APPLICATION OF ADVANCED NON-DESTRUCTIVE TESTING TO EVALUATE THE FOUNDATION DEPTH OF THE EXISTING STRUCTURES

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ABSTRACT: The applications of Parallel Seismic Test to evaluate deep foundations of the existing structures are still new in Vietnam. Under the framework of the basic VAEC project (2003) and project VIE/8/013, the parallel seismic test method (PSM) was evaluated at Center for Nuclear Techniques, Hochiminh City. 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 test site was selected, where the foundation depths can be controlled for the parallel seismic tests were conducted by impacting the driven piles, and the travel times down the pile, through the soil, to a receiver located in an adjacent water-filled borehole were measured.

The primary objective of the test program is to evaluate the accuracy of method in determining the pile length, to evaluate the capabilities of the method and the equipped system SPL-97, to define the type of material which comprises a deep foundation, the distance of the compression wave can travel through the adjacent soil before the signal attenuates beyond recognition and the wave velocities in the various soil strata encountered.

The parallel seismic testing program is described and results are presented. Parallel seismic tests, as conventionally practiced, i.e. with short distance between a structure and an access hole, can be used to define the bottom of the piles, as well as to identify the material type from the computed velocity in the structural material. The conventional approach of using changes of slop of the plot versus first arrival to identify the bottom of a deep foundation works best when the piles are in a soil with uniform stiffness and the accuracy of the evaluated depths can be obtained about ± 0.5m. Supplementing this approach of interpretation by the examining the amplitudes of the first arrival on a plot with the same scale for all records allows one to better interpret signals in more common situations encountered in practice, e.g. a stiffer layer near the bottom of a deep foundation. Due to the signal attenuates beyond recognition, variation of compression wave velocity with depth and the uncertainty in the travel paths, the distance between the foundation and access hole less than 1.5m should be selected. At greater distances, the interpretations of the compiled first arrival profiles becomes more difficult, especially in the conditions where subsurface conditions are unknown. A suggested combination of the parallel seismic technique with gamma logging can improve the reliability of interpreted depths for the complex soil strata.

The acquired capabilities are valuable asset that can clearly be utilized as the effort to apply advanced non-destructive testing (NDT) technique – PSM to the rehabilitation investigations of existing structures.

INTRODUCTION

Non-destructive evaluation (NDE) techniques have been used for a number of years to provide quality control of construction procedures for deep foundations. In recent years, the need to evaluate condition of in-service foundations has arisen as a result of rehabilitation investigations of existing structures and the authorized-mandated inspection of bridges. In some cases, the latter task involves identifying unknown bridge foundation types because plans for older structures have been lost over the years. Evaluation of existing foundations differs from the usual methods of NDE in that structures now cover the tops of deep foundations (inaccessible head condition). The parallel seismic method has been the most suitably used for the inaccessible head condition.

An experimental program was carried out at Center for Nuclear Techniques (CNT) to analyze the applicability of NDT parallel seismic test method to evaluate deep foundations under inaccessible head condition in a controlled site. The purposes of the test program is to evaluate the accuracy of method and capabilities of the equipped system SPL-97 in determining the length of each of the piles, to evaluate the capabilities of the method to define the type of material which comprises a deep foundation, to define the distance the compression wave can travel through the adjacent soil before the signal attenuates beyond recognition, and to determine the compression wave velocities in the various soil strata encountered.

BASIC PRINCIPLES OF TECHNIQUES

The basic technical principle of the parallel seismic test is shown in Figure 1. To perform the test, a bore hole adjacent to and slightly deeper than pile length must be drilled. The exposed structure is struck with a hammer close to the foundation to generate tress wave energy, some of which travels down to the pile and through the soil where the compression wave passage is monitored by a receiver in an adjacent water-filled bore hole. The transit time of stress wave is measured between the point of impact and the receiver. The receiver is initially located at the top of borehole and is lowered a short distance each hammer strike until the entire depth has been sensed. Examination of the first arrival time versus depth for a continuous pile in a homogeneous soil should contain a linear increase in arrival time with depth. If a defect or the end of pile is encountered, the travel time will increase accordingly, indicating the depth of the defect or pile

