Seismic CPTu To Assist the Design on Existing Foundations

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ABSTRACT: Limited space in urban area makes it attractive to reuse the existing foundation. This paper presents a case study on the use of seismic piezocone penetrometer (SCPTu) to conduct parallel seismic test for the determination of the length of unknown foundation. The tip resistance and side friction by cone penetrometer provide the distribution of mechanical properties of the underground layer. The geophones in seismic piezocone tip acts as seismic wave receiver for parallel seismic test that is commonly used to determine the length of unknown foundation. By fusion of both information, the capacity of pile foundation under existing building can be determined. This testing procedure is very attractive for reuse of existing foundations. A case study is provided on the use of SCPTu in a building expansion project.

INTRODUCTION

This paper describes a case study that involves the use of Seismic Cone Penetrometer (SCPTu) to determine the length of unknown deep foundation.   SCPTu is a very useful tool for geotechnical site investigation. The data collected by SCPTu are used to classify soils and determine the soil strength parameters in stratified ground. The seismic function provided by the geophone unit has been traditionally used to perform seismic down hole test for geotechnical seismic hazards assessment. New application scenery was explored in this case study for using SCPTu in a field study program to determine the length of unknown foundation. The geophysical function together with the traditional geotechnical information collected by SCPTu is used to accurately estimate the bearing capacity of unknown foundation. This was incorporated to make recommendations on a building expansion project.

St. Joseph's Hospital is located at 11705 Mercy Boulevard in Savannah, Georgia. The hospital plans to add an additional floor to the existing one-story building located northwest of Hillyer Drive and Mercy Blvd. The one-story building comprises two portions, including a one-story building built in 1966 attached by another one-story building built in 1974 to the south. The entire building is supported on a deep foundation consisting of Augured Cast-in-Place (ACIP) piles. The additional floors will add additional loads on the pile foundations and therefore it is very important to determine if the design capacities of existing ACIP piles could support additional loads.

Information about the lengths and design capacities of ACIP pile can no longer be located according to the St. Joseph's Hospital. Non Destructive Testing (NDT) methods were used to determine the pile lengths and then the pile design capacities were estimated based on the pile lengths and subsurface information collected through Cone Penetration Test (CPT) soundings performed near the piles. Through the NDT methods, the physical characteristics of ACIP piles were determined without causing any physical damage on them. The SCPTu was used instead of commonly used borehole to perform the Parallel Seismic Method. This method provided good results of pile characteristics. This in conjunction with results of geotechnical investigation by CPTu function was used to determine the bearing capacity of the existing foundation.

GEOTECHNICAL SITE INVESTIGATIONS

Based on the CPT soundings performed at this site and reviewing the existing geotechnical study, the site subsurface primarily consists of medium dense sands (SP), clayey sands (SC) and silty sands (SM) in the upper 64 ft. The ground water was present at depths of 8 to 10 ft below ground surfaces. The average tip resistance is 74-95 tsf. The average SPT blow count is 18-21.

Figure 1 shows an example of the measured results by cone penetrometer equipped with pore pressure measurement unit (CPTu) and Standard Penetration Test (SPT). These include the variations of tip resistance, side friction, pore pressure and SPT blow count with depth. Locations with high pore pressure are typically correspondent to clay layers.

