Evaluation of Pile Integrity using Cross Hole Sonic Logging Testing

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ABSTRACT: Low strain integrity testing is currently the most commonly used method to evaluate pile integrity. Whereas, the test has advantages in terms of no advance preparation, the test does yield limited information in many cases. In comparison, the Cross Hole Sonic Logging (CSL) test is a much superior method to evaluate pile integrity. Although it requires advance preparation in terms of installation of steel / PVC pipes before concreting, it provides more clarity on extent and location of defects, concrete quality etc. There is also much more clarity in interpretation of results compared to any other non destructive tests for deep foundations. CSL is now commonly adopted for all major bored piling projects worldwide and has been used in some infrastructure projects in the country. The paper describes the test method in detail, setup arrangements required for testing, equipments, typical output obtained from the test and data interpretation. The paper also briefly describes a typical TOMOGRAPHY output for one pile. Tomography is an extremely powerful tool that provides a 3-D view of defect inside the pile.

INTRODUCTION

Deep foundations integrity testing mostly applies to foundations constructed on-site from concrete such as drilled shafts, auger-cast piles, driven and cast-in-situ piles etc. These are constructed by various methods depending on the site soil profile. It is practically very difficult to inspect and ascertain the pile quality merely by visual inspection as most piles are long enough, concreting or tremie choke may cause specific integrity problems. Defects may also occur due to soil collapse, contamination of concrete, sudden changes in water table, improper flushing of pile bottom causing soft toe condition, delay in between arrival of two batches of concrete, improper extraction of temporary casing, and a variety of other reasons. Poor monitoring or lack of requisite technical skills as piling is a specialized operation has also resulted in quality problems at project sites. Baker (1993) and O'Neill (1999) have documented common defects and their causes.

Integrity testing is a necessary requirement for quality control after installation to detect flaws in the pile that may have been caused due to any of the above reasons. Increase in design requirements of these foundations also require a high-level of quality assurance and control has been created.

Low strain integrity testing is currently the most commonly used method in the country to evaluate pile integrity. However, the method is to some extent dependent on interpretation of velocity versus time curve. The method also does not evaluate integrity for very long piles, or does not tell pile integrity beyond the first major bulb / defect. It may not reveal complete information about soft toe condition or location of defect to some extent is approximate. In comparison, the Cross Hole Sonic Logging (CSL) test is a much superior method to evaluate pile integrity (Likins, et. al.2004). Although it requires advance preparation in terms of installation of pipes before concreting, it provides more clarity in interpretation of results in comparison to other non destructive tests for deep foundations. The test is standardized as per ASTM D6760-08.

OVER VIEW OF CSL METHOD

Principle of the Test Method

When ultrasonic frequencies (for example, >20,000 Hz) are generated, pressure (P) waves and shear (S) waves travel through the concrete. Because S waves are relatively slow, they are of no further interest in this method. In good quality concrete the P-wave speed would typically range between 3600 to 4400 m/s. Poor quality concrete containing defects (for example, soil inclusion, gravel, water, drilling mud, bentonite, voids, contaminated concrete, or excessive segregation of the constituents particles) has a comparatively lower P-wave speed. By measuring the transit time of an ultrasonic P-wave signal between an ultrasonic transmitter and receiver in two parallel water filled access ducts cast into the concrete during construction and spaced at a known distance apart, such anomalies may be detected. Usually the transmitter and receiver are maintained at equal elevations as they are moved up or down the access ducts.

Two ultrasonic probes, one a transmitter and the other a receiver, are lowered and lifted usually in unison in their respective water-filled access ducts to test the full shaft length from top to bottom. The signals from the transmitter and receiver probes and the depth measuring device shall be transmitted to a filled rugged, computerized apparatus for recording, processing and displaying the data in the form of an ultrasonic profile. A typical tube arrangement and testing principles are presented in Figure 1.

