FORENSIC EVALUATION OF BORED PILES FOR A FACTORY PROJECT AT JHAJJAR

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ABSTRACT

A geotechnical forensic evaluation of piles for an industrial facility in Haryana was performed to assess the quality of the piles and to evaluate piles installed using two different types of rigs. Low strain pile integrity tests were performed on all piles to assess the pile length and possible presence of structural defects. Coring was done through questionable piles for the clinching evidence of concrete quality and pile length. Probe holes adjoining piles helped confirm the bulging of piles at shallow depth. The paper highlights the importance of implementing a well-planned quality assurance program to confirm that all piles installed are of the desired quality.

Keywords: pile quality, quality assurance of piles, low-strain pile integrity tests, pile-concrete coring

INTRODUCTION

At a factory site in Jhajjar, Haryana, 246 bored cast-in-situ piles (240 working piles and 6 test piles) were cast for the main building / factory area using two different types of rigs, hydraulic rotary rig and truck mounted rig (TMRs). After casting about 150 piles using hydraulic rotary rig, truck mounted rigs were used to speed up the piling activity. After installation of the piles, the client had doubts on quality of piling work executed at site with regard to the structural integrity of the installed piles, particularly those installed using the TMRs. The pile layout and the rigs used is illustrated on Fig. 1.

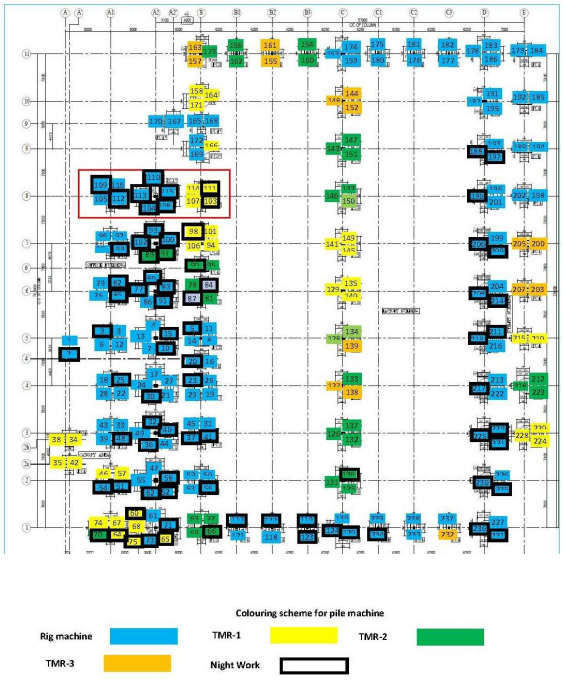


Fig. 1. Pile Rig Usage Layout

Plate 2 illustrates a few piles exposed for the testing and evaluation prior to casting of pile caps.

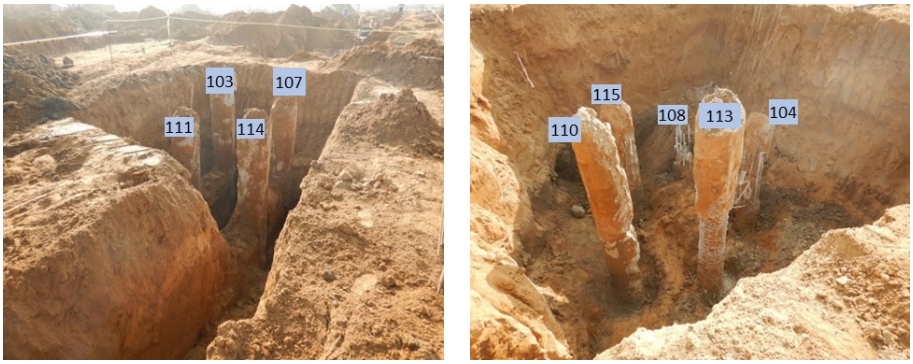


Fig. 2. Exposed Piles

TESTS PERFORMED

The contractor had performed a few initial load tests on test-piles. To evaluate the condition of pile quality the authors carried out a detailed program of confirmatory geotechnical investigation and pile testing as given below:

1. A confirmatory geotechnical investigation was performed which included three boreholes. The results were compared with the previous geotechnical investigation conducted at site.
2. Low-strain pile integrity tests (PIT) were performed on all the piles so as to assess the pile quality, its likely length and to identify the presence of any defects.
3. Concrete coring was done through selected piles to assess the concrete quality and the actual pile length.
4. Probe holes were drilled adjoining selected piles to assess the soil adjoining the pile and to determine the likelihood of bulging of pile.

