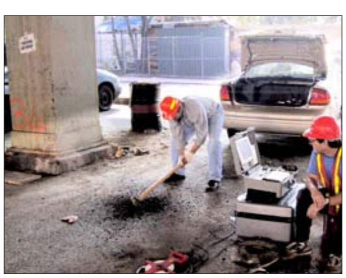
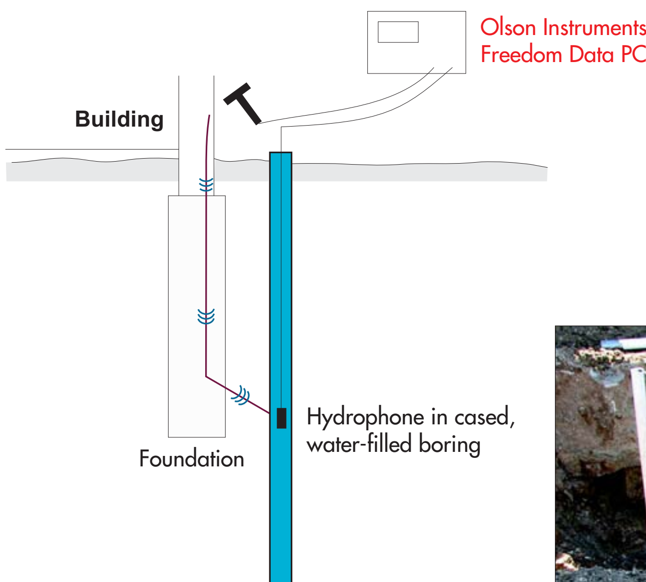


APPLICATION

The Parallel Seismic method is applied to determine the lengths of deep foundations when foundation tops are not accessible, or when the piles are too long and slender (such as H piles or driven piles) to be testable by echo techniques. In addition, the PS method can provide information about the soil below the foundation bottom.

Parallel Seismic involves hitting any part of the structure that is connected to the foundation (or hitting the foundation itself, if accessible) and receiving compressional and/or shear waves traveling down the foundation by a hydrophone or a geophone receiver. The PS investigation can be performed on concrete, wood, masonry, and steel foundations. The receiver is placed in a cased borehole drilled adjacent to the foundation. In soft soil environments, an alternative to drilling a borehole is pushing a seismic piezocone (geophone and hydrophone receivers) into the subsurface with a geotechnical Cone Penetration Test (CPT) rig. Olson Engineering has recently teamed up with Southern Earth Sciences to perform the PS/CPT method and simultaneously obtain accurate geotechnical soil property data (tip resistance, sleeve friction, and pore pressure) and unknown bridge foundation depths. Analysis of the PS data is performed in the time domain. In PS investigations, one relies on identifying direct arrival times of compressional and shear waves at the receiver locations, as well as the wave amplitudes. The PS investigation is performed at 1-2 ft vertical receiver intervals in the borehole. The field setup for PS investigations and the PS/CPT system is shown in the schematic below.



STANDARDS

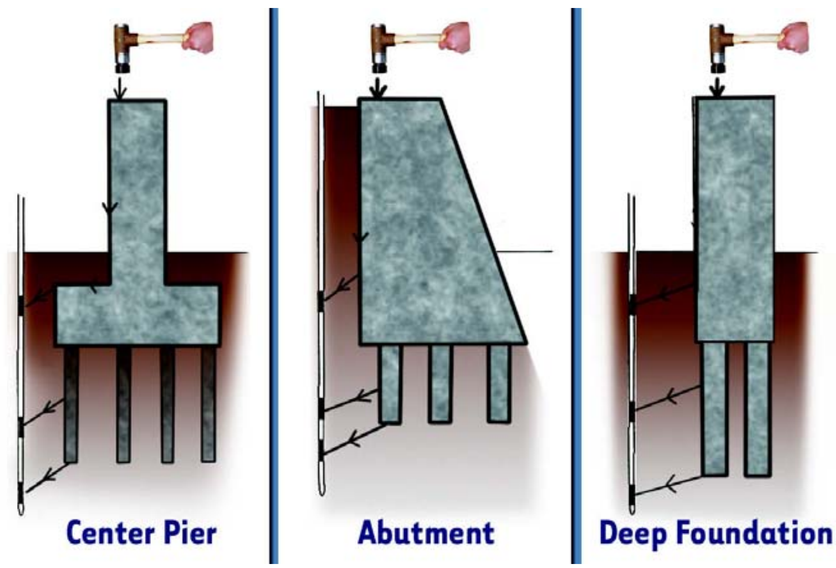
This method is performed in accordance with ACI 228.2R

- **See end of document for full references.**

FIELD INVESTIGATION

ACCESS

Some portion of the structure that is connected to the foundation must be exposed for the hammer impacts. A borehole is typically required but the test can often be performed with a CPT rig pushing the transducer into soft soils. Typically a 2-4 inch diameter hole is drilled as close as possible to the foundation (within 5 feet preferred). The CPT rig used for the PS/CPT system allows the probe to be pushed into the soil at locations as close as 5-7 feet from the foundation edge, depending on access conditions. The borehole should extend at least 10 to 15 feet below the expected bottom of the foundation. In case of hydrophone use, the hole must be cased, capped at the bottom and the casing and hole filled with water. For geophone use, the hole must usually be cased and grouted to prevent the soil from caving in during testing.



