Pile Integrity Testing for Monitoring Pile Construction

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ABSTRACT : Low-strain Pile Integrity Testing (PIT) is a valuable, low-cost tool to locate major defects in, and estimate pile lengths of, bored and driven piles installed on site. It can serve to enhance the confidence level of the engineer on the quality of piles installed. The paper discusses the test procedure and limitations, and illustrates field results of low strain integrity tests performed on RCC bored cast-in-situ piles on infrastructure projects.

1. INTRODUCTION

For a pile to perform successfully under the working loads, it should

- have adequate soil resistance, and
- be structurally sound

The available soil resistance is usually determined by a geotechnical investigation to evaluate the stratigraphy and soil characteristics. Standard static analysis or other methods are used to compute the pile capacity based on the geotechnical data. On most piling projects, a very small percentage of the total number of piles (usually 0.5 to 1%; in rare cases, up to 2%) is load tested to verify that adequate soil resistance is mobilized.

On fast-track infrastructure projects, time schedules are often very tight. The emphasis on site is to achieve the target, and success is measured in terms of how many piles have been installed within a specified time period. The constructed profile and structural integrity of bored piles are functions of subsurface conditions, concrete quality and placement, construction method and workmanship.

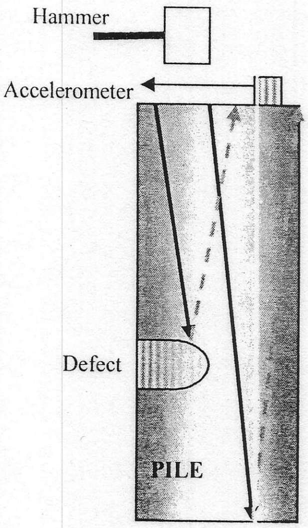

Figure 1 Schematic of PIT

As a result, quality and supervision often takes a back-seat, leading to problems and even failure. In such a scenario, pile integrity tests (PIT) can serve as a quality assurance measure by quickly and inexpensively testing a higher percentage of piles (*Rauche et. al. 1988*).

2. PRINCIPLE

Testing is performed by impacting the pile top with a small hand-held hammer and measuring the response with an accelerometer. Fig. 1 presents a schematic of the test.

Performing the test requires little preparation. The pile head needs to be cleaned and a smooth surface should be prepared. The accelerometer is fixed to the top of the pile using a special wax. Signal enhancement by repeated hammer blows on the pile head helps to minimize effects of noise or other disturbances (*PIT Collector User's Manual, 2005*).

The impact causes a low-strain compression wave to travel down the pile. Wave reflections are created by changes in pile "*impedance*" (related to cross-sectional area, material elastic modulus and density), pile toe and soil/rock resistance effects, as shown on Fig. 2. Where high soil friction forces are present, the pile top velocity is displayed as a function of time with an exponentially increasing magnitude, such that the pile toe reflection is enhanced. Several records with consistent signal should be averaged.

Fig. 3 presents a photograph of the test in progress.

