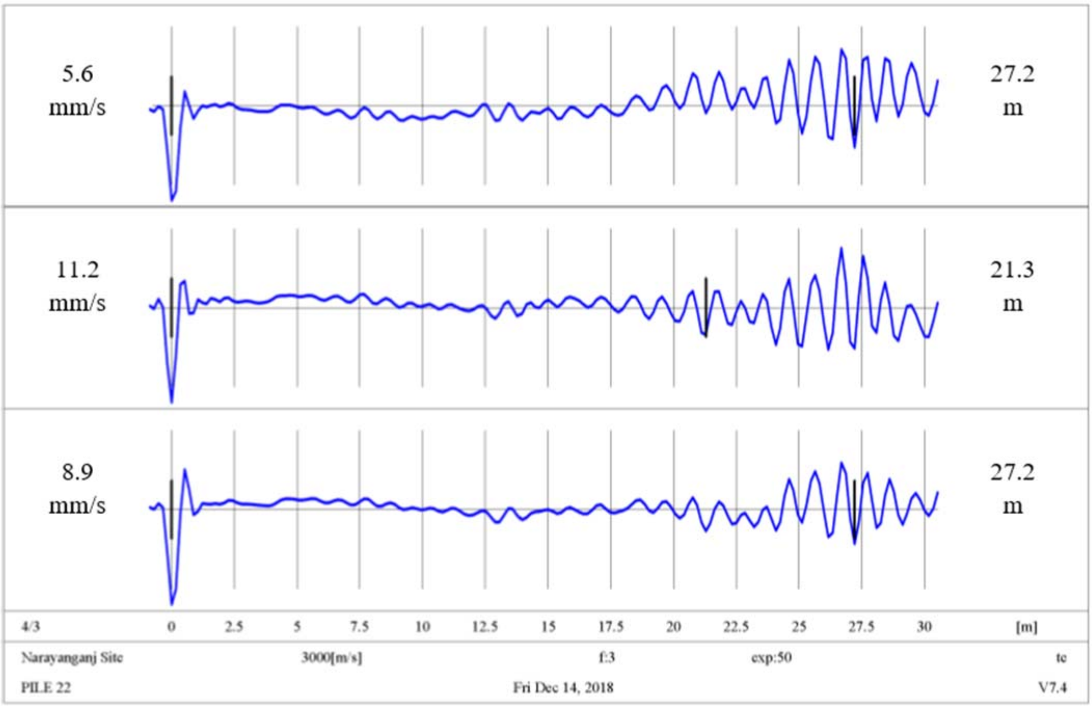

Fig. 3 Characteristic reflectogram of Pile Type-1

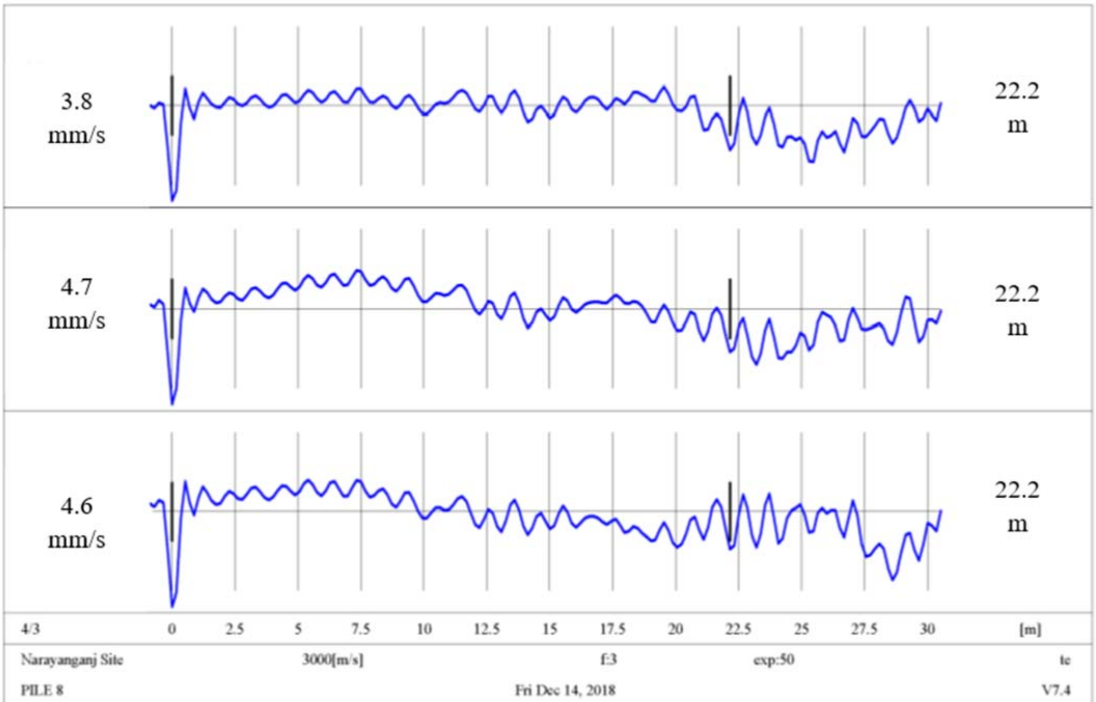

Fig. 4 Characteristic reflectogram of Pile Type-2

Pile Type-2: "Pile Type-2" term has been assigned to a pile if the signal is assessed to have pile head problem as shown in Fig. 4. The possible reasons of this type are minor cracks, necking and low material quality. It can be considered that this type of pile will not affect the functioning of the pile at design working loads but may cause a reduced value of ultimate load capacity and thus a reduced factor of safety and/or durability compared to that of a "Satisfactory" pile. Such a consideration may be justified due to the limitations of the integrity test and also the fact that some variation in the concrete quality in cast-in-situ piles is quite common.

***Pile Type-3*:** Piles have been referred as "Pile Type-3" if the signal is assessed to have discontinuity at certain distance from the pile head as shown in Fig. 5. The likely cause of this type may be ‘crack’ or ‘reduction in cross-section’ or ‘poor concrete strength’ that may significantly affect the proper functioning of the pile.

Pile Type-4: “Pile Type-4” classification has been used to recognize piles if the signal is assessed to have early toe reflection as shown in Fig. 6. This type of pile represents that the pile is made too short or broken or heavily cracked or serious necking exists at certain distance from the pile head.