SITE STRATIGRAPHY

Based on the borehole data, the surficial soil consists of clayey silt up to about 2-3 m depth, underlain by silty sand to about 5-6 m. Below this, sandy silt of low plasticity is encountered to 10.5 m depth, followed by silty sand to 14.45 m depth. SPT values range from 4 to 13 to 2.0 m depth and from 10 to 26 to 5.0 m depth. Below this, the SPT values range from 20 to 38 to 10.5 m depth and from 32 to 71 to 14.45 m depth. A pictorial summary of the borehole profiles is illustrated on Fig. 3.

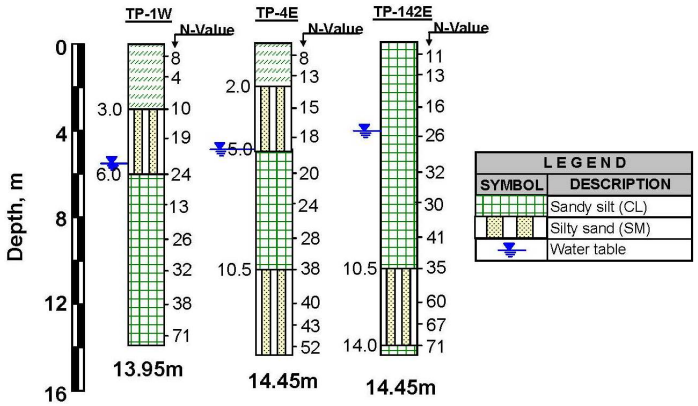
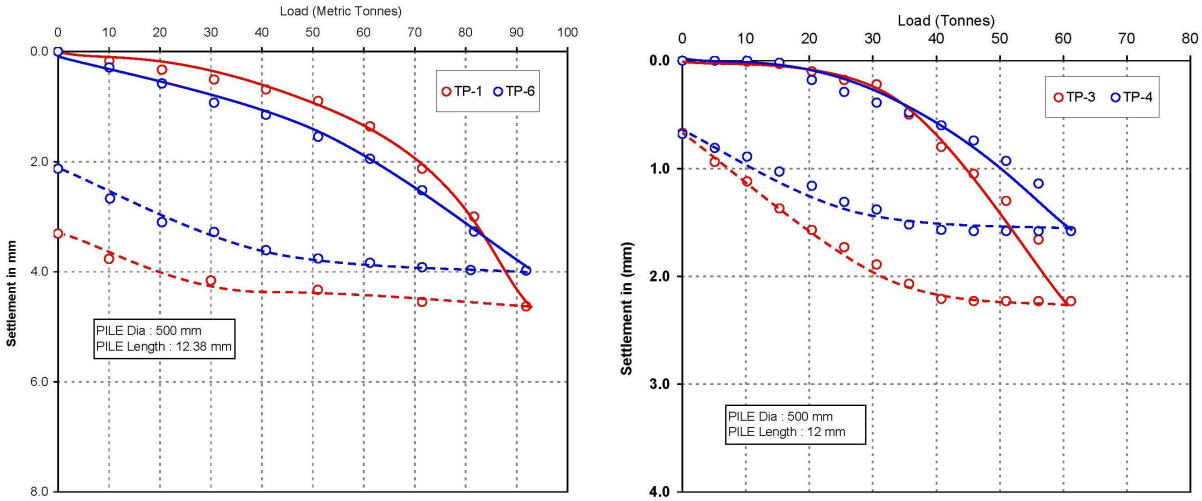


Fig. 3. Typical Boreholes Profile

Although there were some differences in the soil classification in comparison to the data of previous investigation performed by the client, the trend of SPT values is similar.

PILE LOAD TESTS

Initial pile load tests were conducted on 500 mm diameter 12.4 m long test piles. The piles were designed for a compression load of 35 tonnes and pullout capacity of 23 tonnes. All piles were safe under the design load. Under the maximum applied load of 2.5 times the design load, the maximum displacement was less than 5 mm. Typical compression load and pullout test results are presented on Fig. 4.