Olson Instruments Freedom Data PC Parallel Seismic System (PS-1)

COLLECTION OF DATA

In a PS investigation, the structure is struck by a hammer and the response of the foundation is monitored by a hydrophone or a geophone receiver placed in the borehole or the seismic piezocone placed in the subsurface. The hammer input and the receiver outputs are recorded by an Olson Instruments Freedom Data PC Parallel Seismic System (PS-1) and stored for further analysis. The receiver is first lowered to the bottom of the hole and a measurement is taken. Then, the receiver is moved up 1 or 2 feet and the second measurement is made. This process is continued until the receiver has reached the top of the boring. An alternative method for taking data involves initially placing the receiver at the top of the data set taking a measurement, and then moving the receiver down 1 to 2 feet and taking another measurement. This process is continued until the receiver has reached the bottom of the boring.

DATA REDUCTION

PROCESSING TECHNIQUES

Some geophysical processing techniques can be used to help optimize the Parallel Seismic data. These techniques include Auto Gain Control (AGC) and filtering to enhance weak events. IX Foundation, a seismic analysis and display program, allows the full range of data to be viewed at one time. This improves the ability to identify the bottom of the foundation being investigated.

HYDROPHONE DATA

The time arrival of compressional waves is picked from the data for all receiver locations. A plot of the depth versus arrival time is prepared. For uniform soil conditions, two lines are identified in the plot. The slope of the upper line is indicative of the velocity of the tested foundation, and the second line is indicative of the velocity of the soil below the bottom of the foundation. The intersection of the two lines gives the depth of the foundation. For nonuniform soil conditions, the interpretation of Parallel Seismic data can be difficult due to the nonlinearity of the first time arrival.

GEOPHONE DATA

For uniform soil conditions, the geophone data can be interpreted in a similar way as the hydrophone data. When variable soil velocity conditions exist, an alternative to the first arrival time in data interpretation is used. All the traces are stacked and a V-shape is searched for in the data because the bottom of the foundation acts as a strong source of energy (a point diffractor and a reflector), which produces upward and downward traveling waves. When a geophone is used, the borehole is generally not filled with water. As a result, tube waves are minimized so that later arrival of reflected and diffracted shear and compressional waves can be identified.

INTERPRETATION OF DATA

The use of seismic analysis software, such as IX Foundation, allows for determination of approximate pile length easily. The diffraction, or change in slope, that occurs in the data as a result of the pile tip acting as a point diffractor and a reflector is shown in the example data set presented in the *Example Results* section. The software is capable of determining velocity based on the slope of the line and where the two lines of the differing slopes intersect a depth is determined.

