APPLICATION OF ADVANCED NON-DESTRUCTIVE TESTING FOR TESTING THE INTEGRITY OF CONCRETE FOUNDATIONS

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ABSTRACT: Solid foundations are integral important part of any structures. Obtaining accurate and timely information on the integrity of structural foundations is essential for project progress and success. Cross-hole sonic method has been widely accepted for quality assurance and quality control on projects with deep foundations, and to assess the integrity of other civil engineering structures. Under the framework of the basic VAEC project (2003) and project VIE/8/013, the Cross-hole sonic method (CHM) was evaluated at Center for Nuclear Techniques, Hochiminh City (CNT). Background information on principle and general description of the method as it is typically applied in the evaluation of deep foundations are also summarized. A suitable experimental model of the shaft foundations was prepared, where the artificial defects can be controlled for the Cross-hole sonic logging was conducted by measuring the propagation time of ultrasonic signals between two probes in vertical holes in a shaft

The purpose of the test program is to evaluate the ability of the cross-hole sonic method to identify the defects present in the experimental model, to evaluate the capabilities of the method and the equipped system Cs-97, to improve the presentation of test results to meet requirements for interpreting the quality of drilled shafts by processing the data of Cs-97.

The cross-hole sonic testing program is described. Summarizes the results and analysis of the cross-hole sonic logging are presented to highlight both the applicability and limitations of the method. The cross-hole sonic logging evaluation is a valuable non-destructive method in assessing the integrity of deep foundations. The cross-hole sonic logging tests successfully determined the location and extent of the built-in defects on experimental model shaft. Minimum sizes of defects can be detected were about ≥ 10cm with Cs-97. Effects of the directions, detectable sizes and natures of defects were studied. The apparent velocities computed from the cross-hole sonic logging data by prepared software fit the expected range of Ultrasonic Pulse Velocity results from the laboratory tests and can improve the reliability of interpreted quality.

The acquired capabilities are valuable asset to apply the Cross-hole sonic method - advanced non-destructive testing (NDT) technique for testing the integrity of the deep concrete foundations.

INTRODUCTION

Solid foundations are integral important part of any structures and therefore their continual use under acceptable conditions of safety is vital for the overall economic and social development of the community. Construction defects occurring during concrete placement in deep foundations may result in major structural instability and/or safety issues. Obtaining accurate and timely information on the integrity of concrete structures such as drilled shaft foundations is essential for project progress and success. Non-destructive evaluation methods (NDE) are good quality control tools and contribute to the development of more efficient and reliable constructed systems.

Non-destructive methods for testing the integrity of drilled shafts can be classified in two groups: tests which are applied to the shaft head after construction and tests performed in pre-placed access tubes or drilled holes. The latter tests are considered to give the most accurate information on concrete quality, and have no shaft length limitations. The most commonly used down-hole integrity test for drilled shafts is the cross-hole sonic method. Recently, cross-hole sonic logging has become the standard method in the developed countries to characterize concrete structure integrity in drilled shaft piers.

Under the framework of the basic VAEC project (2003) and project VIE/8/013, an experimental program was carried out at Center for Nuclear Techniques (CNT) to analyze the applicability of the Cross-hole sonic method (CHM). The purpose of the test program is to evaluate the ability of the cross-hole sonic method to identify the defects present in the experimental model, to evaluate the capabilities of the method and the equipped system Cs-97, to improve the presentation of test results to meet requirements for interpreting the quality of drilled shafts by processing the data of Cs-97.

BASIC PRINCIPLES OF TECHNIQUES

Cross-hole sonic logging is a derivative of the ultra-sonic pulse velocity (UPV) test. The actual velocity of sound wave propagation in concrete, v, is a function of the density and elastic modulus of that material [1]

$$V = \sqrt{\frac{E(1-\gamma)}{\rho(1+\gamma)(1-2\gamma)}} \tag{1}$$

Where: E = Young's modulus (Pa)
ρ = density (kilogram per cubic meter)
γ = Poisson's ratio