(a) Compression Load Test on Test Piles (b) Pullout Tests on Initial Piles

Fig. 4. Load-Settlement curves - Typical tests on initial piles

Since the test piles passed under compression, pullout and lateral load tests, the contractor claimed that all the piles are deemed to be safe. However, while a few piles were having capacity higher than the design value, detailed evaluation proved that quality of pile construction needs to be evaluated to confirm that all piles are of uniform and acceptable quality.

LOW-STRAIN PILE INTEGRITY TESTS

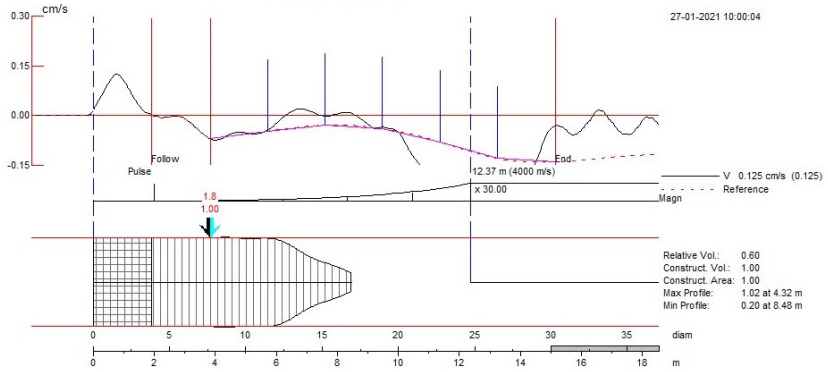
Low-strain Pile Integrity Testing (PIT) is a low-cost tool to locate major defects in piles and estimate pile lengths of bored and driven piles installed at site. It can serve to enhance the confidence level of the engineer on the quality of piles installed (Sanjay Gupta et al, 2008). The test is carried out by the Pulse-Echo (or Sonic Echo) Method, in accordance with the guidelines given in IS: 14893-2021 and ASTM D 5882-16.

PIT is a non-destructive integrity test method for foundation piles and effectively evaluates pile shaft integrity testing by low-strain surface-impact methods (Rausche et al, 1988). It can detect potentially dangerous defects such as major cracks, necking, soil inclusions or voids. It can also be used to assess the pile length (Sanjay Gupta et al 2015).

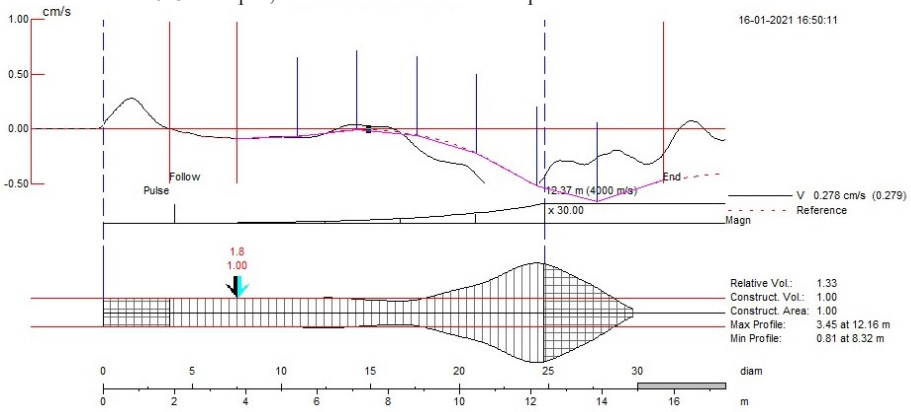
To assess the pile quality, PIT was done on all the piles installed at site. To perform the test, the pile top surface is prepared in order to form a clean, sound and hard concrete for testing. Fig. 5 presents photographs of the test being done on two typical piles.

Fig. 5. Pile integrity tests in progress

The accelerometer is fixed to the top of the pile using a special wax. Signal enhancement by repeated hammer blows on the pile head helped to minimize effects of noise or other disturbances (see PIT Collector User's Manual, 2005). Some typical PIT plots are presented on Fig. 6. Typical results are summarized in Table 1.