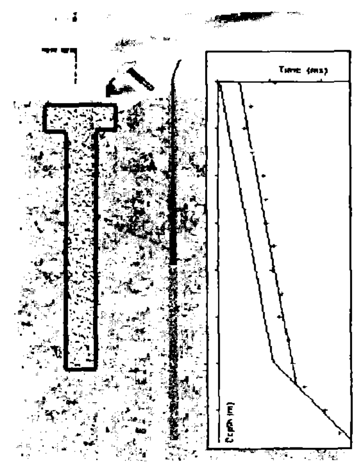


Figure.1: Basic technical principle of the parallel seismic test

Variations in compression wave velocities of soil and the path of a stress wave from the impact point to the receiver in a parallel seismic test can be very complex, depending upon the subsurface profile and the properties of the various layers.

To explain the basic principles of the parallel seismic test, the effects of travel path on first arrival can be simplified in two cases. First, if the soil profile is uniform with a constant compression wave velocity within the area being tested, the travel path would be as that shown in figure 2, this is termed the direct wave, and the travel time for direct wave, t_d , is given by:

$$t_d = \frac{a + \sum_i d_i}{v_{conc}} + \frac{c}{v_p}$$

(1)

Where: d_i - moving step of the receiver

i - number of steps

a - vertical distance between impact point and first position of receiver

v_{conc} - propagation velocity in concrete

c - distance between the pile and the access hole

v_p - Compressive wave velocity in the soil.

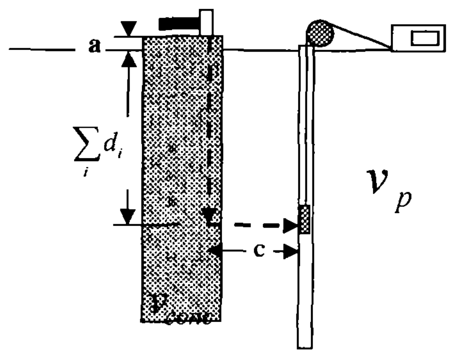


Figure 2: Travel path for the direct wave

Another possible path, second case, which can occur is that of the refracted wave as shown in figure 3. If an upper soil stratum has compressive wave velocities smaller than that of an underlying stratum, then the first arrival time may be cause by a wave which travels from pile though the underlying stratum and up to receiver. The refracted wave generated by the critically incident longitudinal wave will travel along the interface in the lower stratum as shown in figurè 3. By elastic theory, it has been shown that the refracted wave causes a disturbance along the interface and this disturbance generates a wave in the upper medium. This new wave is called the head wave and travels at a velocity in a direction inclined at (90^0 - i_c) to the interface, where i_c is the critical angle of incidence. The travel time for the refracted wave, t_h ,is given by:

$$t_h = \frac{H}{v_{conc}} + \frac{c}{v_{p2}} + [\frac{1}{v_{p1}\cos i_c} - \frac{\tan i_c}{v_{p2}}](H - d - a)$$

(2)

Where: d_i - moving step of the receiver

i - number of steps

a - vertical distance between impact point and first position of receiver

v_{conc} -propagation velocity in concrete

c - distance between the pile and the access hole

v_{p1} -compressive wave velocity in the upper soil layer.

v_{p2} -compressive wave velocity in the lower soil layer.

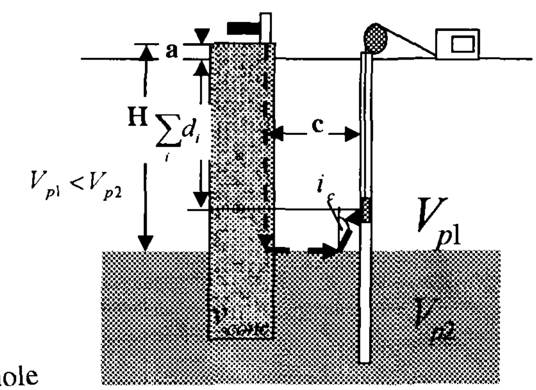


Figure 3: Travel path for refracted wave

Equation 1 and 2 suggest that if one have a stiffer stratum near a pile tip, the shortest time for a wave travel from the pile to a receive will not necessarily be that of the direct path, but will depend on the relative velocities in each stratum and the distance between the pile and access hole. While the possibility of a direct path is maximized if the access hole as close as possible to foundation, there is still a problem of interpreting the slope changes when a stiff layer is located near the bottom of a pile, it remain to be discussed.

