Integrity evaluation of concrete by cross-hole sonic logging in Bangladesh

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ABSTRACT: Cross-hole Sonic Logging (CSL) is now widely used and most common method for evaluating pile integrity. In comparison to the low strain integrity testing, CSL test is much reliable method for quality assurance of pile. This method includes measuring the ultra-sonic sound velocity from emitter to receiver in horizontal plane which determines the anomalous regions and consequently the quality of the concrete. This test requires special preparation in terms of installation of steel pipe before concreting. However, this test also gives us much more accuracy in interpretation of results compared to other nondestructive tests for deep foundations. This test is now practiced all over the world and recently has been used in some major bored piling projects in Bangladesh. The paper illustrates the method, setup arrangements of equipment and data interpretation.

1 INTRODUCTION

Integrity testing of deep foundations generally applies to concrete foundation such as cast in situ piles and driven piles etc. These piles are in different diameter. They are normally used to support heavy structures like bridges, high rise building etc. Depending on variable site soil profile, they are constructed in various methods. Practically it's very difficult to assure the pile quality by visual inspection. Minor or major defects can occur during construction due to contamination of concrete, sudden change in water table, soil collapse and improper flushing of bottom etc. Inadequate technical skill or poor monitoring also affect pile qualities. So integrity testing must be required for quality control of piles to detect flaws that may have been caused due to any of the above reasons. Some examples of defects are voids, honeycombing, cracks, necking, soil inclusions, and corroded rebar (Hassan and O'Neill 1998; O'Neill and Reese 1999). During integrity test, an accurate description of a defect such as its type, size, and location is a prime concern in assessing the structural soundness of a given pile.

2 OVERVIEW OF THE PRINCIPAL

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 between3600 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 receiver, are lowered and lifted usually in uniformly 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.

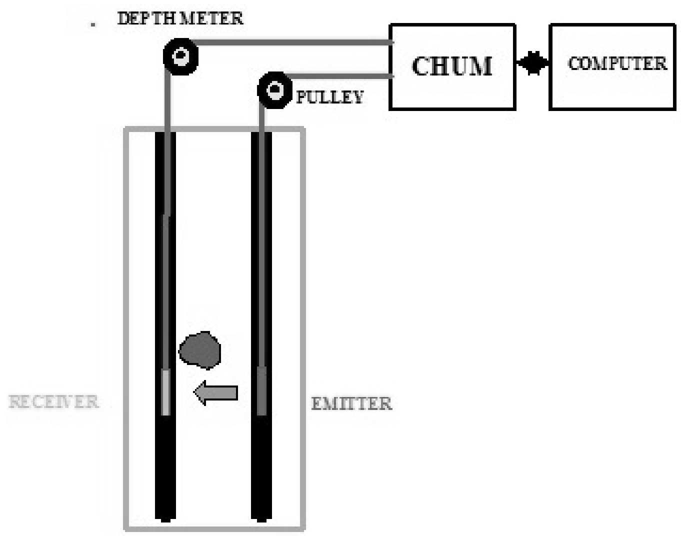


Figure 1. Setup procedure

The transmitter probe generates ultrasonic pulses at frequent and regular intervals during its controlled travel rate. The probe depth and receiver probe's output (time 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 (Figure 2) for each sampled depth.

3 TESTING METHOD

Access ducts are installed during construction of the deep foundation element to be tested. These access tubes may be of PVC or steel and shall be 38 mm or 50 mm 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 1 m or 1.2 m 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.

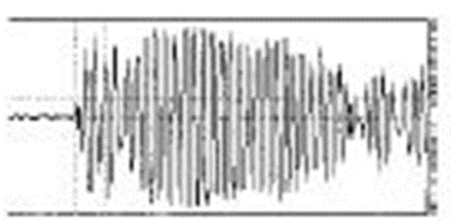


Figure 2. Amplitude versus time graph (ASTMD6760-02)

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. The measurement is typically conducted by lowering the probes inside the access tubes and then pulling them at constant rate so that scans are obtained generally at every50mm 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.