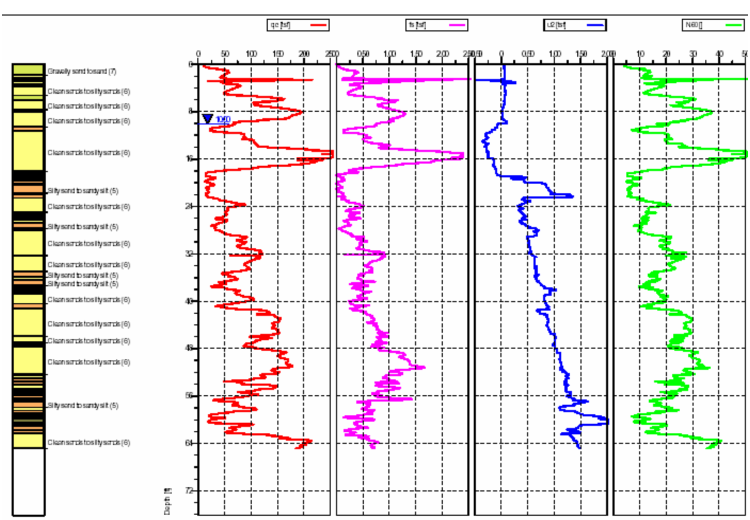


Fig. 1 Example Results of CPTu Test

FIELD SCPT TESTING PROGRAM

Figure 2a shows the outside view of the building wall. It also gives an overview on the locations of NDT tests in reference to the existing buildings. In order to perform the NDT tests, the upper soils below the pile cap and around the piles were removed manually at both outside and inside the walls. The dimensions of pile caps and piles were measured and shown in Fig. 2b. Parallel Seismic Tests were performed for piles installed below Column A3 and Column A19 of the building. The detailed procedures and findings are described and analyzed in the following context.

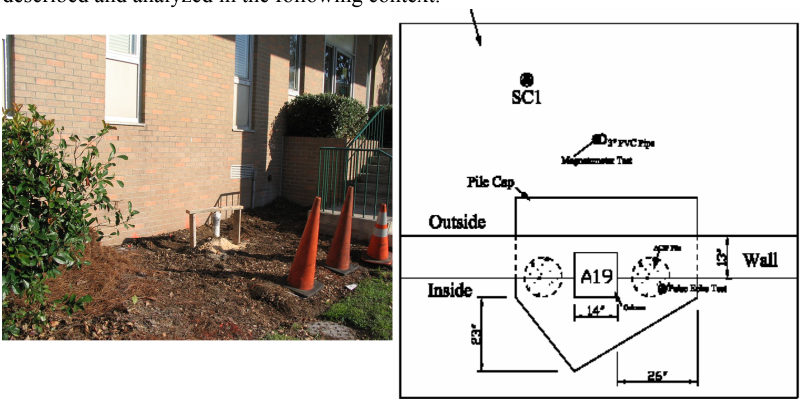


Fig. 2 (a) view of outside building (b) plane view of Column A19 and locations of drilled shaft

Parallel Seismic Tests is a widely accepted procedure to determine the length of unknown foundation (Telford et al. 1976, Olson et al. 1995, Liao et al. 1998, ASTM 2004). Figure 3b shows the conduct of Parallel Seismic Tests with the SCPTu. It typically involves drilling a borehole adjacent to the unknown foundation. Seismic recording units, either by borehole geophones or hydrometer, are lowered down to the borehole at give intervals to certain depths that is beyond the depth of the unknown foundation. At each depth, a seismic wave is sound by using a hammer to tap on the side of the wall or the pile cap. This seismic wave then propagates along the pile and reaches the geophone or hydrophone (Figure 3a). When the group of the seismic waves recorded at different depths is placed together, a systematic change in the trend of the first arrive in the wave train gives an estimation on the depth of the unknown foundation. This test can be performed for concrete, wood, masonry or steel foundations.

In this project, a novel testing procedure was employed. Parallel Seismic Tests are performed by 1) pushing a Cone Penetration Test with a Seismic Element (SCPTu) adjacent to a foundation element; 2) striking the foundation element to generate shear waves, the SCPTu can measure the arrival time of the waves; 3) performing this test at repeated intervals, the length of unknown foundation elements is determined. Figure 3a below shows the settings of a typical Parallel Seismic Test. The SCPTu used here extends beyond its traditional function of determining the soil type and strength data of the bearing stratum. The geophone in the cone tip acts as seismic receiver for the Parallel Seismic Tests.

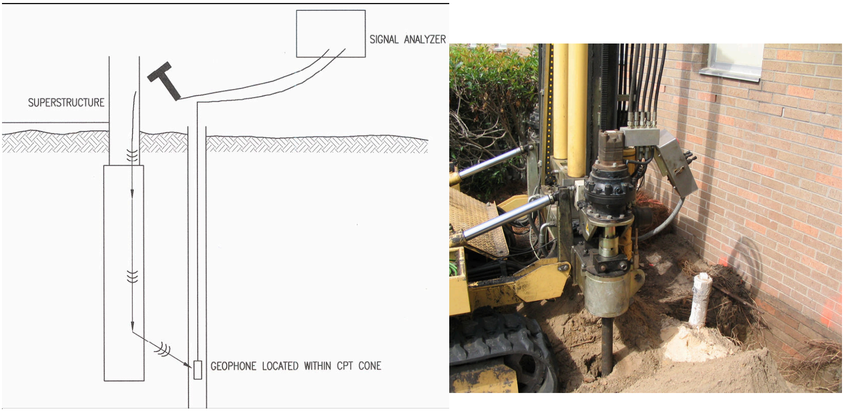


Fig. 3 a) Schematic of Parallel Seismic Testing; b) Parallel Seismic Test Using SCPTu