EXPERIMENTS

Experimental site and procedures of tests

In the co-operation with Construction Company No. 5, suitable field-testing was done on a construction site of the An Loc high building project. 03 groups (named D, E, N) of driven piles were selected for the parallel seismic testing. 03 cased boreholes for testing were drilled 60 mm in diameter and are cased with 60 mm diameter PVC. Depths of the boreholes ranged from 18m (group D), 28m (group E) to 50m (group N). The distance between the borehole and each pile in one group ranged about from 0.4m- 3.0m (figure 4).

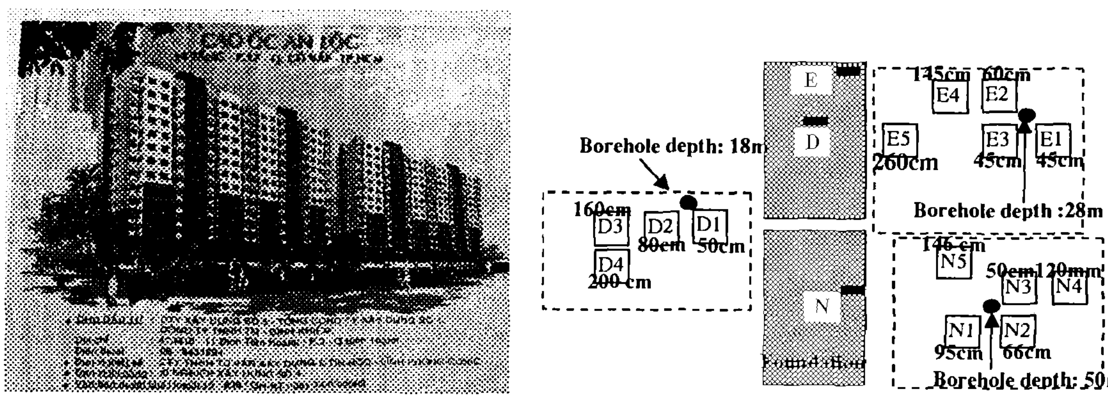


Figure 4: Plan view of test site

The equipment SPL-97-CEBTP-FRANCE utilized for the parallel seismic tests was supplied by project VIE8013. Each pile of the driven pile groups was tested. 03 series of test were conducted for each pile. For each test series, the receiver was placed in the top of each access hole and lower in increments of 0.5m after each impact until the entire depth has been sensed, to create the profile of received signals.

Test results

Depth of foundation

First arrival times have been selected from each individual hammer impact, and plots of depth versus first arrival time have been constructed for all piles. To most common to interpret the data is identify the pile bottoms as the depth in the compiled profile where there is a change in slope of lines of first arrival time. Another indication of the depth of a foundation is the depth where the amplitude of the first arrival significantly decreases when data are plotted at the same scale for all test. The results of the parallel seismic tests for each piles of group N are shown in Table 1. The Difference of the evaluated depths of piles can be obtained about ± 0.5m.

Table1: The results of the parallel seismic tests for the pile group N

	N1	N2	N3	N4	N5
Actual pile length (m)	19.5	9.5	11.0	21.0	10.5

Evaluated length by PSM (m)	19.64	9.53	10.78	20.72	10.59
Difference (m)	0.14	0.03	0.22	0.28	0.09

Distance of access holes

To define the distance, the compression wave can travel through the adjacent soil before the signal attenuates beyond recognition. To clearly show the trend of the data, summary plots which show all access holes for each pile on one figure are presented in Fig. 5