Pile 126: Major defect at about 6-8 m depth, either due to reduction in pile cross-section or concrete discontinuity at this depth



Pile 142: Major increase in pile impedance below about 10 m depth below test level. Pile length seems OK

Fig. 6. Typical pile integrity test results together with profile analysis

Some of the PIT results were inconclusive. Inconclusive PIT data (inconsistent results, absence of clear toe response, etc.) is suggests that the pile structural integrity is doubtful. The absence of clear, repeatable PIT data would generally indicate poor pile top preparation, weak or discontinuous pile concrete,

presence of shallow defects, highly non-uniform pile cross-sections and other structural or construction-related problems.

Table 1. Typical results of low strain pile integrity tests

Pile No.	Type of Rig used	PIT Data Interpretation / Test Conclusions
TP-1	Hydraulic Rotary Rig	Large variation in pile cross-section with depth. Increase in pile impedance below about 5 m depth.
TP-4	Hydraulic Rotary Rig	Early toe response. Pile may be short (9-10 m). Further investigation is required.
26	Hydraulic Rotary	Major defect (reduction in pile impedance) at about 6-8 m depth, which may be either due to reduction in pile cross-section or concrete discontinuity at this depth
72	Truck Mounted Rig	Reduction in pile impedance between 6-9m depths, followed by major increase in impedance.
94	Truck Mounted Rig	Major defect (reduction in pile impedance) at about 6-8 m depth, which may be either due to reduction in pile cross-section or concrete discontinuity at this depth
142	Truck Mounted Rig	Increase in pile impedance below about 10 m depth below the test level.
182	Hydraulic Rotary Rig	PIT could not be performed due to improper pile top preparation or presence of weak concrete at the test level.

Overall, the PIT indicated that about 17 working piles were likely to have major defects.

PILE CORING

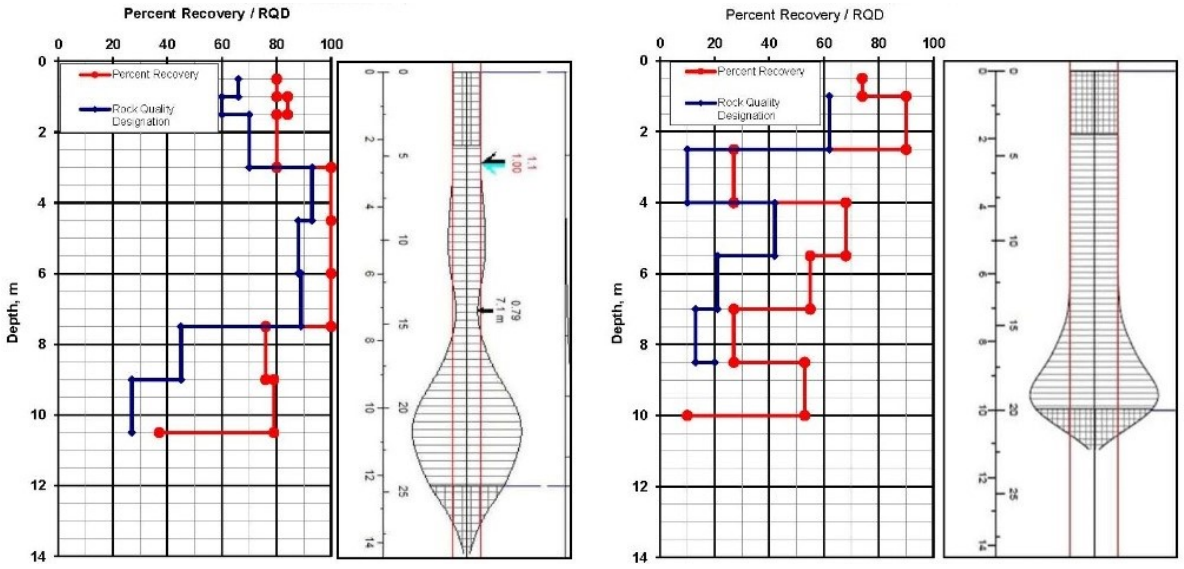
A few selected test piles were evaluated further by coring through the piles. Experience has shown that coring through the concrete (Sanjay Gupta et al, 2017) can effectively evaluate the concrete quality and depth and also assess the condition of the pile toe. Fig. 7 illustrates pile coring in progress.

