

## Failure of bored piles of a factory building – Forensic evaluation

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### ABSTRACT

Excessive settlement was observed in piles installed for a factory building in Haryana. The paper presents results of forensic evaluation of two failed 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:** failed piles; forensic evaluation, pile integrity test; pile-concrete coring; parallel seismic test

### 1 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 pre-fabricated factory building in the state of Haryana in north India. The piles were designed for an axial compression capacity of 50 tonnes.

During the erection of the steel structure for the pre-engineered building, excessive 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 so as to develop remedial measures. This included a geotechnical investigation, non-destructive geophysical tests and coring through piles.

Results of the investigation on two failed piles (Pile Nos. 238 and 239) are detailed here to illustrate the methodology to evaluate the pile quality.

### 2 PROJECT DETAILS

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

During 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. For detailed evaluation of the problem and to reconfirm the stratigraphy, a geotechnical investigation consisting of boreholes and static cone penetration tests was performed in the vicinity of piles that experienced failure.

This was followed up with non-destructive tests

such as low strain pile integrity tests and parallel seismic tests. Coring through the pile concrete provided the clinching evidence of the defects in the piles.

### 3 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.

The cone tip resistance  $q_c$  values also show a similar trend with low  $q_c$  values to 10-12 m depth. Plots of  $q_c$  versus depth are presented on Fig.1.

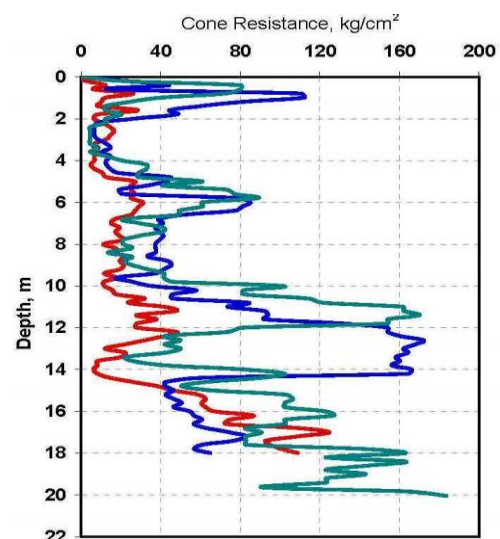


Fig. 1. Cone tip resistance versus depth

Fig. 2 presents typical borehole data.

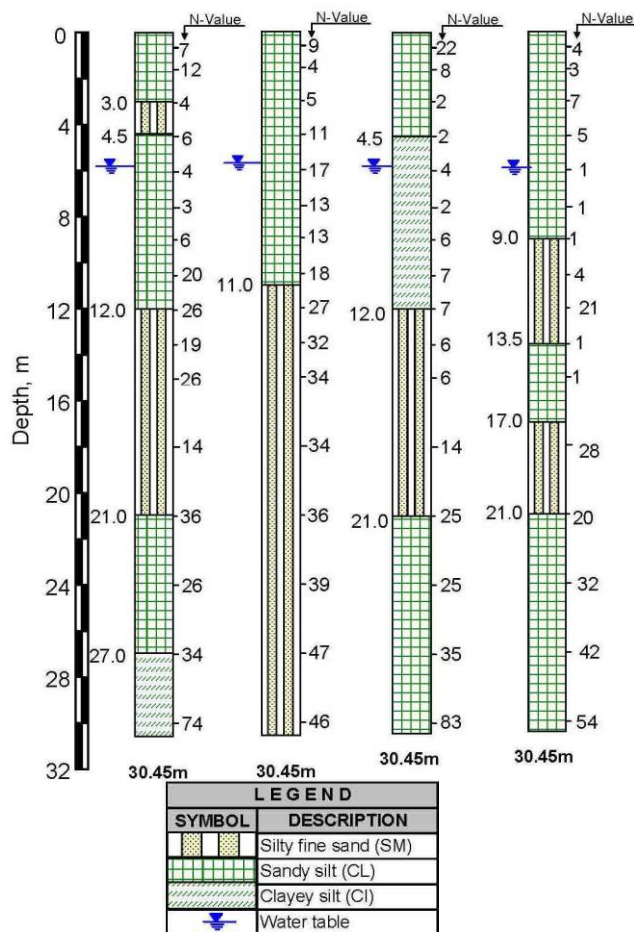


Fig. 2. Typical borehole data

### 3 NON DESTRUCTIVE TESTS TO ASSESS PILE QUALITY

#### 3.1 Low Strain Pile Integrity Tests

Low-strain pile integrity test using a hand held 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. Typical result of test on Pile 238 is presented on Fig. 3.