Parallel Seismic Tests were performed at a distance of approximately 3 ft from the exposed pile cap near Columns A3 and A19 outside the buildings (the schematic location of A19 is shown in Figure 2). A CPT cone instrumented with an accelerometer was pushed into the ground to record the seismic waves at a depth interval of every 3 ft until a depth of 65 ft. At each depth, seismic wave is generated by using a hammer to tap on the side of the wall. The propagating waves were recorded by the geophone embedded in the cone of the SCPTu unit.

RESULTS OF PARALLEL SEISMIC TESTING

Model development to interpret measured signals

Figure 4 shows the recorded signals at different depths near column A3. The processed signals with four major wave trains are also identified and shown in this figure. Four possible types of seismic wave trains are shown in the schematic plot. The first one is the compression wave through concrete pile until arrives at the approximate elevation of the geophone. It then propagates through soil or water to the geophone. The other three types of waves follow similar propagation path. These include the compression wave of water, compression wave in soil and shear wave in soil. The travel times required for the wave trains to arrive at geophone are given in Eq. (1).

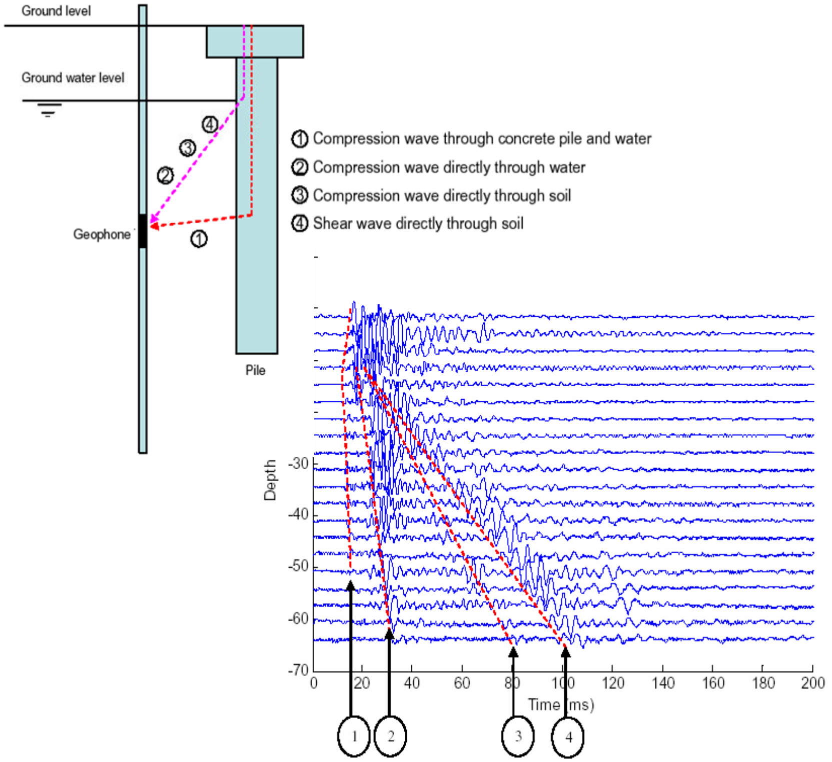


Fig. 4 Recorded signals at A3 with wave trains identified (the possible wave train propagation paths and modes are shown in the schematic drawings)

$$t_{Train,No.1} = \frac{d}{V_c} + \frac{\Delta}{V_{soil}} \tag{1a}$$

$$t_{Train,No.2} = \frac{L}{V_w} \tag{1b}$$

$$t_{Train,No.3} = \frac{L}{V_{c,soil}} \tag{1c}$$

$$t_{Train,No.4} = \frac{L}{V_{s,soil}} \tag{1d}$$

where d is the depth of the geophone, Δ is the horizontal distance between geophone and pile, V_c is the speed of stress wave in concrete, V_w is the speed of compression wave in water, $V_{c,soil}$ is the speed of compression wave in soil, $V_{s,soil}$ is the speed of shear wave in soil.