Fig. 7. Pile Coring in Progress

Typical concrete cores collected from TP-4 are illustrated graphically on Fig. 8. Fig. 9 summarizes the recovery and RQD values together with the interpreted pile profile from PIT results for two typical piles. Table 2 presents the interpretation based on the concrete coring through the piles.

Note: Soil encountered below 10.5 m depth

Fig. 8. Pile Coring Results: TP-4



Pile TP-1 Pile TP-4

Fig. 9. Concrete Core Recoveries and RQD values correlated with PIT Profile Analysis

Table 2. Summary of pile coring results – Observations and interpretations

Pile No.	Design Pile Length, m	Pile Length from PIT, m	Actual Pile Length determined from coring, m	Observations and Interpretations
TP-1	12.37	12.3	9.75	The actual length of the pile is less than the anticipated length of 12.37 m. Necking observed at 7.1 m depth.
TP-4	12.37	9.0 - 10.0*	9.0	Soil was met below 9 m depth. The actual length of the pile is less than the anticipated length. Pile integrity results suggested pile length of 9 to 10 m.
TP-6	12.37	12.37	9.0 – 10.5	The actual length of the pile is less than the anticipated length of 12.37 m. Also, steel reinforcement was encountered at about 6.0 to 9.0 m depth.

* PIT results show reduction in pile length.

As per the results of crushing strength tests on concrete core sample obtained from pile coring, the density of concrete for most samples are lower than the standard value of 2.44 g/cc. Also, the results of the crushing strength of the samples are on the lower side indicating that the quality of concrete is poor.

PROBE HOLES AROUND PILES

Around selected piles in which bulging was suspected, probe holes of 150 mm diameter were drilled by auger at four diametrically opposite locations. The bores were drilled about 20 cm away from the edge of the pile. The purpose was to evaluate possible bulging of the piles (increase in pile cross-section) at deeper depths, as indicated by the PIT results. The probe holes were extended up to about 14-15 m depth below ground level, which is beyond the anticipated length of the pile.

If concrete is encountered in the probe holes, this will indicate bulging of the pile. If concrete is not encountered, either the PIT impedance increase is due to other reasons (variations in concrete density or soil resistance, for example), or the bulging may be less than 200 mm (and hence not captured by the probe bores). Typical probe hole results for two piles are presented on Fig. 10. Table 3 presents the interpretation based on the probe-hole data.