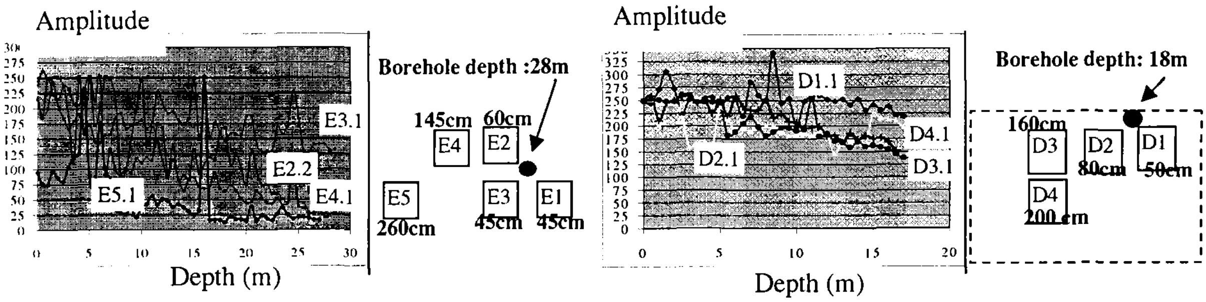


Figure 5: Attenuation of received signals from group E and D

Due to the signal attenuates beyond recognition, variation of compression wave velocity with depth and the uncertainty in the travel paths, the distance between the foundation and access hole less than 1.5m should be selected. At greater distances, the interpretation of the compiled first arrival profiles becomes more difficult, especially in the conditions where subsurface conditions are complex.

Propagation velocities in piles and soil

As a means to identify the type of material which comprises a deep foundation, the propagation velocity of concrete can be estimated as the slope of first arrival time versus depth line in the soil adjacent to the pile. The propagation velocities computed from the results of parallel seismic tests are summarized in table 2.

Table 2: The propagation velocities computed from the results of parallel seismic tests

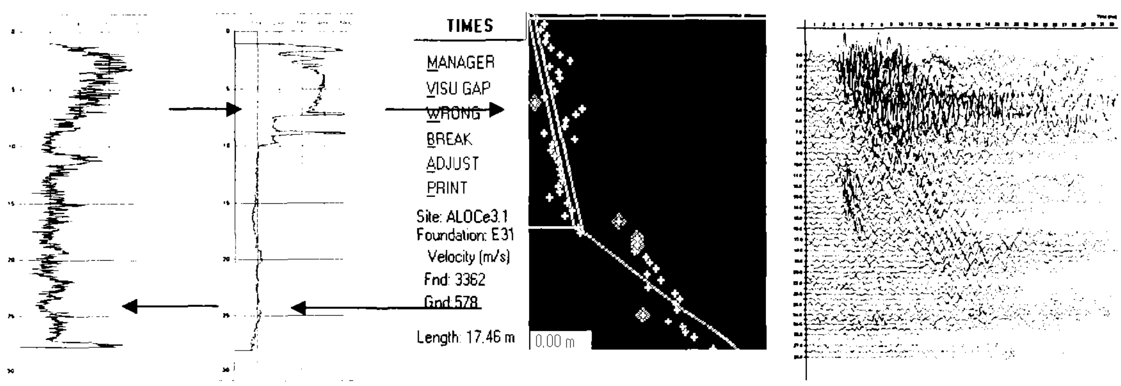
		Velocities in piles	**Velocities in soil**	**Depth of pile**
Group N	N1	2.331 Km/s	0.700 Km/s	19.64m
	N2	3.700Km/s	0.811 Km/s	9.53m
	N3	2.325Km/s	0.721 Km/s	10.78m
	N4	2.272Km/s	0.675 Km/s	20.72m
	N5	3.807Km/s	0.810 Km/s	10.59m
Group E	E1	3.491Km/s	0.439Km/s	18.49m

	E2	3.360Km/s	0.424Km/s	15.86m
	E3	3.362Km/s	0.578Km/s	17.46m
	E4	3.284Km/s	0.452Km/s	16.32m

As shown in table 2, the compressive velocities in soil are most suitable with reference data of subsurface soils [1], the propagation velocities in pile group E correspond reasonably well with the range velocities representative of the concrete, 3.300km/s-3500km/s as were measured at the top of piles by Ultrasonic pulse velocity PUNDIT. The propagation velocities in pile group N are much lower than the velocities were measured by PUNDIT. Joints of the two piles mating surface during piling may not be good and this can be the likely cause.