Estimation of pile length

Estimation of the pile length from the parallel seismic testing can be made by observing the change of the propagation speed of the first wave train; or it can be estimated by observing the change of the amplitude of wave train before and after exceeding the toe of pile. The later approach works when the energy of impact source is controlled or the signals are acquired using a string of geophones together with the same impacting source.

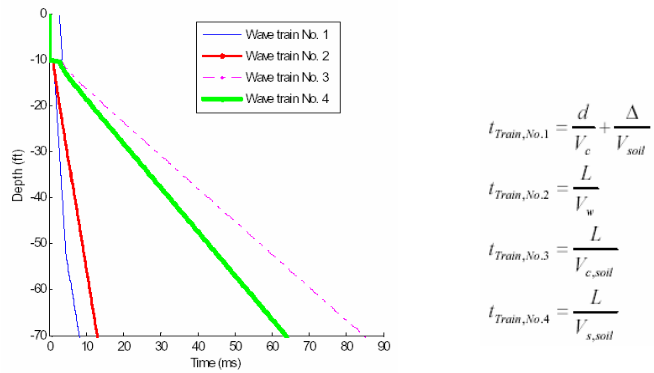
From the testing data collected at A3, the first wave train can be clearly observed up to a depth of 47.6 ft. The speed of this wave train is 12340 ft/sec, which is approximately the speed of wave in concrete. Thus this formation of this wave train corresponds to the travel of seismic wave along the pile. Referring to the principle of Parallel Seismic testing, this implies that the length of the pile foundation is at least up to 47.6 ft.

Similar observations were found on the testing data collected at column A19. The wave trains can be clearly identified up to 50.1 ft.

Under the ideal condition, it should be able to observe the change of slope for the first wave train in the Parallel Seismic testing signals (from speed of traveling in concrete to speed of traveling in pore water). These are illustrated in the predicted signals in Figure 5a. However, this can not be clearly identified from the testing data collected in these tests. The possible causes might be: 1) the interference of background noise. Since the geophone is located in the cone attached to the DCPT rig, the resonance frequency components corresponding to the CPT rod might be a major source of background noise; 2) insufficient amount of energy delivered to the testing pile due to in accessibility to the pile itself; 3) the insufficient depth of investigation compared with the length of pile.

Results of sensitivity analyses using the simplified wave propagation model are conducted to further validate the previous conclusion. Compared with pile length of 50ft, assuming the length are pile 30 ft or 40 ft, they will resulted in the delay of wave train arrival of around 2.4 ms and 1.1 ms respectively (Figure 5b). These difference should have been sufficient large to be identified considering the fact that the quality of signals above 50 ft are clearly edible. The sensitivity analyses further validated that the identification of the pile length based on the speed of the first wave train is sound.

(a)



(b)

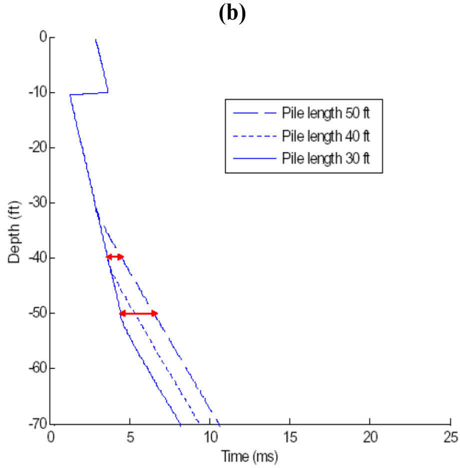


Fig. 5 (a) the predicted first arrival of different wave trains using the propagation paths shown in Figure 4, (b) the sensitivity of the first arrival on the pile length.

In summary: From the testing data collected at column A3, the first wave train was observed up to a depth of 47.6 ft. This implies that the length of the drilled shaft is at least up to 47.6 ft. The testing data collected at Column A19 further validated this assessment. The recorded signals show that first wave train from the Parallel Seismic testing at Column A19 can be clearly identified up to 50.1 ft.