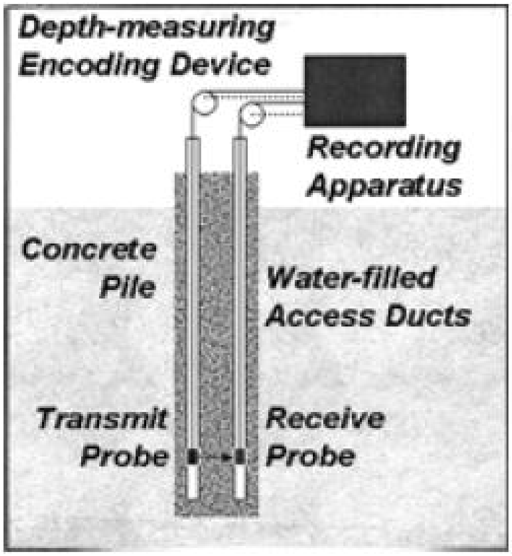

Fig.1 Test arrangement

The transmitter probe generates ultrasonic pulses at frequent and regular intervals during its controlled travel rate. The probe depth and receiver probe's output (timed relative to the transmitter probe's ultrasonic pulse generation) are also recorded for each pulse. The receiver's output signals are sampled and saved as amplitude versus time (Fig. 2) for each sampled depth. These signals can be then nested to produce a "waterfall" diagram. Refer to Figure 3 that is also a part of Case Study

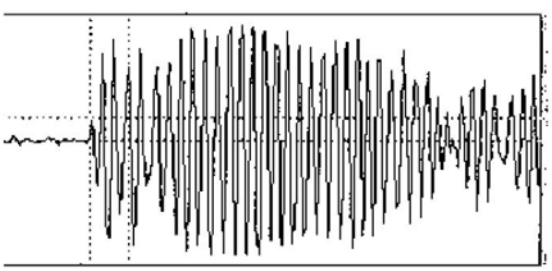

Fig. 2 1ms duration ultrasonic pulse from receiver

Test Procedure

Access ducts are installed during construction of the deep foundation element to be tested. These access tubes maybe of PVC or steel and shall be 38mm or 50mm internal diameter. The total number of installed access ducts in the deep foundation element should be consistent with good coverage of the cross section. Generally one access tube maybe provided for every 300m diameter of the pile. Thus 4 access tubes shall be provided for a 1m or 1.2m pile and they can be in the four opposite directions inside the pile.

The access tubes shall be straight and free from internal obstructions. The exterior tube surface shall be free from contamination (for example, oil, dirt, loose rust, mill scale etc.), and for PVC tubes the surface shall be fully roughened by abrasion prior to installation, to ensure a good bond between the tube surface and the surrounding concrete. The access tubes shall be close ended at the bottom and fitted with removable end caps at the top to prevent entry of concrete or foreign objects, which could block the tubes prior to testing operations.

The access tubes shall be installed such that their bottom is as close as possible to the bottom of the concrete deep foundation element so that the bottom condition can be tested. The access tubes shall be provided a minimum concrete cover of one tube diameter. They shall be secured to the inside of the main axial reinforcement of the steel cage at frequent and regular intervals along their length to maintain the tube alignment during cage lifting, lowering and subsequent concreting of the deep foundation element. The tubes should be filled with water prior to, or within one hour of concreting to avoid effects of heat of hydration due to curing of concrete.

The tests shall be performed at least 3 to 7 days after casting depending on concrete strength and shaft diameter (larger diameter shafts may take closer to 7 days). Early testing times may result in lower speed as the concrete has not attained full strength yet but may provide instant preliminary information about the quality of pile shaft.

Measurement

The measurement is typically conducted by lowering the probes inside the access tubes and then pulling them at a constant rate so that scans are obtained generally at every 50mm interval. After completing scans across one pair of tubes repeat the procedure to scan cross-diagonals and side diagonals to complete the test procedure.
After completing data acquisition, view the ultrasonic profile obtained. Check the ultrasonic profile quality. The waterfall graphics should be of good resolution and contrast. Compare the length of the measured ultrasonic profile with the measured access duct length. If the ultrasonic profile indicates an anomaly, then the suspect anomaly zone may be further investigated by special test procedures or other tomography techniques.