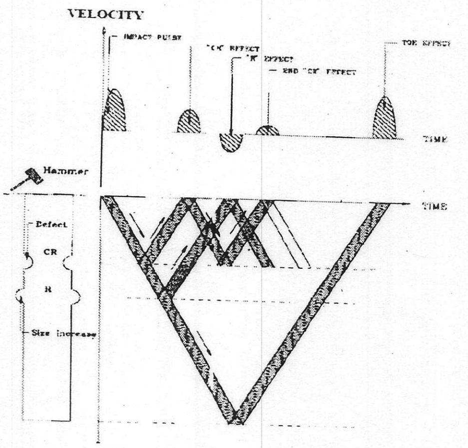

Figure 2 Wave Propagation

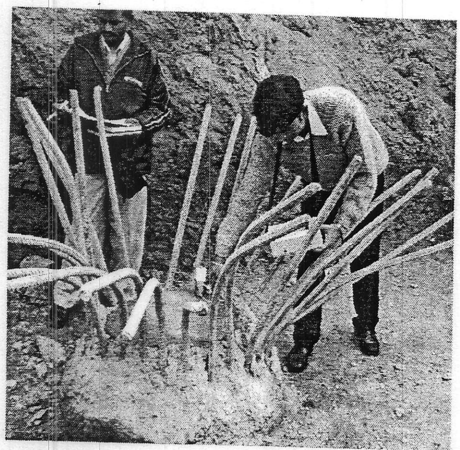

Figure 3 Pile Integrity Test in Progress

The output from the accelerometer is fed into the PIT Equipment. The test record is typically presented as the pile top velocity which includes the incident impact and resulting wave reflections.

The response is analyzed to assess the pile concrete quality, presence of muck / soft material at the pile toe, necking or bulging of pile, discontinuities in the pile, etc. The analysis is based on the wave equation principle. As a stress wave propagates through the pile concrete, it is reflected back from an interface that has a different modulus of elasticity. Thus, in a good pile, a strong reflection would be obtained from the pile toe. If a pile has a defect, a reflection would be obtained from such a defect. Reductions in impedance (i.e. defects) cause reflected tension waves and bulges produce reflected compression waves. Typical PIT results are illustrated on Fig. 4.

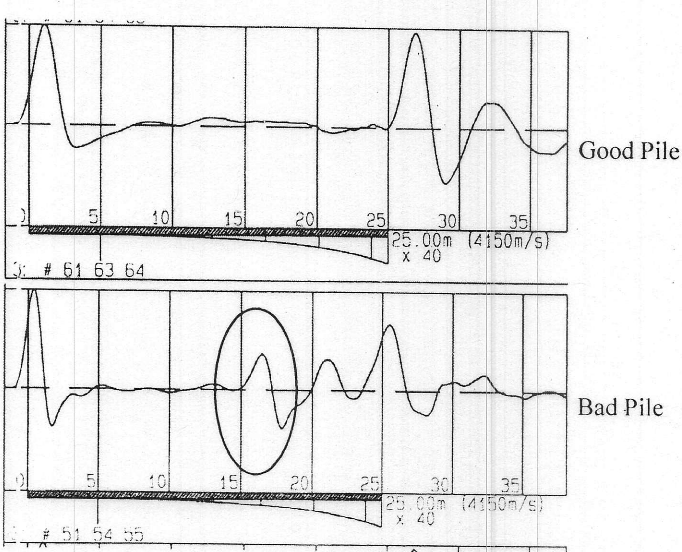

Figure 4 Typical PIT Results

3. CASE STUDIES

Two case studies demonstrating the use of PIT method to assess the pile quality are presented herewith. The PIT data has been evaluated to assess the quality of pile concrete and the likely presence of any discontinuities. Results have also been correlated to pile load test data.

