The parallel seismic method for foundation depth evaluation: a case study in Arthur Alvim, São Paulo, Brazil

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Abstract

A case study on the application of the seismic test of recent use in Brazil, called Parallel Seismic (PS), to evaluate the depth of a 250-mm diameter root-pile belonging to the foundations of a telecommunication steel monopole located in Arthur Alvim, São Paulo, Brazil, is presented. The foundation element is inserted in a sandy clay soil. The estimated depth of the foundation element was obtained by analysis of the results from the PS test. It was evaluated as being equal to 11 m, which was later verified to be in agreement with the pile's design drawings. When the possibility to drill boreholes at a site under investigation exists, the method presented in this article becomes a good option for the determination of the unknown depth of foundation elements.

Introduction

The parallel seismic (PS) test is a geophysical technique developed in France several decades ago for the determination of the unknown depth of foundation elements, which has a methodology similar to that of the downhole test. Also, studies have been conducted to develop the PS test for evaluation of pile integrity (Liao et al., 2006; Huang and Chen, 2007; de Groot, 2014). Practical advantages of the PS test are the applicability of the test for different foundation materials (e.g., concrete, steel, wood or masonry) and the possibility of testing even when the pile head is not accessible.

Lack of knowledge of the foundation depth is a frequent problem in Civil Engineering, and arises from the non-availability of blueprints, the absence of a foundation project, or existing, but unreliable information. The geophysical surface methods are generally unsatisfactory for this type of problem. The PS test, which for its execution requires a borehole positioned very close to the foundation element to be investigated, is able to provide more accurate and reliable results. The length of the foundation pile is an important parameter for evaluating bearing capacity, in the case of reusing the structure for other purposes, for example, when subjected to higher loads.

This work presents the result of a PS test to evaluate the unknown depth of a 250-mm diameter root-pile belonging to the foundations of a telecommunications tower located in Arthur Alvim, municipality of São Paulo, Brazil.

Parallel Seismic test (PS)

The principle of the PS test is quite simple. A pulse is generated by the impact of a small sledgehammer hitting against any exposed part of the structure connected to the foundation (or on the foundation itself if it is available) producing elastic waves predominantly of the compressional type (P-wave) that propagate through the foundation element. Due to the large contrast in elastic properties existing between the ground and the material that constitutes the foundation (concrete, in general), seismic waves are refracted and captured by three-component geophones (or hydrophones) placed in a borehole near to the foundation (around 1 m), and recorded on a seismograph (Figure 1).

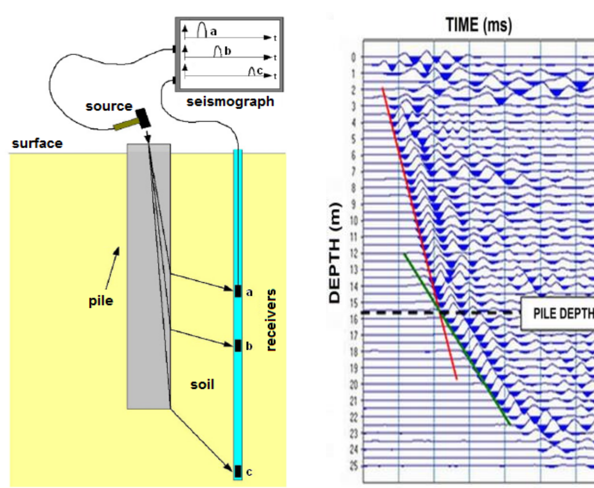

Figure 1 - Parallel Seismic method: a) field test (left) and typical results (right) (Modified from Niederleithinger, 2012).

The test may be performed on concrete, steel, masonry or wood foundations. The hole must have a depth which exceeds by at least 3 to 5 m the maximum expected depth for the foundation element. The preparation of the borehole should follow the guidance similar to those used to perform the downhole or crosshole testing. A PVC-pipe casing must be installed in the borehole, with its bottom end capped and the annular space between the pipe and the wall of the borehole filled with grout to ensure good contact with the ground.

If hydrophones are used, the cased borehole should be filled with water. If geophones are used the borehole must be dry.

The seismograph records the seismic wave that is generated on the surface by the impact of the hammer and captured by the geophones positioned in the borehole. The procedure is performed starting at the bottom of the hole to the surface, usually at regular intervals of 0.5 to 1 m. The test results consist of a seismogram containing the seismic traces recorded at different depths tested.