CASE STUDY: 1

Cross hole sonic logging test was conducted at a project in Western India to assess and check the pile integrity for potential problems like cross sectional changes, honeycombing, concrete quality, continuity, etc. The test was conducted as per ASTM D6760-08. The test was carried out on 1000mm reinforced concrete bored piles.

Four steel tubes of 50mm internal diameter were installed. The length of tubes was 12.10m and was kept 0.36m above the concrete level. Figure 3 shows the configuration of access tubes installed in the pile for testing.

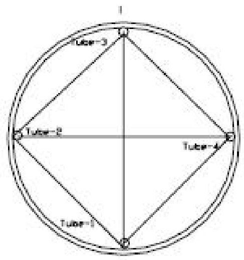

Fig. 3 Layout of access tubes for CSL test at Mumbai

All the installation procedures as described above were followed. Readings were taken by pulling the transmitter and receiver at a constant rate from the bottom to top of the tubes. For each scan the First Arrival Time (FAT), Wave Speed and Energy diagram was obtained. The FAT is the time taken by the wave to reach from transmitter to emitter and is typically the onset of the water fall diagram. The WS was computed knowing the distance between the tubes and since the time of travel between both the tubes is known. The entire sequence was then repeated for other tubes. Since 4 tubes were installed six scans were available for the piles. Figure 4 shows waterfall, energy and wave speed diagram for one typical scan. The WS results are presented in Table 1. This is the average WS for the entire shaft and individual wave speed values can be obtained from the WS diagram.

Table: 1 Access Tube Details

Sr No	Tube Corridor	Total length of tubes (m)	Length of tubes above concrete (m)	Tube spacing (m)	Ave. wave speed (m/s)
1	1-2	12.10	0.36	0.48	4619
2	2-3	12.10	0.36	0.44	4559
3	3-4	12.10	0.36	0.47	4110
4	4-1	12.10	0.36	0.46	4323
5	1-3	12.10	0.36	0.64	4545
6	2-4	12.10	0.36	0.68	4648

The wave speed obtained is a useful tool to evaluate concrete quality. However, because the tubes might not be perfectly straight or even parallel, a fixed absolute limit of a wave speed value cannot be used for evaluation for perimeter profiles. Wave speed is best determined from the test results from the major diagonals. The wave speed is also affected by age of concrete, localized bending of tubes etc. and hence many times the energy is considered a more important parameter in evaluating the results.

CASE STUDY: 2

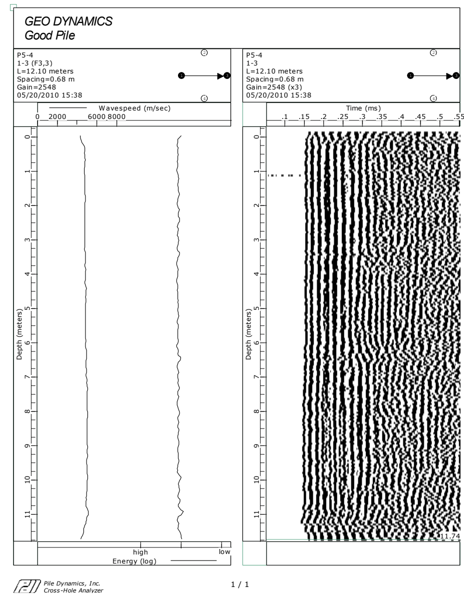

Fig. 4 Waterfall diagram for 1000mm pile shaft

At another project site, three tubes were installed inside a bored pile of 1000mm diameter. CSL output for this pile is attached in Figure 5. The pile shows good concrete quality throughout its length except in the zone of 17.0m. However, it shows clear indication of pile damage around 17.0m in the form of missing waterfall diagram, Energy and Wave Speed graph. The pile was also assessed by conducting a low strain pile integrity test separately as shown in Figure 6. PIT data also shows clear defects around 17.0m depth.