Combination of PSM and gamma logging

Variation in compression wave velocities of soil and the fact that the path of a stress from impact point to receiver in a parallel seismic test can be complex, depending upon the subsurface profile and properties of various layers, are the main reasons in the difficult interpretations. The bottom of the foundation can easily be masked by changes in compression wave velocities at soil strata boundaries. Gamma logging techniques can provide some properties of soil layers and information of stratum to improve the reliability of interpreted depths for the complex soil strata. The effect of layer changes on first arrival times is confirmed by gamma logging. (figure. 6)

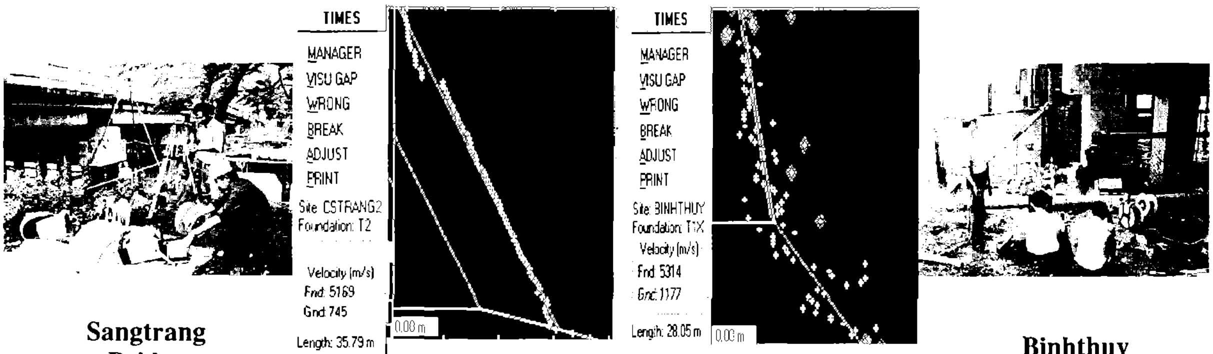


Natural gamma | Gamma- gamma | First arrival time versus depth | Same scale of amplitudes

Figure 6: Combination of PSM and gamma logging for interpreting the evaluated depth

Application of PSM technique to structure

Transport Consultant Company No.7 accepted the procedure using the PSM technique to evaluate the depths of the foundations in the investigations for some bridges under upgrading in Can Tho city. The document of these bridges has been lost over the years and the wars. The evaluated depth of the Sangtrang Bridge by PSM technique has been used to provide information to upgrade the bridge. The results [3] and activities in parallel seismic testing at some bridges are described in figure 7



Sangtrang Bridge

Binhthuy Bridge

Figure 7: Parallel seismic testing at the Sangtrang Bridge and Binhthuy Bridge

CONCLUSION

Based on the parallel seismic testing performed at the test site and at the bridges, the following conclusion can be drawn :

- If the access hole was within 1.5m of the piles, the bottom of the driven piles can be identified using the change of slope of first arrival times versus depth and the depth where the amplitude of the first arrival significantly decreases.
- The standard approach of defining the bottom of foundation is to determine the slopes of the first arrival times plotted versus depth works well when there is a soil of uniform stiffness near the bottom of the foundation.
- The bottom of the foundation can easily be masked by changes in compression wave velocities of soil strata boundaries. A suggested combination of the parallel seismic technique with the gamma logging can improve the reliability of interpreted depths for complex soil strata.
- The apparent propagation velocity of the piles can be determined from slope of the first arrival time versus depth agreed well with the propagation velocity through concrete – as a means to identify the type of material which comprises a deep foundation.

The results of this works show the potential of parallel seismic test method can be applied to a wider range of complex site condition. The acquired capabilities are a valuable asset that can clearly be utilized as a part of an effort to apply the advanced NDT techniques for rehabilitation investigations of existing structures.

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