The basic technical principle of cross-hole sonic logging method is shown in Figure 1. The cross-hole sonic logging method is an ultrasonic test that involves measuring the propagation time of ultrasonic signals between two probes in vertical ducts in a shaft. These ducts can be tubes which were cast into a shaft during construction, or drilled through an existing shaft after it has been in service. The variation in signal arrival time enables one to assess and locate areas of low density, and so damaged concrete. Indeed in homogeneous concrete, free of defects and variation of quality, the ultrasonic pulse velocity is on the order of 4000 m/sec, depending on its composition. Concrete containing soil inclusions, gravel, betonies or honeycombing has a much lower propagation velocity so that the presence of these irregularities is immediately obvious. The amplitude and the sinusoidal shape of the signal will change as well if there is anything but sound concrete along the path of the wave path. Signal attenuation, or loss of energy, is sign of poor quality zones because more energy is transmitted through sound concrete than through poor concrete.

Using equipment Cs-97, this test measures the apparent time between probes, not true velocity. The apparent wave speed through concrete can be calculated knowing the distance and the time taken by an ultrasonic pulse to go through the material between a transmitter and a receiver. The accuracy of the method is dependent on the accuracy with which the transmission path length between the probes has been determined. These distances measured at the top of the ducts. This apparent velocity incorporates all the concrete conditions between the probes including the concrete, water couplant, and ducts

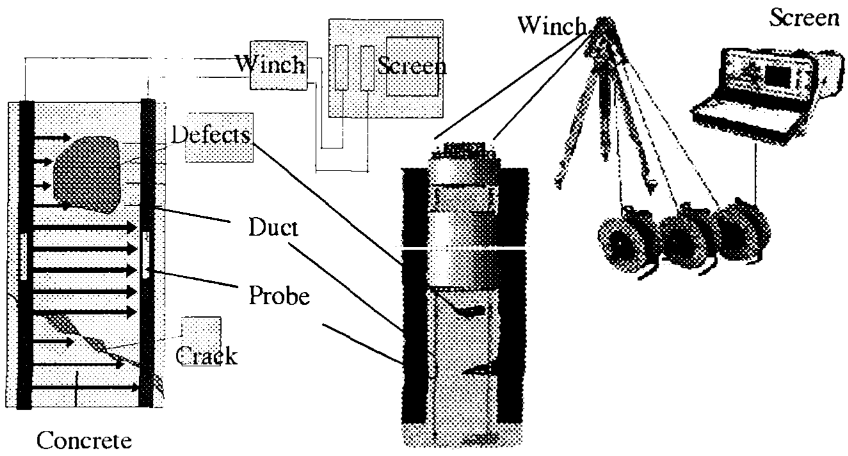


Figure 1: Basic technical principle of cross-hole sonic logging method

EXPERIMENTS

Experimental model and procedures of tests

A suitable experimental model of the shaft foundations was prepared, where the artificial defects can be controlled for the Cross-hole sonic logging was conducted. There are 04 concrete blocks in the experimental model and two ducts were cast into each block during construction. The details of defect characters are descried in figure 2