By determining the first arrival time of the wave, a line can be adjusted, which provides the value of the velocity of the P-wave (V_P) in the material foundation (usually concrete, which has a high value for V_P) and in the surrounding soil (usually with a V_P value lower than the foundation´s). The depth at which the slope changes is attributed to the maximum depth of the foundation element.

The evaluating of the depth of a 230-cm diameter caisson using the PS test in São Paulo provided good results, when the obtained depth was compared to the depth depicted in the caissons documentation (Gandolfo et al., 2015).

Description of the test site

At the investigated site the existing steel monopole has a dodecagonal geometry and 42 m in height, at the top, an outer diameter of 0.493 m, and at the base, 1.481 m. The structure is located at Pierre Fermat Street, Artur Alvim, São Paulo. Figure 2 shows the monopole with its antennas and other details.

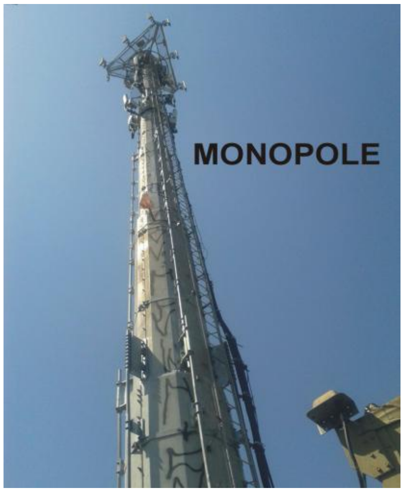

Figure 2 - Monopole's view in Artur Alvim, São Paulo.

The structure is fixed on a foundation block with dimensions (3.1 x 3.1 x 1.1 m), which comprises 8 root-piles with 250-mm diameter each (Figure 3).

In order to enhance the signal reception for the seismic test, the borehole was drilled very close to the foundation (Figure 4).

The borehole for the PS test, at depth of 19 m, was drilled 0.4 m distance from the block. It was cased with a PVC pipe of 85 mm in diameter (thick wall) and its lower end capped. The annular space between the pipe and the wall of the borehole was filled with cement grout.

The stratigraphic profile at the location of the borehole is depicted in Figure 5. The soil is predominantly sandy clay with resistance increasing along depth. It is important to note that in the first 2 m the soil has a soft consistency. Beyond 4 m, the soil has a firm consistency. The water level was found to be at 2 m depth on the date of SPT test.

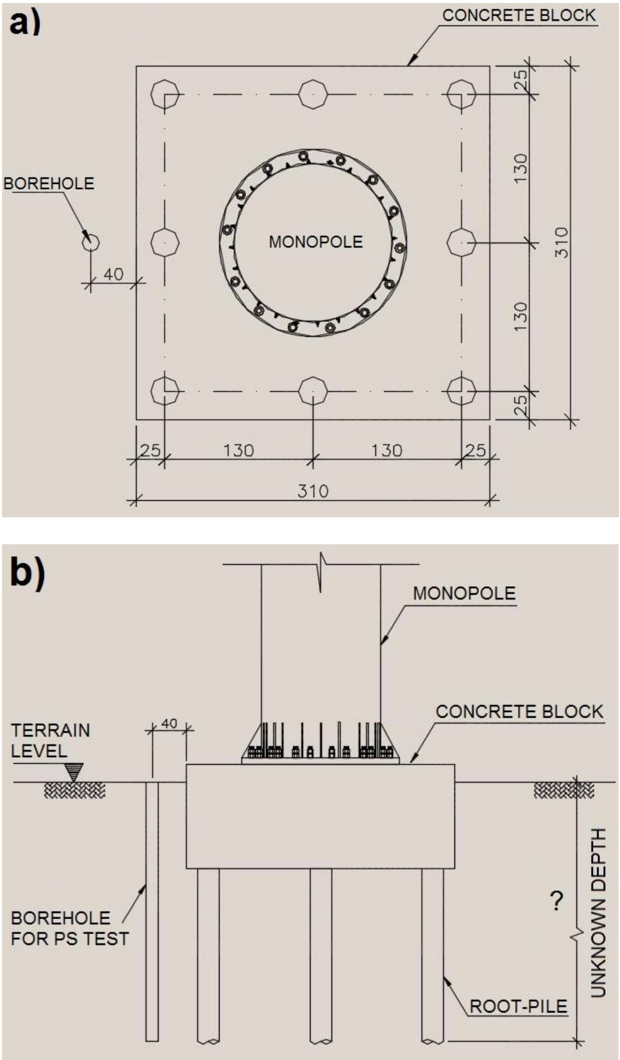

Figure 3 - Foundation block detail: a) plan view (above); b) cross sectional view, showing the elevation of the block depicting three root-piles and the borehole used for the PS test (below).