PILE CAPACITY ESTIMATION

Based on the results of parallel seismic test, it is conclude that the ACIP piles are embedded to a depth between 47 and 50 ft below existing grades. After excluding the thickness of pile caps, the ACIP pile should have an embedment length between 44 and 47 ft. To be conservative, a pile length of 44 ft is considered when calculating the pile design capacity. The pile capacity is calculated by using LCPC method (French Method) based on the CPT sounding data obtained at two sounding locations. Based on the analysis, the existing ACIP pile should have an allowable compression capacity of 50 tons with a factor of safety of 2 (Fig. 6). An uplift capacity of 30 tons may be used for the addition design. Based on the thickness of the pile caps used, it appeared the piles were embedded more than 12 inches into the pile cap, so the piles should behave similar to piles with fixed head connection. A lateral load of 12 kips is recommended as lateral design load for an allowable pile head deflection of 0.25 inches.

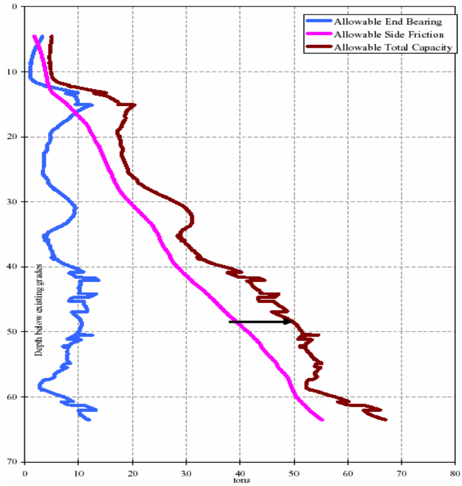


Fig. 6 Pile Net Bearing Capacity With Depth using French Method

SUMMARY AND CONCLUSIONS

This paper introduces the application of seismic piezo-cone SCPTu in parallel seismic test to nondestructively determine the length and bearing capacity of unknown ACIP pile foundation. SCPT was used to perform the parallel seismic test to estimate the length of the unknown ACIP pile. This information was used in conjunction with geotechnical data to estimate the bearing capacity of the existing foundation. Combined application of geophysical and geotechnical functions of SCPTu assisted the decision by the property owner on the building expansion plan. This method combines the function of SCPTu as both geotechnical investigation tool and geophysical survey tool. To ensure the successful application of this method, it is important to conduct a well planned testing program and perform sound interpretations of geophysical signals.

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Effects of Damping and Dynamic Soil Mass on Footing Vibration

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ABSTRACT: Effects of different kinds of damping and dynamic soil mass on horizontal and vertical footing vibration, e.g. dynamic stiffness and footing mass, have been analyzed. Total damping should include material damping and geometrical damping. Material damping tends to reduce the dynamic stiffness of the footing. Dynamic soil mass and the effect of footing mass with respect to the geometrical damping have been considered in the vibration analyses. Expressions for total mass, total damping and total dynamic stiffness of the system for horizontal and vertical vibration have been presented in this paper for use in these analyses.

The differential equation for evaluation of these effects and some important circular frequencies for horizontal vibration of a rigid footing on an elastic half space are discussed. The newly presented expressions for total mass, total damping and total dynamic stiffness could be used to calculate whether permanent displacement or resonant frequency and the maximum amplitude of vibration will occur.

INTRODUCTION

Rainer (1975) considered three sources of damping in dynamic structure-foundation interaction: inter-storey damping (not considered here), foundation material damping, and radiation damping. He found the material damping in the foundation soil contributes significantly to the overall damping ratio by comparing the numerical results from two methods of calculating the damping ratio for structures on compliant foundations. One method employs the calculation of the system damping ratio from the dynamic amplification factor; and the other uses the modal damping ratio from energy considerations.

Radiation damping results in energy being removed from the compliant system by the foundation medium during a dynamic disturbance by propagation of waves into the support medium (Rainer 1975). Radiation damping is commonly called geometrical or viscous damping. External viscous damping is caused by the structure moving through surrounding air (or water, in some cases), and it is generally less significant than other sources of damping.

Friction damping is another type of damping considered by many researchers including Richart et al. (1970) who mentioned the footing system comes to rest after some finite time interval, whereas a viscously damped system theoretically never stops moving.