3.1 Case Study 1 : Piles for Proposed Mall in Noida, U.P.

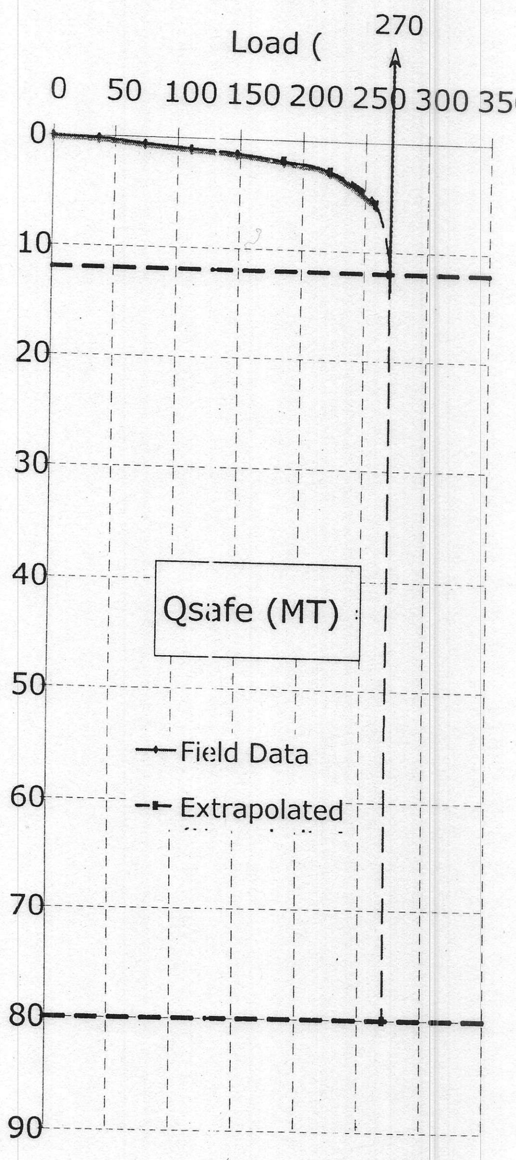

Figure 5 Pile Load Test Results

Project Background: PIT was performed on 800 mm diameter bored cast-in-situ piles installed at a Mall project coming up in Noida, U.P. Initial (cyclic) pile load tests were performed at the site, which indicated an ultimate pile compressive capacity of 270 MT. Subsequently, PIT was also performed on site as a quality control / quality assurance measure.

Site Stratigraphy: The soils encountered at the site are alluvial in nature and consists predominantly of fine-grained soils to about 2.0 m depth, underlain by a silty sand stratum to the maximum explored depth of 25-45 m, as depicted on Fig. 6. The depth to groundwater level has been reported to be between 8.3 to 8.7 m below original ground surface elevation at the time of the field investigations.

At the time of pile load tests and PIT testing excavation had already been carried out to about 7 m depth below OGL. The pile cut-off-level (COL) was at the excavation level.

Cyclic Pile Load Test Results: Initial vertical (cyclic) pile load test was carried out at the site on Pile No. TP-1. The test was carried out to a vertical pile deflection of 5.64 mm at 259 MT load. When the next load increment i.e. to 296 MT was applied, the deflectometer started moving at constant speed continuously and the pressure gauge did not show any increase in pressure. The test was thus stopped at this stage as the pile failed by plunging and was not offering any resistance (Fig. 5). Thus analyzing the test results, the test pile TP-1 is considered safe for an axial compressive load of 135 MT, considering that the pile failed by punching at a static load of 270 MT.

Pile Integrity Test Results: PIT was performed on fourteen (test and routine) piles at the site, including TP-1, to assess the pile quality at the site.

A pictorial representation of the site stratigraphy in the vicinity of TP-1 is illustrated on Fig. 6, along with the corresponding PIT result. The PIT record has been placed alongside the borehole profile for comparison purpose. The PIT record obtained at TP-1 suggests good pile shaft integrity. A clear pile toe