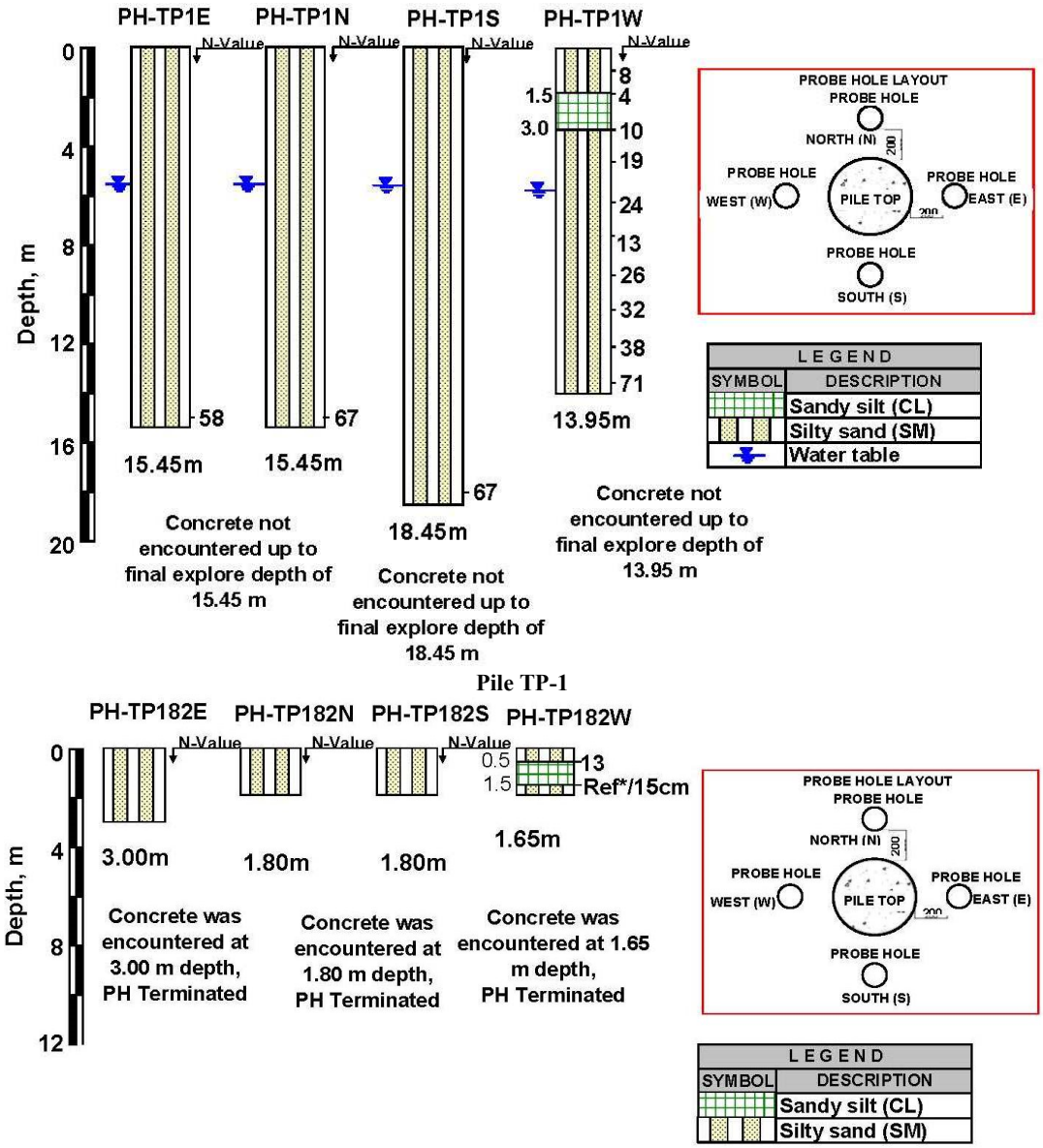


Fig. 10. Probe-Hole Profiles

Table 3. Summary of results of probe holes around three piles

Pile No.	Probe Hole Results				Overall Conclusions
	North	South	East	West	
TP-1	No concrete was encountered	No concrete was encountered	No concrete was encountered	No concrete was encountered	No bulging of pile indicated by probe hole; concrete density may be less
142	No concrete was encountered	No concrete was encountered	No concrete was encountered	No concrete was encountered	No bulging of pile indicated by probe hole
182	Concrete was encountered at 1.80 m depth	Concrete was encountered at 1.80 m depth	Concrete was encountered at 2.0 - 3.0 m depth	Concrete was encountered at 1.65 m depth	Concrete was encountered at 1.8 m depth suggesting increase in pile diameter (bulging) at about 1.5-2.0 m depth.

The probe holes clearly indicated bulging at Pile 182. At TP-1, coring indicated weak concrete of somewhat lower density which corroborates well with the probe hole data. The authors are of the opinion that at Pile 142 also, concrete quality may be poor.

CONDITION OF SOME EXPOSED PILES

Photographs of some exposed piles shown on Fig. 11 confirm that the pile quality at shallow depth leaves much to be desired. Bulging, poor concrete quality, exposed reinforcement, lack of concrete cover, etc. were observed in many cases.

Pile 96 — Bulging at shallow depth in Pile 96

Pile 108 — Poor concrete quality in Pile 108

Pile 113 — Exposed reinforcement in Pile 113

Fig. 11. Condition of some of the exposed piles

CONCLUSIONS

The study conclusively proved that several piles at the project site had to major defects. The combination of pulse echo low strain integrity test, pile coring and probe holes around the piles are effective methods to identify pile lengths as well as possible presence of defects / discontinuities. The combination of these tests is an effective forensic approach to assess the quality of the piles installed.

The authors emphasize here that results of static load tests are not sufficient evidence that the piles installed at the project site are of acceptable quality. A well-planned quality assurance program is required to ensure that every pile is evaluated and assessed.

Low strain pile integrity tests are an effective and economical way to identify piles of questionable integrity. Such piles may be investigated further by high strain dynamic load tests or static load tests. Probe holes adjoining the piles can help identify bulging at shallow depths. Coring through the pile-concrete may be resorted to if substantial reduction in pile length or major defect / integrity is suspected.

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