EFFECTIVENESS

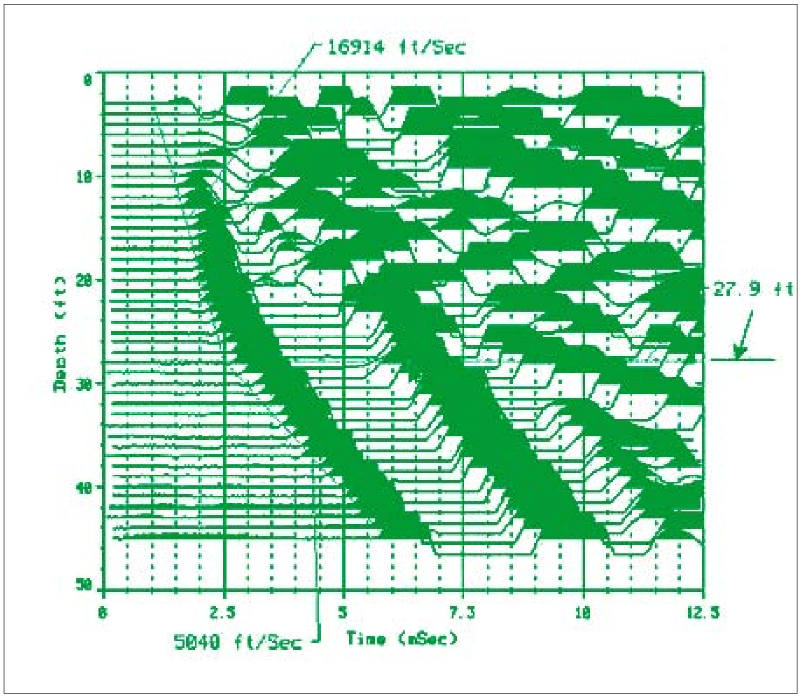
The PS method is more accurate and more versatile than other nondestructive surface techniques for determination of unknown foundation depths. The accuracy of the method depends on the variability of the velocity of the surrounding soil and the spacing between the borehole and the foundation element. Depths are normally determined to within 5% accuracy or better. A borehole is typically needed for Parallel Seismic tests, which adds to the cost of the investigation (unless borings are also needed for other geotechnical purposes). For soft soil environments, the combined Olson/Southern Earth Sciences PS/CPT rig can be used to push a seismic piezocone into the subsurface, thereby eliminating the need for a borehole. The borehole should be within 5 ft of the foundation, which sometimes cannot be achieved due to field constraints. Note that for very uniform soils (such as saturated sands), a successful test can be performed with up to 15-20 feet spacing between the source and the borehole. As the borehole moves away from the foundation, interpretation of the PS data becomes more difficult and the uncertainty in the tip depth determination becomes greater. The PS/CPT system is not useable at sites with shallow rock or boulders or for sites with shallow bedrock or sites where the piles bear into bedrock. Thus, the PS/CPT system is most suited for testing driven piles or other foundations placed into relatively soft soils.

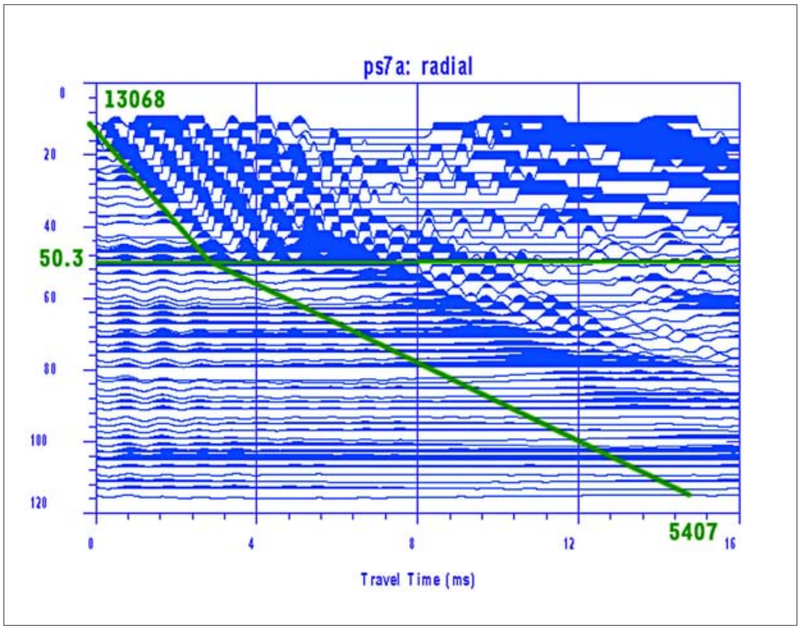
EXAMPLE RESULTS

To illustrate the concepts of the Parallel Seismic tests, two example results from a hydrophone and a geophone are presented in the figures below.

PS - SHEET PILE

The first figure shows PS results from tests performed on a sheet pile in saturated soils. The bottom of the sheet pile is identified at 27.9 ft where the compressional wave velocity changes from 17,000 ft/sec (velocity of steel) to a velocity of 5000 ft/sec (velocity of water). Note the clear PS data due to the favorable surrounding soil conditions due to saturation. In these cases, it is very easy to interpret the PS results.





PS - CONCRETE PILE

The figure to the left shows PS results from tests performed on a concrete pile in saturated soils. The bottom of the concrete pile is identified at 50.3 feet where the compressional wave velocity changes from 13,000 ft/sec (velocity of concrete) to a velocity of 5,400 ft/sec (velocity of water).

REFERENCES

Standards and Governmental Reports

- ACI 228.2R, "Nondestructive Test Methods for Evaluation of Concrete in Structures", *ACI Manual of Concrete Practice, Part2, Construction Practices and Inspection, Pavements*, ACI International.

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- "Stress Wave NDE Methods for Condition Assessment of the Superstructure and Substructure of Concrete Bridges," Olson, L. D. (2004) TRB 2004 Workshop, 2004.
- "Combined Measurement of Unknown Foundation Depths and Soil Properties with NDE Methods,"Olson, L. D., Sack, D. A., Slaughter, S. H. (2003) Transportation Research Board.

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