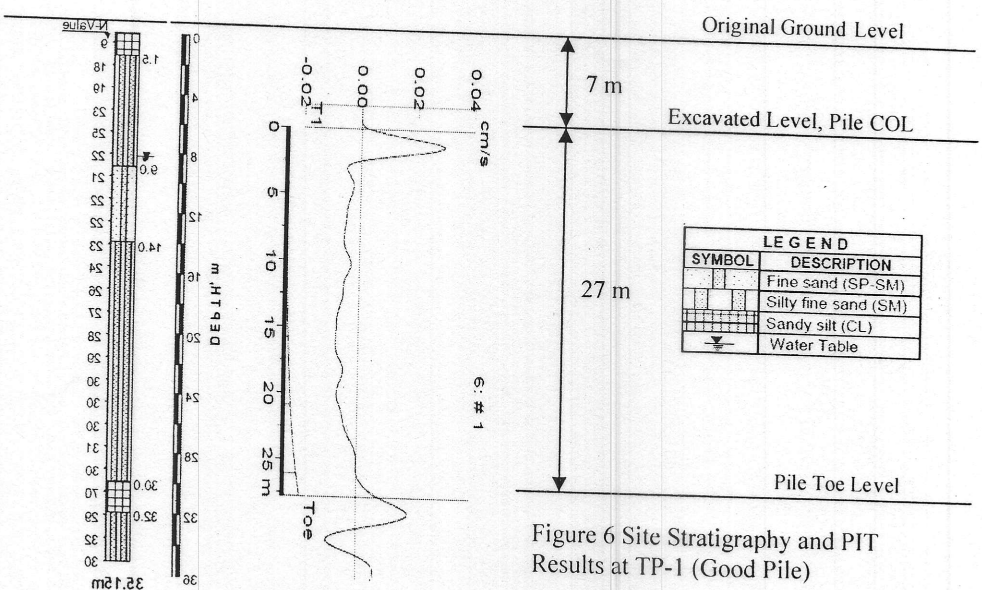

Figure 6 Site Stratigraphy and PIT Results at TP-1 (Good Pile)

response was obtained at 27 m depth, which corresponds to the design pile length.

Some of the PIT results from testing of routine piles installed at the site that showed potential defects are illustrated on Figs. 7 and 8.

The PIT record illustrated on Fig. 7 indicates possible variations in the pile cross-section with depth. This was probably the result of borehole enlargement at some depths, either due to borehole cave-ins or large variation in soil stiffnesses with depth.

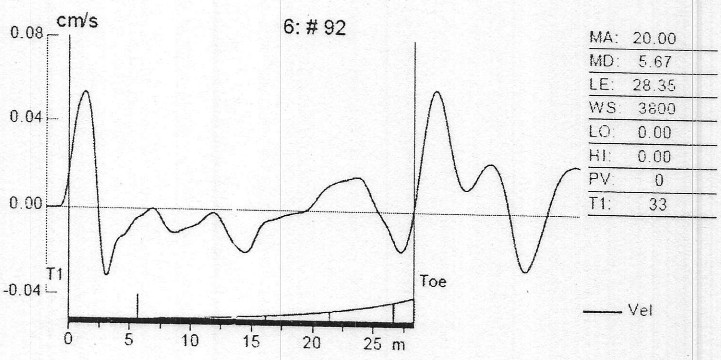

Figure 7 Variations in pile cross-section

On the other hand, the PIT records illustrated on Fig. 8 showed a clear reflection at 16~18 m below pile cut-off-level. This indicates a possible major defect at that depth or the pile may be short at this location.

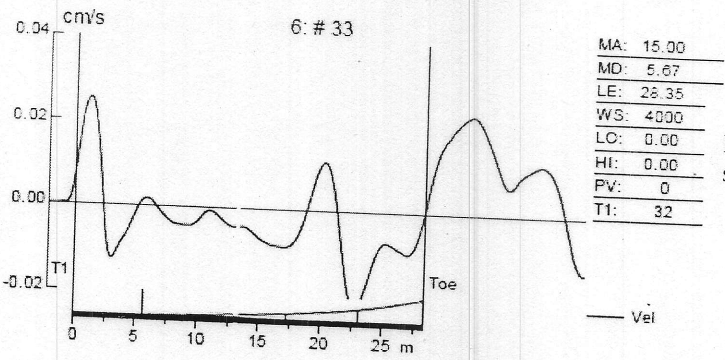

Figure 8 Major defect at 16~18 m depth (or short pile)

3.2 Case Study 2 : Piles for Rail Overbridge (ROB) in Malout, Punjab

Project Background: At this bridge site 1000 mm diameter, 14 m long RCC bored cast-in-situ piles were installed. Sample PIT results are presented below (Figs. 9 and 10).

PIT Results: While the soundness of most piles appeared to be within acceptable limits, weak toe response was observed in one of the piles (Fig. 10). As per the authors' assessment, it is likely that concrete at the pile toe may not be sound or there may be some loose soils at the toe. The weak toe response may also be a result of high friction soils along the pile shaft.