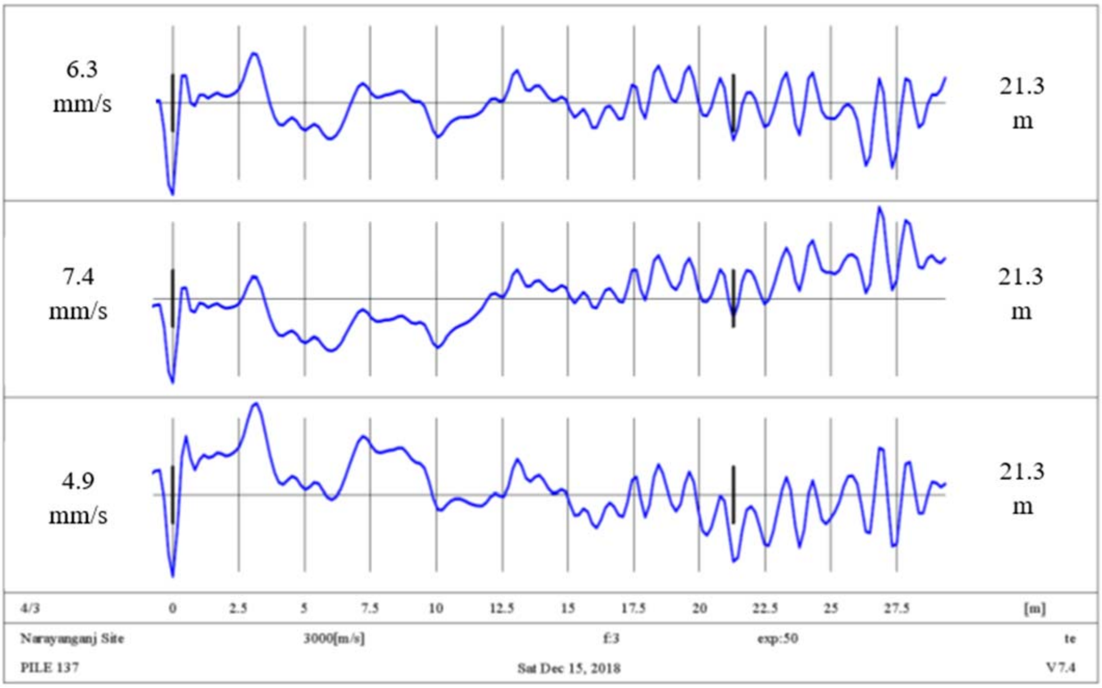

Fig. 5 Characteristic reflectogram of Pile Type-3

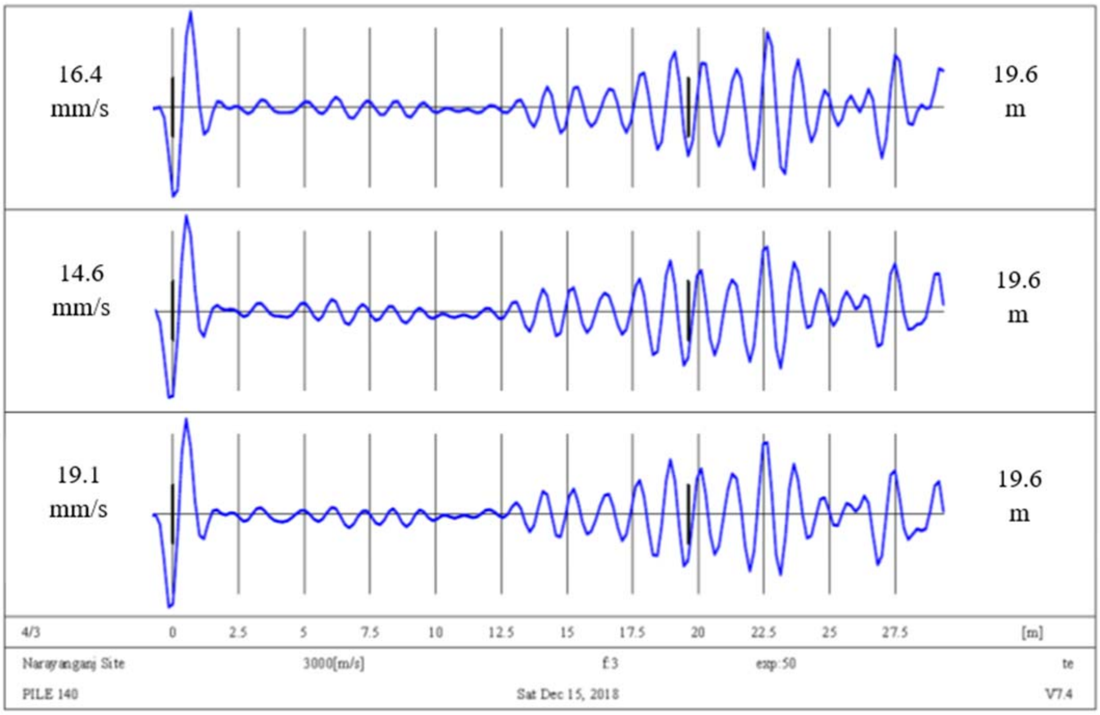

Fig. 6 Characteristic reflectogram of Pile Type-4

Pile Type-5: Piles have been assigned as “Pile Type-5” if the signal is assessed to have late toe reflection as shown in Fig. 7. The possible cause of this type may be lower material quality or pile younger than other piles.

Pile Type-6: A pile is reported as "Pile Type-6" if the signal is assessed to have no clear toe reflection as shown in Fig. 8. The likely cause of this type may be large friction and deviating material properties at pile toe.

