

# **FORENSIC EVALUATION OF DEFECTIVE BORED PILES OF AN INDUSTRIAL PLANT**

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## **ABSTRACT**

Settlement was observed in piles installed for an industrial facility in Haryana. The paper presents results of forensic evaluation of two piles. Low strain pile integrity tests (PIT) and parallel seismic tests (PST) were used to effectively identify the defects. To physically confirm the defects, coring through the pile concrete was done. The study effectively identified the nature of the defects and the depth at which the piles had major discontinuities.

**Keywords:** defective piles, geotechnical forensic evaluation, pile integrity test, parallel seismic test, pile-concrete coring

## **INTRODUCTION**

Bored piles of 600 mm diameter extending to 16 m depth below cut-off level of 1.3 m below GL had been installed for an industrial plant in Haryana. The piles were designed for an axial compression capacity of 50 tonnes. During the erection of the steel structure for the pre-engineered building, settlement was observed in some of the pile caps. These pile caps had two piles each below them.

A forensic investigation was undertaken by the authors to help the owner evaluate the severity of the problem and to develop remedial measures. The paper presents results of geotechnical investigation conducted at the site, coring through piles to assess the concrete quality and geophysical tests conducted to assess the problem. Results of the investigation on two piles (Pile Nos. 238 and 239) are detailed here to illustrate the methodology to evaluate the pile quality.

## **PROJECT DETAILS**

Loose sandy silt and silty sand was encountered to about 10-12 m depth at a factory for a heavy industry in Haryana. To transfer the loads safely, RCC piles of 600 mm diameter were installed to 16 m depth below the cut off-level of 1.3 m depth to support the pre-engineered buildings. Each pile group had two piles with each pile designed for an axial compression capacity of 50 tonnes.

During the erection of the steel structure for the factory, settlement was observed in some of the pile caps even before the full load was transferred through the columns. To evaluate the problem in detail and to reconfirm the stratigraphy, a geotechnical investigation consisting of boreholes and static cone penetration tests was performed in the vicinity of the piles that experienced failure.

This was followed up with geophysical tests that included low strain pile integrity tests and parallel seismic tests. Concrete coring through the piles provided the clinching evidence of the defects in the piles.

## **SITE STRATIGRAPHY**

The soils at the site are alluvial in nature and consist primarily of sandy silt of low plasticity from the ground surface to 9-12 m depth underlain by silty sand to 21 m depth. Sandy silt is met below the sand stratum to 30 m depth. Groundwater was encountered at about 5.8 m depth. SPT values are low to about

10-12 m depth with some values as low as 1-4. Figure 1 presents typical borehole data drilled in the vicinity of the failed piles investigated. Fig. 2 presents photograph of borehole in progress in the factory premises.