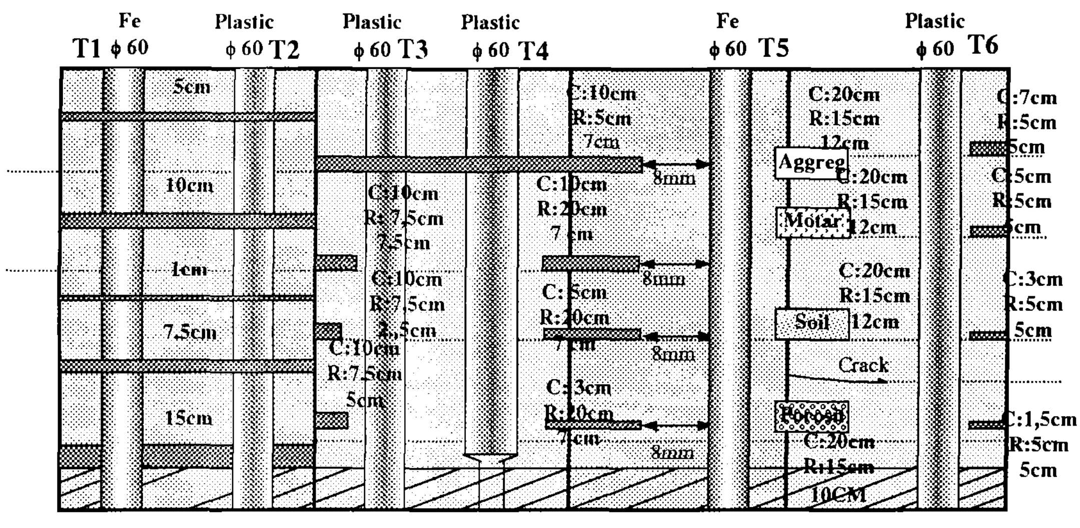
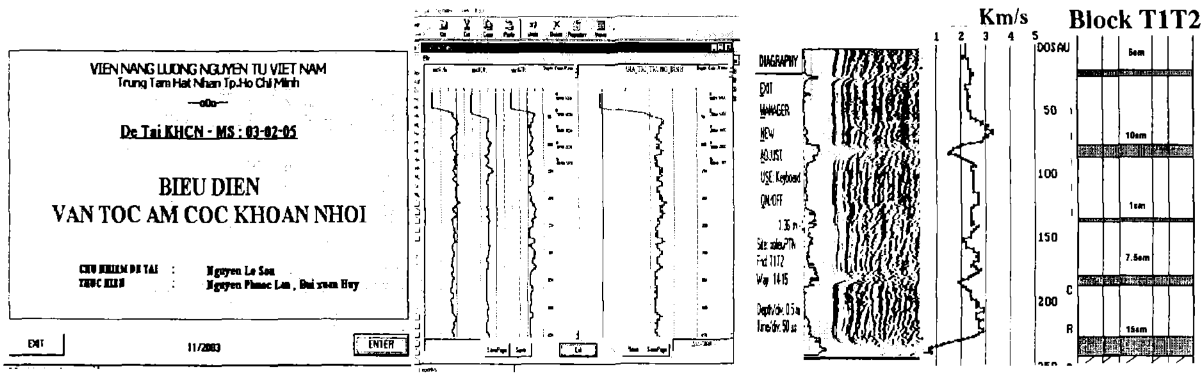


Figure 2: Experimental model

The equipment Cs-97-CEBTP-FRANCE utilized for the cross hole sonic logging tests was supplied by project VIE8013. Each duct couples of the concrete blocks was tested. For each test, the probes are usually kept at the same elevation to create a horizontal travel path between the transmitter and the receiver. The probes were placed in the bottom of the ducts and lifted usually in unison in their respective water-filled access ducts to test the full shaft length from bottom to top, to create the graphs of received signals.

Develop the software for processing the data of Cs-97 to present the pulse velocities:

Using equipment Cs-97, the CHM tests measures the apparent time between probes, not true velocity. Supplementing this approach, software was developed. The apparent velocities computed from the CHM data by prepared software fit the expected range of Ultrasonic Pulse Velocity results from the laboratory tests and can improve the reliability of interpreted quality. Supplemented presentation met requirements for interpreting the quality of drilled shafts from the data of Cs-97. The demonstration of software was shown in figure 3.