4 CSL RESULT INTERPRETATION

The interpretation of CSL results requires experience and understanding of the capabilities and limitations of the method. Shaft quality assessment from CSL is primarily based on the first arrival time (FAT) of the signal. The concrete wave speed can be estimated by dividing the distance between the access tubes by the FAT. The wave speed of concrete can be used as a judgment of the overall concrete quality because wave speed is related to concrete compressive strength. However, during the placement of rebar cage or concrete, the access tubes often move slightly out of parallel and ultimately the distance between the tubes is not always constant with depth. Therefore, it is more practical to evaluate the FAT as a relative measurement for each individual shaft, comparing signal delays to a ‘‘running’’ average of data from the same shaft. Often a running average of approximately 75 consecutive data points, which would represent approximately the surrounding3.75 m, are averaged for comparison to evaluate local defect. Signal strength is another important measurement for evaluation of CSL data. The signal strength is converted to signal ‘‘energy’’ by integrating the signal over a defined time. Relatively low energy can indicate poor quality concrete or a defect in the shaft. Often a major defect will cause both a significant FAT delay and decrease in relative energy. Interpretation of a major defect from CSL is often intuitive, however, evaluating a relatively minor FAT delay or energy decrease requires engineering judgment. Likins et al.(2007) suggested the scales shown in Table 1 and actions described after. Flaws should be addressed if they are indicated in more than 50% of the profiles. Defects must be addressed if they are indicated in more than one profile. Addressing a flaw or defect should include, at a minimum, an evaluation by tomography if the area of concern is localized, and/or additional measures such as excavation, core drilling, or pressure grouting. Defects or flaws indicated over the whole cross-section usually require repair or replacement.

Table 1. Suggested comparison wave velocity rating for concrete from ultrasonic test (Likins et al. 2007)

Comparison wave velocity,m/sec (by Malhotra)	General conditions
>4570	Excellent
3660-4570	Good
3050-3660	Questionable
2130-3050	Poor
<2130	Very poor

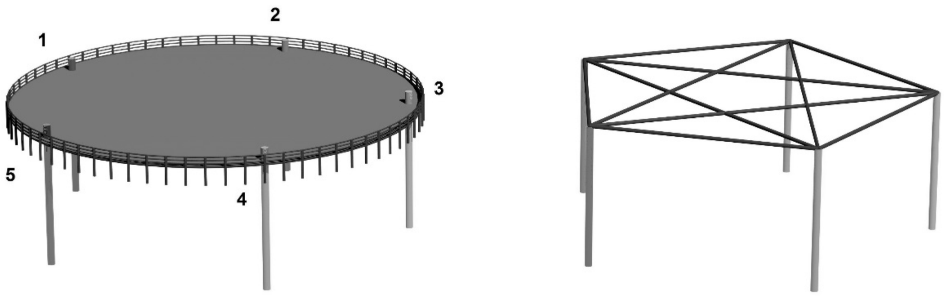
Case Study 1: Crosshole sonic logging test was conducted at 2nd Bhairab Railway Bridge Project to assess and check the pile integrity for potential problems like cross sectional changes, honeycombing, and concrete quality.

The test was carried out on 2.5 m reinforced concrete bored piles. Five steel tubes of 50.0 mm internal diameter were installed. The length of tubes was 62.025 m and was kept was kept 0.2 m above the concrete level. Figure (3) shows the configuration of access tubes in the pile. Reading was taken by pulling the transmitter and receiver at a constant rate from the bottom to top of the tubes.