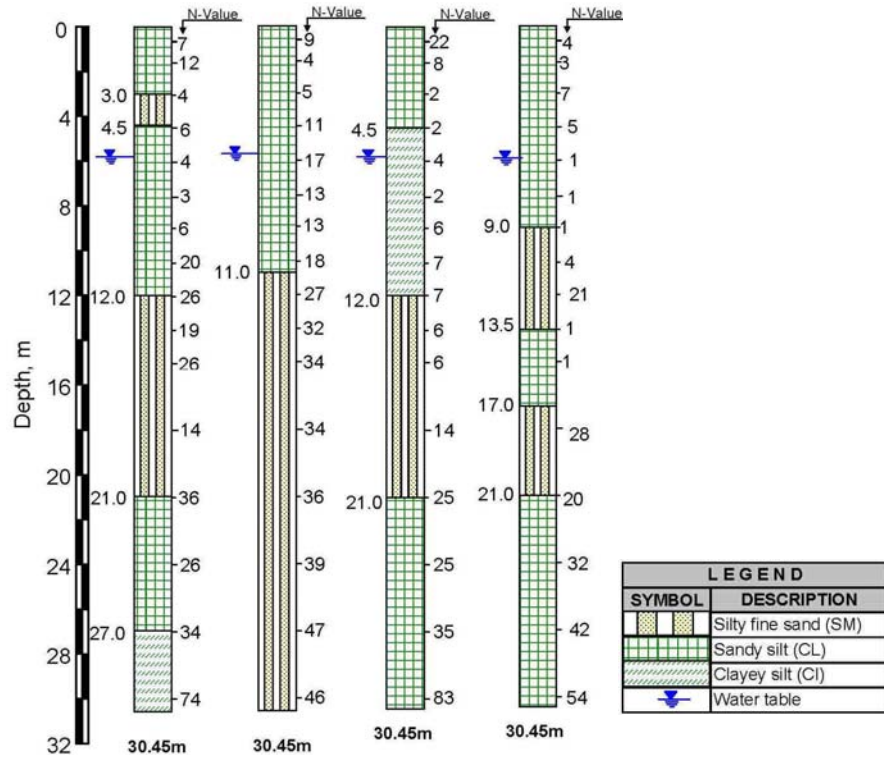


Fig. 1. Typical Borehole Data

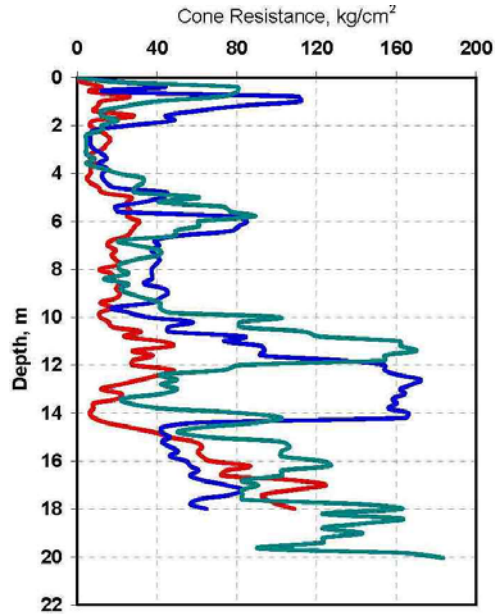


Fig. 2. Borehole in progress inside the factory structure

The cone tip resistance values also show a similar trend with low  $q_c$  values to 10-12 m depth. Figure 3 presents a photograph of the static cone penetration in progress. Plots of cone tip resistance versus depth are presented on Fig. 4.



**Fig. 3. Static cone penetration test in progress**



**Fig. 4. Cone tip resistance versus depth**

## **NON-DESTRUCTIVE TESTS TO ASSESS PILE QUALITY**

### *Low Strain Pile Integrity Tests*

Low-strain pulse echo response test (pile integrity test, ASTM D 5882-00) using a handheld hammer was initially tried out by excavating a pit adjacent to the pile cap to expose the pile and impacting it from the side. But since the response was not good, the test was again carried out after dismantling the pile cap (Rausche et al, 1988). A small portion of the exposed pile top was leveled, and an accelerometer was placed on it. The hammer was impacted on the pile. A photograph of the test in progress is presented on Fig. 5.



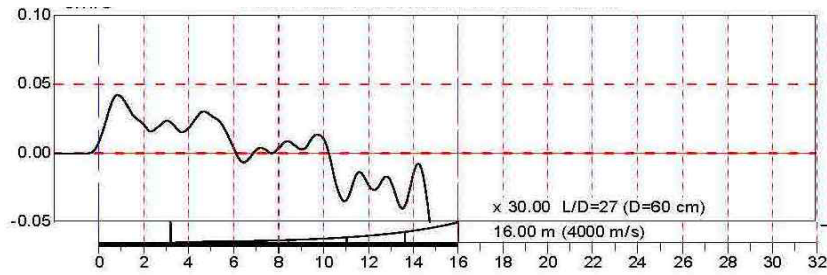
**Fig. 5. Pile integrity test in progress**

The evaluation of PIT records was conducted in the time domain using the Pulse-Echo method. The pile top velocity is displayed as a function of time with an exponentially increasing magnitude such that the pile toe reflection is enhanced. The averaged, amplified velocity (in cm/s), averaged for several impacts, is presented on Figs. 6 and 7 as a function of the pile length. The input compression wave from the

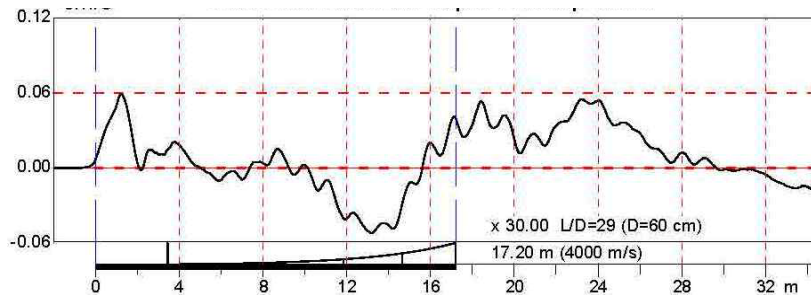
hammer is reflected from pile toe (or a change in cross sectional area or pile material quality) and returns to the pile top at a time related to the speed of travel of the wave in the pile material. Pile length is computed based on the assumed wave speed (c) and measured wave arrival time (t) using the following relation:

$$c = 2L/t$$

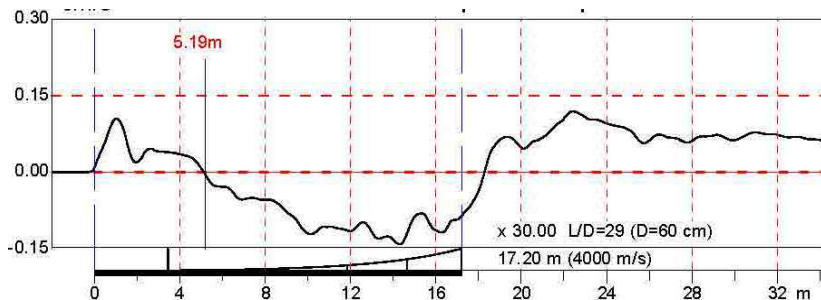
PIT results for Pile 238 are presented on Fig. 6 for pile impacted from the side and on Fig. 7 for pile impacted on the top. Similar data for Pile 239 are presented on Figs. 8 and 9 respectively.



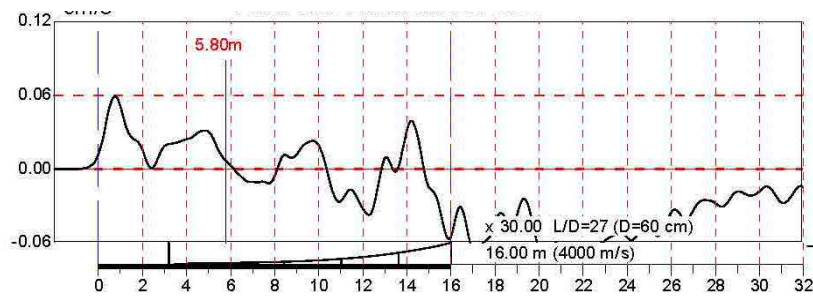
**Fig. 6: Typical PIT record - Pile 238 impacted from side**



**Fig. 7: Typical PIT record - Pile 238 impacted from top**



**Fig. 8: Typical PIT record - Pile 239 impacted from side**



**Fig. 9: Typical PIT record - Pile 239 impacted from top**

Table 1 presents a summary of the interpretations from the pile integrity tests.

**Table 1. Results of pulse echo low strain Pile integrity Test (PIT)**

Pile No.	Test Condition	Number of Tests Attempted*	Observations and Interpretations
P238	Test done by excavating a test pit and striking the pile top from the side	6	Poor data quality. Test inconclusive.
	Test done from top of pile cap	4	Poor data quality. Test inconclusive.
	Test done from pile COL after dismantling the pile cap completely	17	Strong reflection at 3.5-3.6m depth, possibly due to bulging at this depth
P239	Test done by excavating a test pit and striking the pile top from the side	7	Data indicates either a defect at 6m depth below pile COL, or the wave could not penetrate below this level.
	Test done from top of pile cap	15	Weak toe reflection seen at the anticipated pile tip level. But uncertain and needs verification
	Test done from pile COL after dismantling the pile cap completely	19	Strong reflection at 3.5-3.6m depth, possibly due to bulging at this depth

\* Each test being average of 6 blows

It is noted that the variation in pile cross-section at 3-4m depths coincides with the presence of groundwater table. Since the pile boring was carried out using manual winch equipment without liners, it is likely that there might have been enlargement in the pile bore diameter at the groundwater table depth.

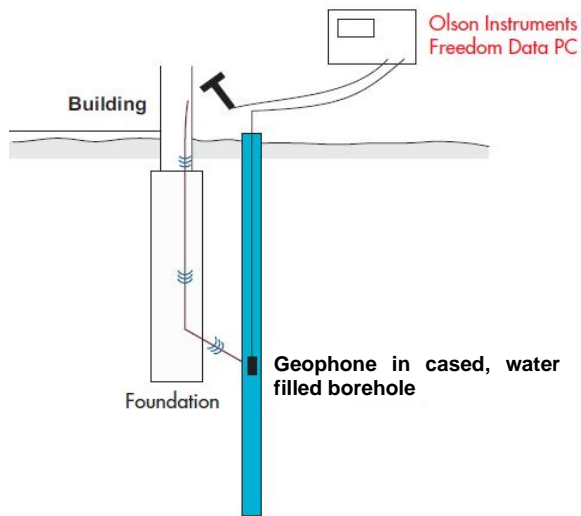
Due to significantly strong reflections from 3.5-3.6 m depths in Piles 238 and 239, it was not possible to determine the pile integrity below this depth. The authors suggested that the pile be exposed for physical inspection at this depth. However, the project owners refused to allow for the same, and chose to install additional piles at this location instead.