Graphs of Cs-97 Velocity graph

Figure 3: The demonstration of software computes the apparent velocities

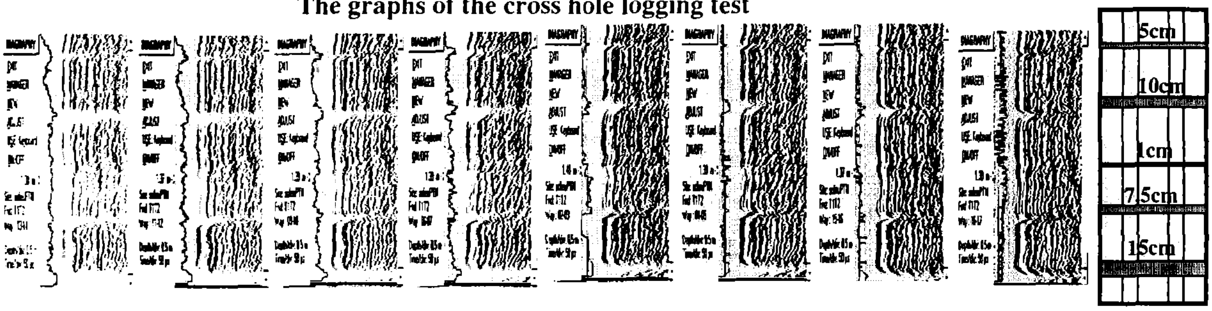
Test results

Setting the test sensitivities

The sensitivity settings of the equipped Cs-97 were selected to carry out the CHM tests on the concrete block T1T2. The results of tests for each setting are shown in figure 4.

The graphs of the cross hole logging test

Block T1T2



H1: KĐ05/ <30%CRT | H2: KĐ10/ <30%CRT | H3: KĐ15/ <30%CRT | H4: KĐ20/ 60%CRT | H5: KĐ30/ 100%CRT | H6: KĐ35/ 140%CRT | H7: KĐ30/ 160%CRT | H8: KĐ40/> 200%CRT

Figure 4: Setting the test sensitivities

Base on graphs shown in figure 4, the optimal sensitivity (H5, figure 4) to receive 04 arrival pulses of 100%CRT should be selected for setting the test sensitivities.

Effect of test speed

The different test speeds of the equipped Cs-97 were selected to carry out the cross hole sonic logging tests on the concrete block T5T6. The obtained results shown that the effects of test speeds could not be significantly detectable if selected different speeds were below sufficient speed to collect data (figure 5).

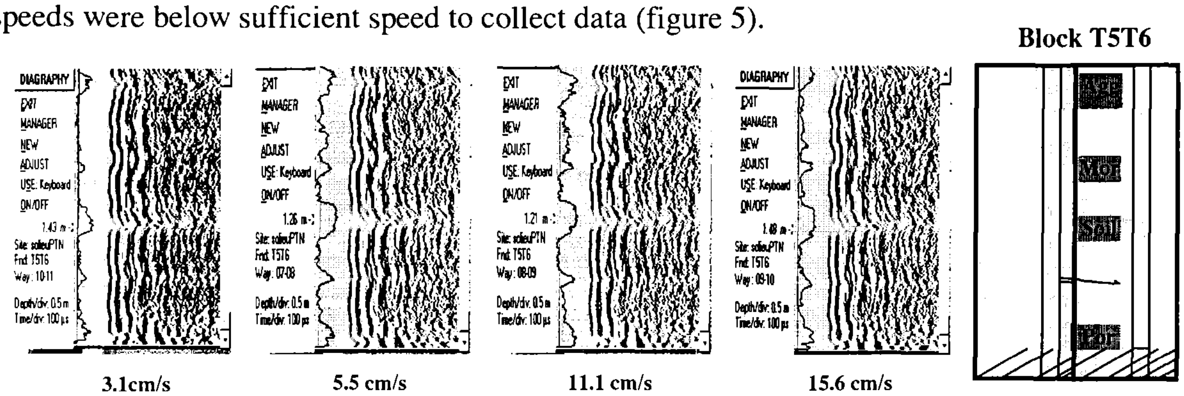


Figure 5: Effect of test speed

Ability of the cross-hole sonic tests to identify defects using equipped Cs-97

Effects of the directions, detectable sizes and natures of defects were studied on blocks T1T2, T2T3, T4T5 and T5T6 (figure 5, 6). Ability of CHM tests to identify the defects was affected by the orientation of defect planes. The plane defects (such as horizontal crack) located parallel with the path of the sonic wave and sizes < 1.0cm could not detected (figure 6B). To detect this defect, the arrangement of the probes at slightly different levels and perform an inclined evaluation was suggested (figure 6A). Detectable sizes of single defects using Cs-97 were about ≥ 10cm, it shown that signal frequency of Cs-97 at about 40KHz. Ability of CHM tests to identify the defects was affected by defect natures. One can clearly notice from figure 5 that it is difficult and hazardous to detect reliably the weak concrete (lost coarse aggregate) using the graphs of Cs-97. The velocity graph was developed in this study can improve the interpreted quality. The foundation concrete were contained sand, soil, honeycomb ... can be detected clearly.