Figure 4 - Borehole for the PS test at 0.4-m distance from the block.

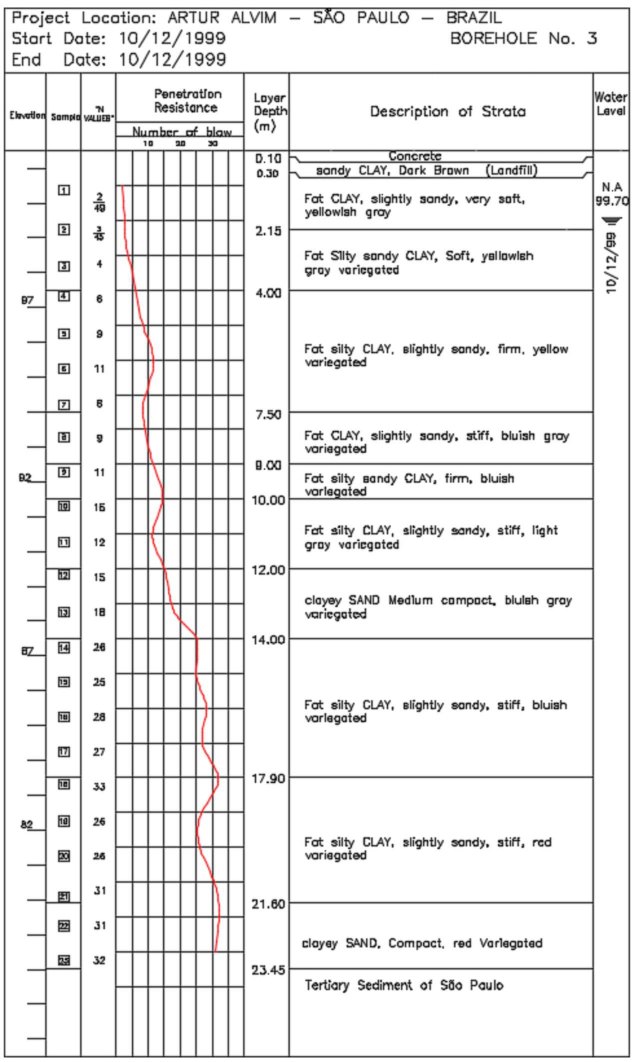

Figure 5 - Stratigraphic profile at the site.

Field data acquisition

For carrying out the PS test at the site, the following equipment was used (IPT, 2015): a) seismograph SmartSeis model of 12 channels (Geometrics), b) downhole geophones (8 Hz) with three components (triaxial) and pneumatic clamping mechanism in the wall of the hole and c) 1.8-kg sledgehammer to generate seismic waves with a coupled transducer (trigger) (Figure 6).

The impact of the hammer was applied directly against the central portion of the concrete block (Figure 7). The signal received by the geophone into the borehole was recorded at regular intervals of 0.5 m, starting at the maximum depth reached by the sensor (18 m) to the vicinity of the ground surface (0.5 m).

Figure 6 - Equipment used for the execution of PS test: seismograph (above on the left); 1.8-kg sledgehammer with trigger (above on the right); triaxial geophone hole with pneumatic system to fix in the hole (below on the left); equipment on the site (below on the right).

Figure 7 - PS test being performed in the telephone tower foundation.

Results

Figure 8 shows the seismogram obtained from the PS test by recording the traces of the vertical component of the geophone.

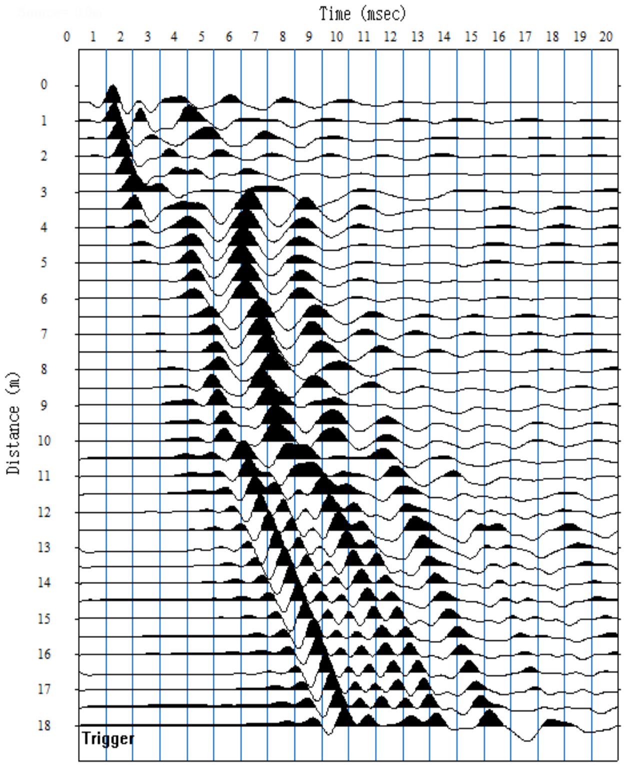

Figure 8 - Seismogram obtained from the PS test.