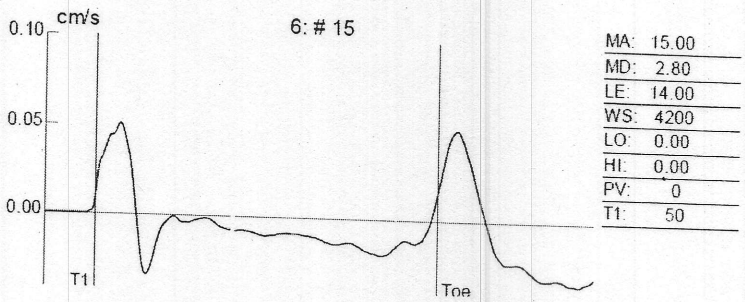

Figure 9 Good Pile (14 m length)

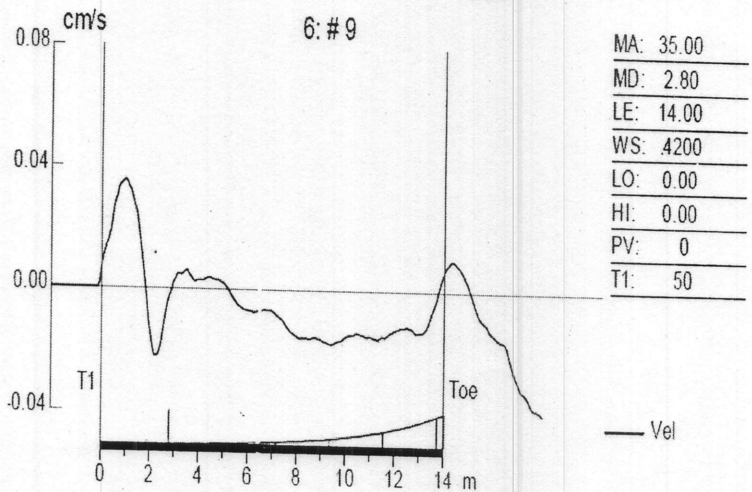

Figure 10 Weak Toe Response

4. LIMITATIONS

The following are the limitations of the Pile Integrity Test Method (*Rausche et al, 2000*):

- The length of pile interpreted from PIT depends on assumed wave speed, soil strength, pile uniformity, actual diameter and length, as well as equipment noise, filters and resolution.
- Highly non-uniform piles are difficult to interpret.
- The stress waves may be reflected or blocked at locations of severe cracks or manufactured mechanical joints. Therefore, no information can be retrieved from locations below such cracks or joints. Small defects may be hard to find. Some test results may be inconclusive.
- PIT records showing potential defects do not necessarily mean that the pile quality is poor or that the pile should be rejected. The decision on whether or not to accept the pile should be taken after comparing PIT records of several piles on the project site and load testing questionable piles.
- The acceptability of pile integrity as determined by the PIT does not have any correlation with the safe load that the pile can carry. This should be confirmed by pile load tests.

5. CLOSURE

PIT can be successfully used during foundation construction to assist engineers and contractors with quality control/quality assurance needs. The method offers several advantages over other testing methods, including other non-destructive methods, for its rapid deployment, mobility, speed and low cost. It is capable of quickly producing information on the possible presence of defects such as voids, breaks, discontinuities or inclusions; and provides ressonable estimates on pile length.

The successful application of the technology, however, requires a clear understanding of its limitations, as well as the operator's familiarity of the system and experience with pile foundations.

The authors are of the opinion that PIT testing should be included in the evaluation process of the foundations, in conjunction with standard geotechnical borings, pile load tests, field observations etc. to ensure that the project quality requirements are satisfied on the field.

6. REFERENCES

Rausche, F., Likins, G. E., Hussein, M.H. (May 1988), "Pile Integrity By Low And High Strain Impacts", Third International Conference on the Application of Stress-Wave Theory to Piles: Ottawa, Canada; 44-55.

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PIT Collector User's Manual, October 2005.