#### *Parallel Seismic Tests*

To assess the depth of the piles, parallel seismic test was performed in accordance with ASTM D4428/D4428M-00. The test can give reasonable assessment of depth of foundation and concrete quality (Sanjay Gupta et al 2015). The test involves impacting the exposed pile to generate seismic wave energy that travels down the pile and is sensed by a geophone receiver in a nearby borehole.

For this, a 150-mm diameter borehole was drilled about 1 m distance from the pile. The borehole was cased with 75 mm diameter PVC casing. The annular space between the borehole wall and the casing was backfilled using cement-bentonite grout.

A 5-kg hammer with a Teflon tip was used to impact the pile top. Triaxial geophones were lowered in the cased borehole to receive the compression and shear waves traveling down the foundation. Data acquisition to pick up the first arrivals (Primary wave) was done at every 1 m depth interval up to the final borehole depth of 20 m. A schematic of the test set-up is illustrated on Fig 10. Figure 11 is a photograph showing lowering of geophone into the hole.

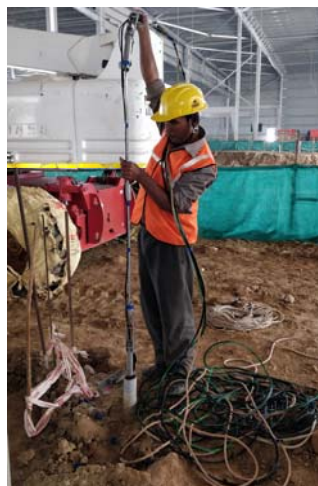


**Fig. 10. Schematic of parallel seismic test**



**Fig. 11. Borehole for parallel seismic test adjacent to pile cap**

Figure 12 presents a photograph showing the lowering of geophone into the borehole.



**Fig. 12. Geophone being lowered into borehole**

Figure 13 presents a plot of the measured wave velocity versus depth. The measured wave velocities are fairly low ( $\sim 1000$  m/s) in the top 12-15m depth, indicating that we are picking up tube waves- waves that travel down the water in the PS tube and not down the shaft. While there is no usable data obtained from P283, the sudden increase in measured wave velocity at P-239 at about 13.5m depth indicates a change of medium, i.e. earlier arrival of refracted waves travelling through the pile shaft, as compared to direct tube waves.

Table 2 presents the interpreted pile profile from the parallel seismic test.

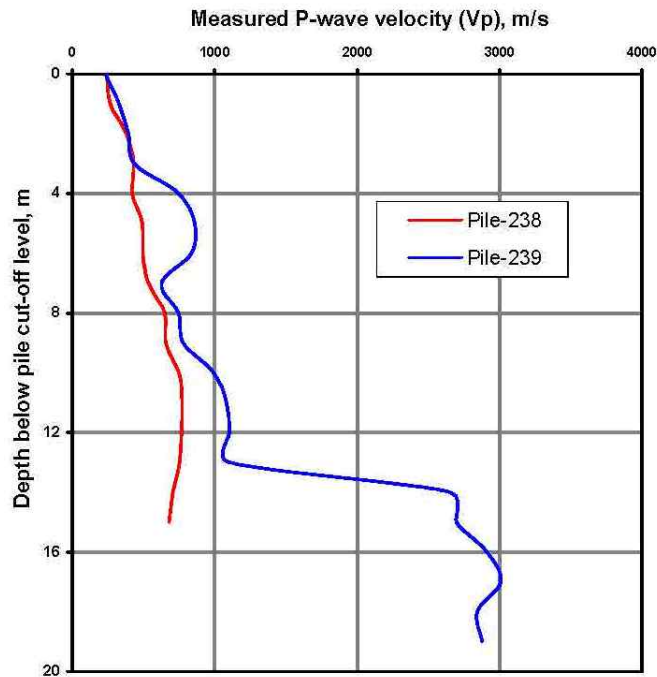


Fig. 13. Parallel Seismic test: P-wave velocity vs. depth

Table 2. Interpretations from parallel seismic test

Pile No.	Possible Change in Impedance below Pile COL	Interpreted Pile Length below COL	Observations and Interpretations
238	~ 5 & 11 m	Unclear	Pile length could not be ascertained due to poor quality PS data (possibly due to soil cavitation in the test vicinity)
239	~ 3.5 m	Approx. 13.5 m	Some change in wave speed observed at 3.5m depth [matches PIT data]. Distinct change in wave velocity at 13.5 m depth [matches coring observations]

### CORING THROUGH PILE

To confirm the pile quality and continuity, drilling was done through the piles using a hydraulic rotary core drilling rig. The drilling rig was set up at the pile-centre and leveled so as to drill vertically through the pile. A double tube core barrel with a 32-carat diamond impregnated core bit was used to maximize the core recovery and minimize mechanical fractures in the core. Fig. 14 presents a photo of the pile coring in progress.