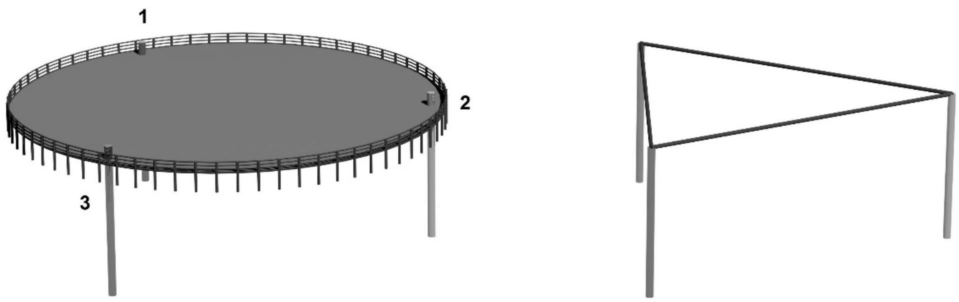
For each scan the first arrival time (FAT), wave speed and attenuation were obtained. The FAT is the time taken by the wave to reach from transmitter to emitter. Since time of travel between both tubes is known, the wave speed was computed with the known distance between the tubes. The entire sequence was then repeated for other tubes. Since five tubes were installed ten scans were available for the piles. Figure 4(a) shows length vs. FAT, wave speed diagram for one typical scan.

Case Study 2: At another project site located in Dhaka, project named Research on Static Dynamic Load Test, three tubes were installed inside the reinforcement of bored piles of 1.0m diameter. The layout of pipes is shown in Figure 3(b).

Figure 4(a) shows good quality of concrete all over the pile. But in the Figure 4(b) shows good quality of concrete to the length of 22.0 m then gradually decreases. However, it shows clear indication of damage at around 27.0 m, huge change in FAT, wave speed and attenuation. The pile also shows soft toe from the length of 27.0 m.

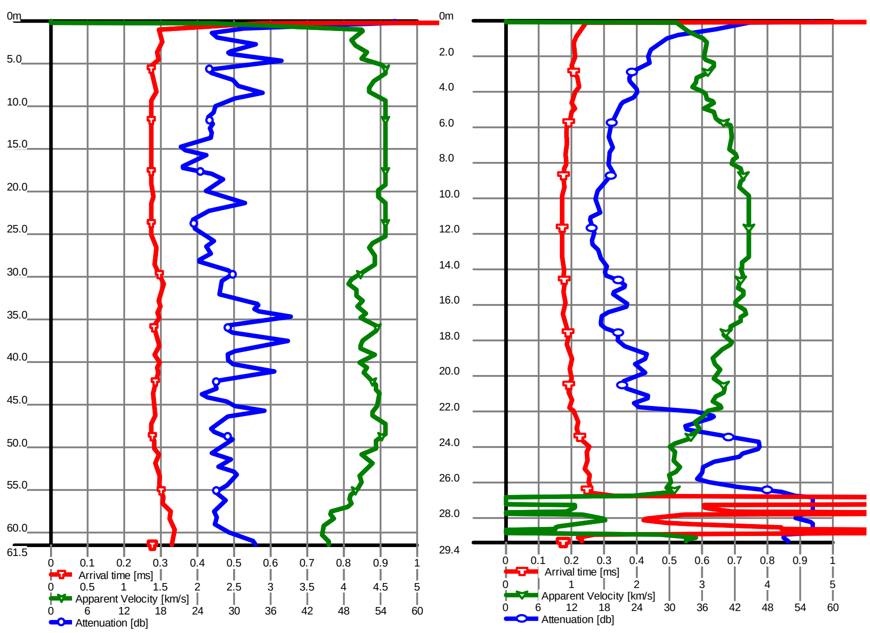


(a)



(b)

Figure 3. Layout of access tubes for CSL Test at (a) Bhairab (b) Dhaka.



(a) (b)

Figure 4. Profile diagram of (a) 2nd Bhairab railway bridge, (b) Static dynamic research

5 CONCLUSIONS

The case study one showed the valuable concrete quality from CSL tests on large pile. Concrete average wave speed varied from 4000 m/s to 4500 m/s were calculated from theoretical tube distance. This wave speed results indicate a consistently good quality of concrete. *Case study 2* showed clear damage after 27.0m. The wave speed, FAT and attenuation have changed abruptly there. There is a clear indication of damage or low quality concrete.

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