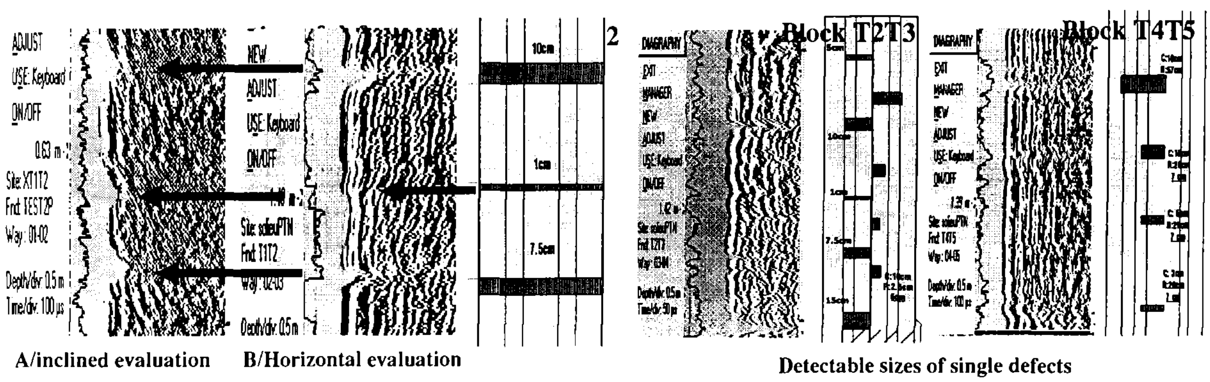


Figure 6: Ability of the cross-hole sonic tests to identify defects using equipped Cs-97

Assessing the integrity of deep foundations

Cross-hole sonic logging tests are performed on the drilled shafts. The data obtained from these tests are used in assessing the integrity of foundation concrete. The procedure to analysis the data of the CHM test in assessing the integrity of foundation concrete was suggested as follow:

- The quality of foundation concrete will be evaluated by the computed velocity chart. The evaluation of velocity shall conform to the guidelines established in table 1 (ASTM 6760-2002)
- The integrity of pile was interpreted by specially parameters from wave chart of Cs-97. Interpretation of the transmit time, amplitude and shape of waves shall conform to the guidelines established in table 2 (NF P94-160-1 - French standards)

Table 1: Relationship between the pulse velocity and quality of concrete (ASTM 6760-2002)

Pulse velocity	Quality of concrete
> 4570	Very good
3660 - 4570	Good
3050 - 3660	Doubtful
2135 - 3050	Poor
< 2135	Very poor

Table 2: Interpretation of wave charts of Cs-97 (NF P94-160-1)

Quality of pile concrete	Transmit time	Amplitude of wave	Shape of wave chart
Good	Regularity	No large decrease	Normal
Have defect	Irregularity increase	Have decrease	Abnormal
Crack/break	Suddenly increase	Suddenly decrease	Abnormal

CONCLUSION

The Analyses of the obtained results from CHM tests performed at the experimental model and on structures can lead to the conclusions that:

- CHM test is more suitable for testing the integrity of the deep drilled shafts
- CHM tests successfully determined the location and extent of the built-in defects on experimental model. The main defects can be detected clearly.
- Ability of CHM tests to identify the defects was affected by the orientation, detectable sizes and natures of defects. Minimum sizes of single defects can be detected were about ≥ 10cm with Cs-97.
- The apparent velocities computed from the cross-hole sonic logging data by prepared software fit the expected range of Ultrasonic Pulse Velocity results from the laboratory tests and can improve the reliability of interpreted quality.
- High precision of distance between transmission and reception transducer is needed to compute the apparent velocities, but it is difficult to ensure the space between two tubes from the top to bottom in practice. This problem must still be studied to correct the ray travel time.
- The more quantitative interpretations of defects from CHM tests have continuously studied, especially in using computed tomography technique.

The acquired capabilities are valuable asset to apply the cross-hole sonic method - advanced NDT technique for testing the integrity of the deep concrete foundations.

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