Fig. 15 is a pictorial summary of the drilling records and the core recoveries and RQD values for Piles 238 and 239. The observations and interpretations based on the pile coring are discussed in Table 3.



Fig. 14. Coring through pile in progress

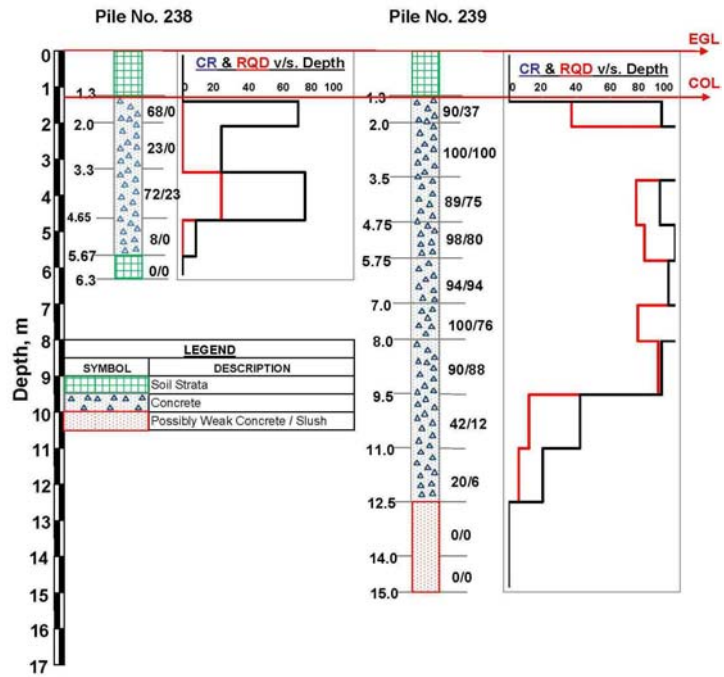


Fig. 15. Results of coring through pile

Table 3. Observations and Interpretations from pile coring data

Pile No.	Maximum Explored Depth below COL	Depth at which soil was encountered	Observations and Interpretations
238*	6.3 m	5.67 m	<p>Bent longitudinal reinforcement pieces were found in last core run from 4.65-5.67 m depth. Soil was encountered in the pile bore at 5.67-6.3 m depth, and the coring was terminated in soil at 6.3 m depth.</p> <p>The pile may be bent / damaged at about 5-6m depth. Alternatively, there may be a major defect (soil inclusion, necking, short pile) at this depth.</p>
239*	15.5 m	12.5 m	<p>0-9.5 m depth: Fairly good core recovery indicating expected pile concrete and continuity.</p> <p>9.5-12.5 m depth: Core recovery % dropped significantly, which may be due to weak or discontinuous concrete.</p> <p>Below 12.5 m depth: Nil recovery &amp; RQD values.</p> <p>Color of the return water was gray, indicating that we were still drilling through concrete and not soil. Possible presence of weak concrete or slush, possibly intermixed with soil.</p> <p>Some reinforcement pieces (16 mm dia) were encountered in core run from 14 to 15m depth. Pile coring could not be extended below 15m depth due to reinforcement bars being encountered.</p>

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Authors are of the opinion that the effective pile length may be only about 12.5m depth, below which weak concrete / pile bore muck is encountered, indicating poor bottom cleaning during pile installation.

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\* *Expected pile length below cut-off level = 16 m*

## CONCLUSIONS

The study conclusively proved that the piles failed due to major defects in the piles. The combination of pulse echo low strain integrity test and parallel seismic test are effective non-destructive test methods to identify pile lengths as well as possible presence of defects / discontinuities. Coring through the concrete gave confirmatory evidence of the defects and pile quality. The combination of these tests is an effective forensic approach to assess the quality of the piles installed.

The findings and overall conclusions of the forensic investigation are summarized below.

**Pile 238:** Pile is bent or broken below 5.67 m depth, below which the testing results are uncertain due to variations in pile cross-section and possible cavitation in surrounding soil strata. The poor pile structural integrity, combined with the presence of loose soils in the pile vicinity, are a likely explanation for the pile settlement experienced at this location.

**Pile 239:** Effective pile length may be 12.5-13.5m, below which weak concrete / slush is encountered. Tests indicate poor bottom cleaning prior to pile concreting, which shall affect pile performance in-situ.

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