The data showed inconsistent and erratic results. Even when the test was carried out from the pile cut-off level (COL) after dismantling the pile cap, the results were fairly inconclusive. This is fairly uncommon, since the PIT is a very well-established method (Sanjay Gupta et al, 2017).

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

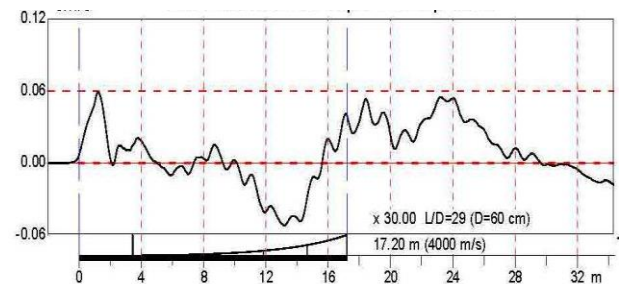


Fig. 3. Typical PIT record: Pile 238 impacted from top

Table 1. Results of pulse echo / low strain Pile integrity Test (PIT) on the failed piles

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. Test inconclusive.
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. Test inconclusive.

\* Each test being average of 6 blows

#### 3.2 Parallel Seismic Tests

To assess the likely depth of the as-installed piles, parallel seismic tests were performed in accordance with ASTM D4428/D4428M-00. The test can give reliable 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 pie 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 cap. The borehole was cased with 75 mm diameter PVC casing. The annular space between the borehole wall and the casing was filled 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 4. Figure 5 is a photograph showing lowering of geophone into the hole.

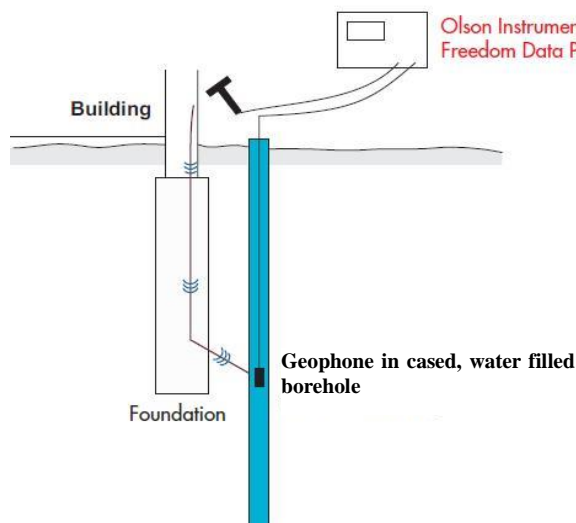


Fig. 4. Schematic of parallel seismic test set-up

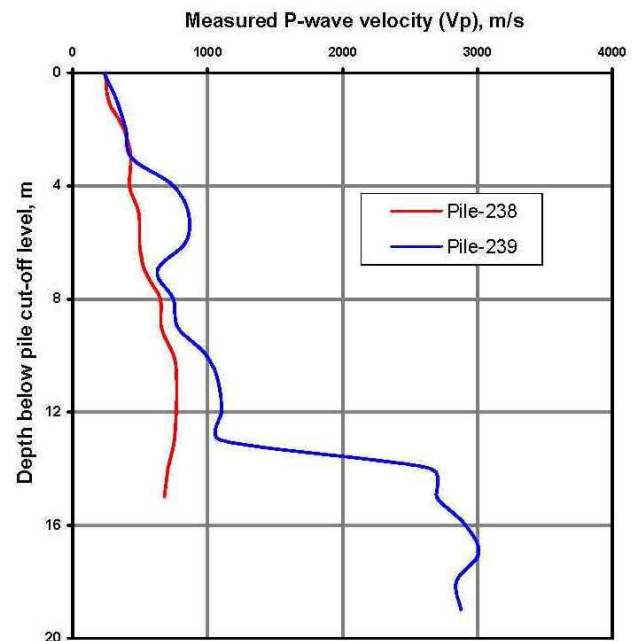


Fig. 6. Results of parallel seismic test

Table 2. Interpretations from parallel seismic test on the failed piles

Pile No.	Possible Impedance Change below COL	in Pile	Interpreted COL	Pile Length below	Observations and Interpretations
238	~ 5 & 11 m		Approx. 15m (unclear)		Data quality very poor below 15 m depth, possibly due to cavities in the soil strata. Some changes in wave speed observed at 5 m [matches coring and PIT observation] and 11 m depths.
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 Data quality very poor below 19m depth, possibly due to cavities in the soil strata.