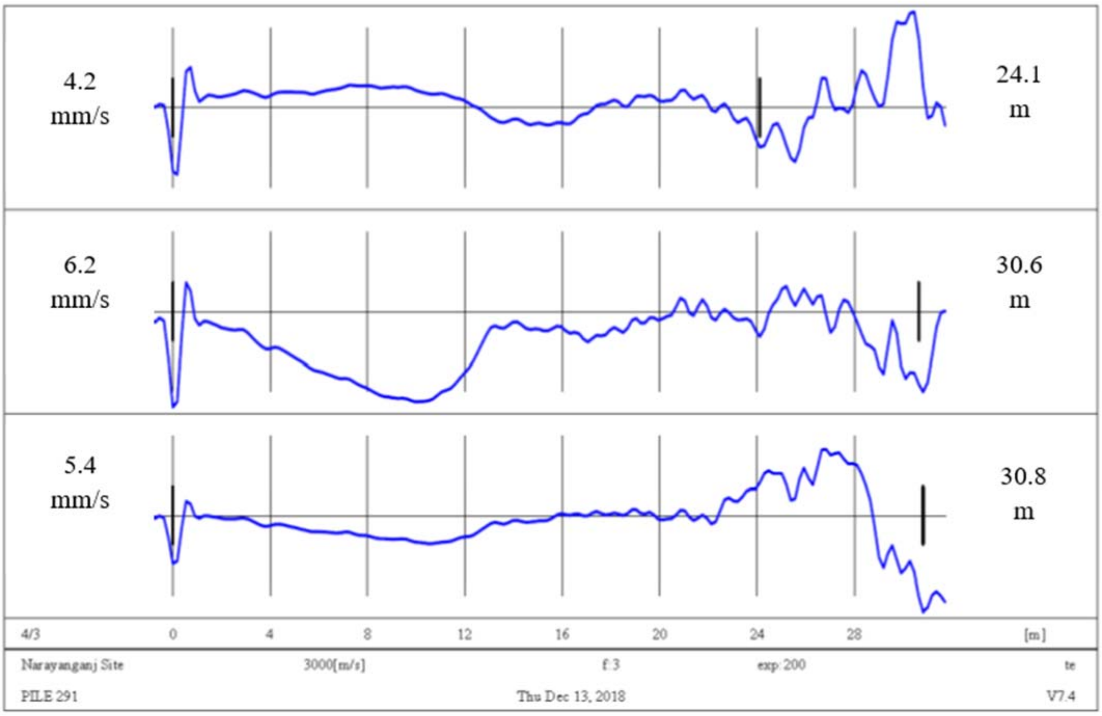

Fig. 7 Characteristic reflectogram of Pile Type-5

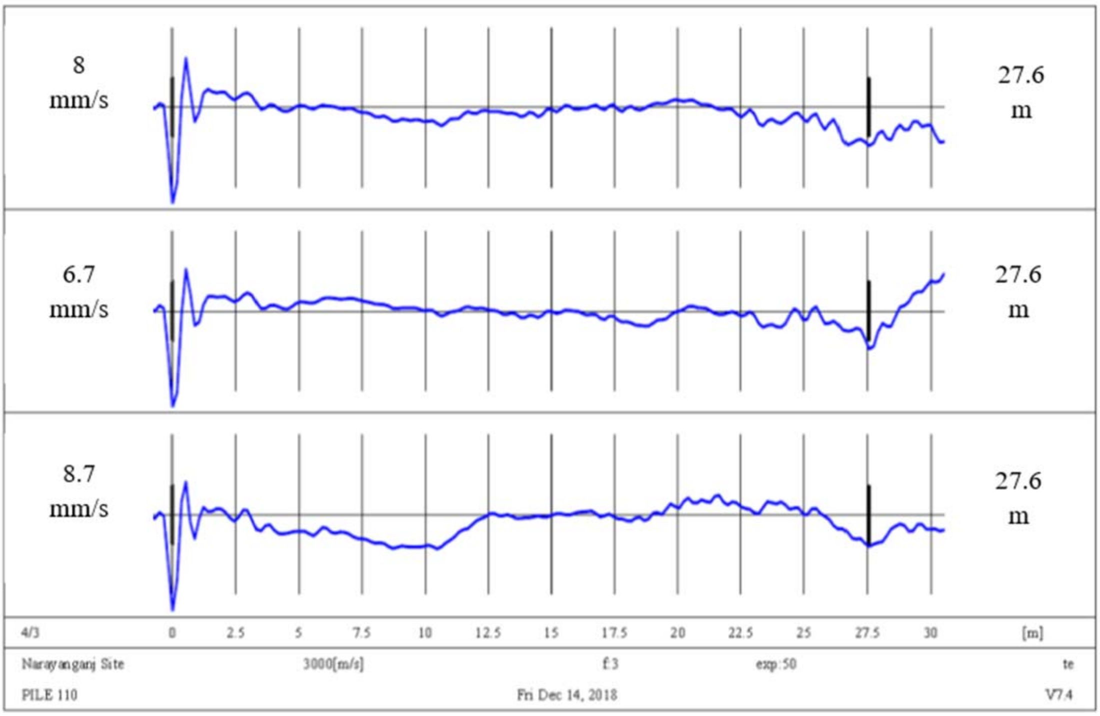

Fig. 8 Characteristic reflectogram of Pile Type-6

A classification of the tested piles has been presented through a pie chart in Fig. 9. From the pie chart it is found that out of 387 cast-in-situ piles 206 (53%) piles have been identified as Pile Type-1, 116 (30%) as Pile Type-2, 16 (4%) as Pile Type-3, 32 (8%) as Pile Type-4, 7 (2%) as Pile Type-5 and 10 (3%) as Pile Type-6.