Picking the first arrival times of the P-wave in the seismogram, the plot of time versus depth was obtained, allowing the velocities estimation and interpretation of the unknow depth of the foundation element (Figure 9).

The point of inflection corresponding to the change in slope of the fitted straight lines, changing from V_1=3733 m/s (velocity of the seismic P-wave in the concrete foundation) to V_2=1956 m/s (velocity of the P-wave in the saturated soil, below the foundation) was interpretaded as being the depth of the foundation element.

Based on the above criterium, the depth of the root-pile was estimated as being equal to 11 m (Figure 9).

As shown in Figure 10, the actual depth of this foundation element is precisely 11 m, as obtained by the PS test carried-out at the site.

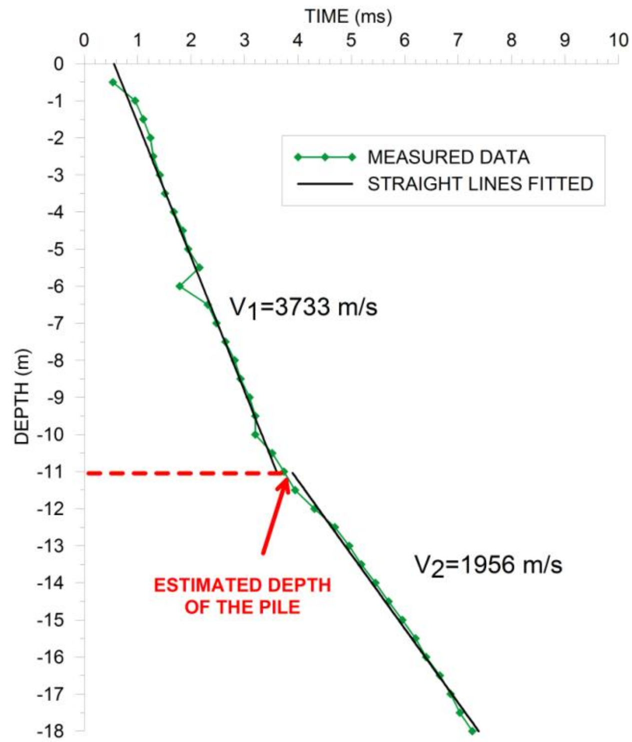

Figure 9 - Time versus depth plot obtained from the first arrival times of the P-wave read from the field seismogram of Figure 8.

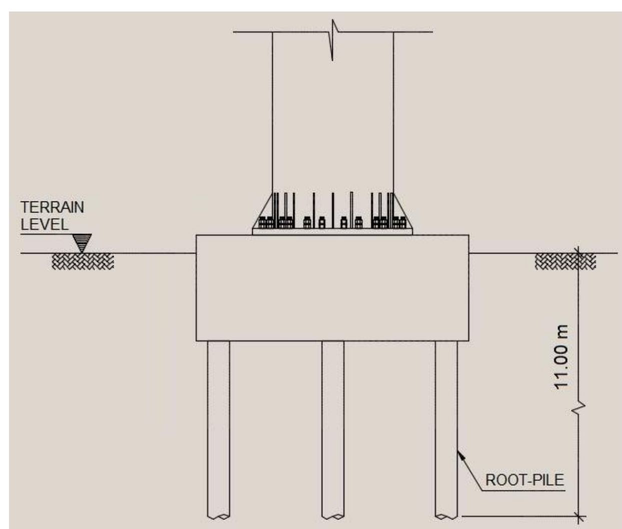

Figure 10 - Foundation design showing the actual depth of the root-piles (11 m).

Conclusions

The PS test performed in the case study presented here with a foundation that consisted of a concrete block with root-piles of a 250-mm diameter provided a very satisfactory result. As it is still a recent application in Brazil, it requires methodological improvement.
The test should be used in other types of foundations with different characteristics in terms of type, building material, geometry, diameters, etc., for a more thorough evaluation of the potential of this technique and improvement of the operational procedures.

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