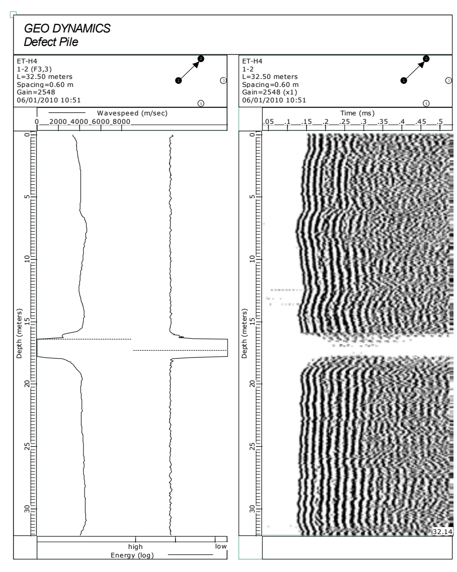

Fig. 5 CSL test data for defective pile.

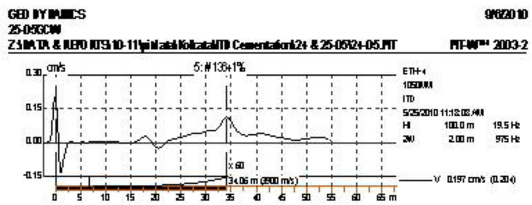

Fig. 6 PIT data for defective pile.

TOMOGRAPHY

CSL data obtained at project sites may or may not show defects. It is also likely that only few of all the scans obtained at the jobsite show defect. It is important in such cases to know the extent of defect along the pile length and also its extent in the lateral direction. This is possible with the TOMOGRAPHY analysis that can be used to obtain a 3-D analysis or a pictorial view of the defect. Tomography analysis requires minimum 4 tubes inside the pile and six scans and uses concrete wave speed as a parameter to obtain the output. The method evaluates both the extent and magnitude of defect. Further discussion is beyond the scope of this paper. Figure 7 shows a typical output from TOMOGRAPHY analysis for a pile that has defect at 6m-8m from test level. Only one scan is presented for the sake of brevity although six scans were obtained for this 1000mm diameter bored pile. The pile can either be replaced or repaired by knowing the exact location and extent of defect from such analysis.

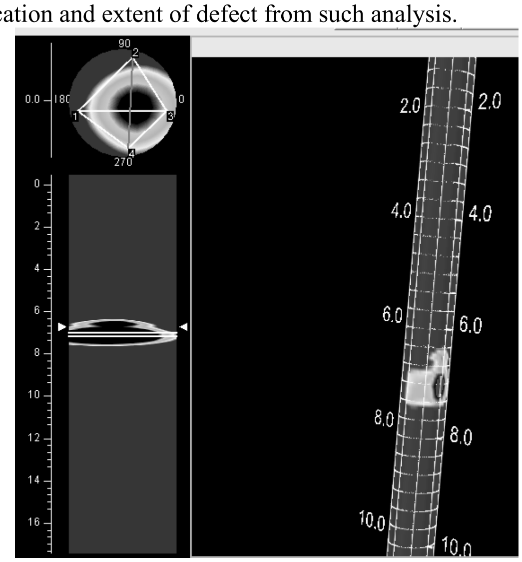

Fig. 7 Typical output of Tomography

CONCLUSIONS

Cross Hole Sonic Logging Test is a superior test compared to low strain testing as it clearly identifies the location and extent of defect. Depending upon the criticality of the job, most specifications worldwide now recommend 10-20 percent or even up to 100 percent of the piles to be installed with tubes for CSL testing at the project sites. The method is particularly useful for initial piles as it if the pile fails or passes a test later, the CSL test may identify if the failure is due to workmanship or soil. The extra cost of tubes to some extent is compensated by the superior and more information obtained about the quality of each pile. If steel pipes are used, then they also serve as additional steel inside the pile.

The CSL test has certain limitations like the pile for testing needs to be selected in advance before the test. The method does not identify small imperfections that maybe present in the cover zone or in the outside periphery of the pile. Improper tube installation or poor care of joints inside the tubes for longer piles may result in tubes being filled with contaminated concrete resulting in blockage of tubes and only limited data available for interpretation. However, in general, CSL testing is the new standard for those who want to have a complete check on quality of deep foundations and has been extensively used at all major projects worldwide in the recent times.

REFERENCES

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