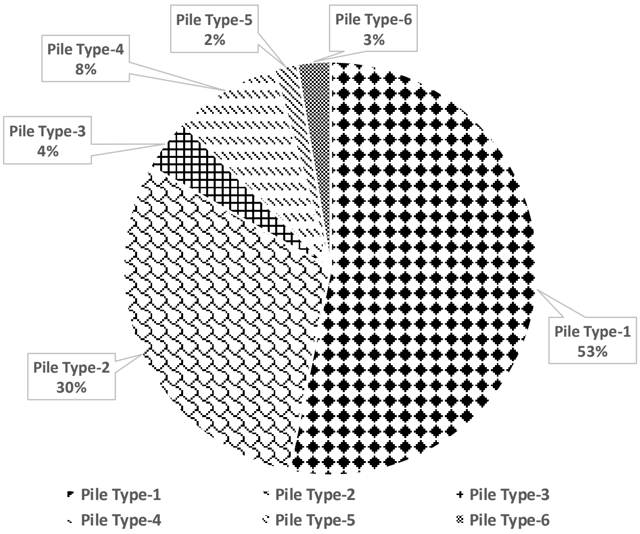

Fig. 9 Pile classification based on characteristic reflectograms

Piles have been further classified as 'Satisfactory', 'May be Satisfactory' and 'Unsatisfactory' through interpreting reflectograms in terms of integrity of the constructed piles and quality of construction materials. Piles classified as "Pile Type-1" can be considered as 'Satisfactory'; "Pile Type-2", "Pile Type-5" and "Pile Type- 6" can be referred as 'May be Satisfactory'; "Pile Type-3" and "Pile Type-4" needs to undergo further investigation since these piles can be recognized as 'Unsatisfactory'.

Most of the characteristic reflectograms of the piles indicate some uncertainty regarding the quality of the concrete at the toe indicating possibility of containing soil inclusions and relatively poorer quality of concrete. This is in general true for the kind of piling methods used for cast-in-situ RCC piles in our country. Additionally, the PIT tests in some cases indicate minor cracks at the top of the pile. This may be result of either cracks forming during breaking of pile head and/or due to presence of soil inclusions at the displaced concrete at the pile top. Some of the test results indicate irregularity of pile cross section throughout the length of pile. In a few piles reduced cross section near the mid-section, cracks, voids or air gaps are also indicated by the reflectograms.

Some of these piles may be selected for performing load tests to definitely ascertain pile quality. There was the presence of water around some of the piles which significantly distorts and dampens the signals as obtained in the reflectograms making it very difficult to come to any definitive conclusion regarding the quality of the piles. Also, lack of appropriate smoothening, finishing and polishing of the pile head resulted in distorted signals obtained in the reflectograms which are difficult to interpret. However, in general the pile construction quality at the site appeared to be satisfactory. However, it is to be kept in mind that PIT provides only a qualitative evaluation of the piles. For definitive information regarding pile load capacity and deformation under load, further extensive investigation needs to be undertaken.

V. Conclusion

Pile integrity tests have been performed on cast-in-situ piles installed for construction of pumping station and a classification of the piles has been prepared based on the extracted characteristic reflectograms. Out of 387 cast-in-situ piles 53% of piles have been categorized as Pile Type-1, 30% of piles as Pile Type-2, 4% as Pile Type-3, 8% as Pile Type-4, 2% as Pile Type-5 and 3% as Pile Type-6. In addition "Pile Type-1" has been termed as 'Satisfactory'. It is to be noted that based on the results from pile integrity tests, certain decisions cannot be made regarding the pile bearing capacity. So to ascertain the serviceability of cast-in-situ piles, additional comprehensive studies are required to be performed based on the pile defects identified from pile integrity tests.

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