#### 4 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. 7 is a pictorial summary the pile coring results.

Pile 238 was probably bent or broken below 5.67 m depth as indicated by soil met below this depth. Drilling was terminated at 6.3 m depth. Below 9.5 m depth, Pile 239 concrete is probably weak and discontinuous. Also, below 12.5 m depth, there is lost of soil, slush / muck mixed with the concrete.

Table 3 presents the observations and interpretations from the examination of the concrete cores and recovery / RQD values.

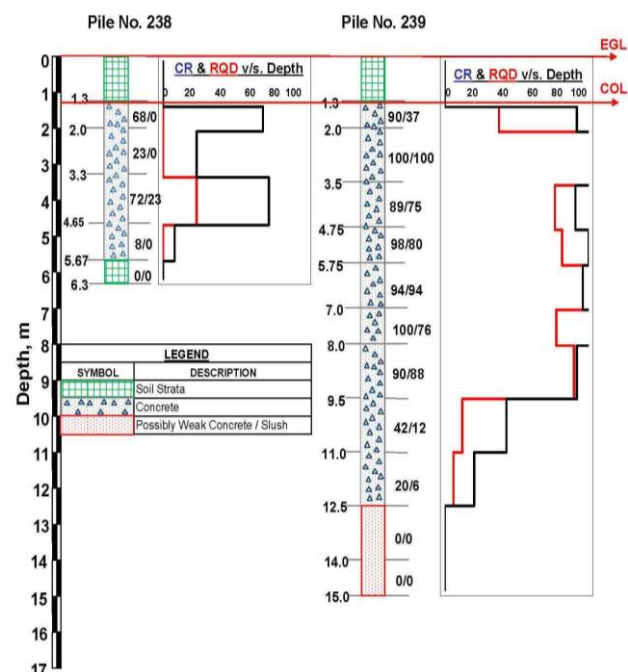


Fig. 7. Pile Coring Records for Piles 238 and 239

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	Bent longitudinal reinforcement pieces were found in the last core run from 4.65-5.67 m depth. The pile may be bent / damaged at this level. Possible defect (concrete discontinuity, necking etc). 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.
239*	15.5 m	12.5 m	0-9.5 m depth: Fairly good core recovery indicating expected pile concrete and continuity. 9.5-12.5 m depth: Core recovery % dropped significantly, which may be due to weak or discontinuous concrete or soil inclusions. Below 12.5 m depth: Nil recovery & RQD values. Color of the return water was gray, <i>indicating that we were still drilling through concrete and not soil</i> . Possible presence of weak concrete or slush, possibly intermixed with soil. Some reinforcement pieces (16 mm dia) were encountered in core run from 14 to 15m depth. May be either due to bending of the pile bore or reinforcement cage below 14m depth. Pile coring could not be extended below 15m depth due to reinforcement bars being encountered.

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

## 5 CONCLUSIONS

The study conclusively proved that the piles failed due to major defects and poor construction quality. 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 of the forensic investigation for two of the failed piles investigated are summarized in Table 4. The tests conclusively proved that Pile 238 was damaged at 5.67 m depth. This pile cannot be relied upon to transfer any load. Skin friction component of Pile 239 upto 13.5 m depth may partially contribute to the pile capacity. But its end bearing component is unreliable.

Table 4. Conclusions of forensic assessment of Piles 238 and 239 that had experienced failure

Pile No.	PIT Results	Parallel Seismic Test Results (PST)	Pile Coring Results	Overall Conclusion
238	Strong reflection at 3.5-3.6m depth. Test inconclusive	Interpreted pile length below COL may be 15 m. Data quality very poor below 15 m depth. Some changes in wave speed observed at 5 m depth [ <i>matches coring &amp; PIT observation</i> ] and 11m depth	Pile bent / discontinuous at 5.67m depth	Effective pile length may be 15 m but pile is bent or broken below 5.67 m depth. Results are uncertain due to variations in pile cross-section and possible cavitation in surrounding soil strata.
239	Strong reflection at 3.5-3.6m depth. Test inconclusive	Interpreted pile length - 13.5 m [ <i>matches coring data</i> ] Some change in wave speed observed at 3.5m depth [ <i>matches PIT data</i> ] Data quality very poor below 19 m depth, possibly due to cavities in the soil strata.	Pile is 12.5m long	Effective pile length may be 12.5-13.5m, below which weak concrete / slush may be encountered. Variations in pile cross-section and verticality suspected.

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