# EVALUATION OF UNKNOWN FOUNDATION DEPTH USING PARALLEL SEISMIC (PS) TEST - A CASE STUDY

Otávio Coaracy Brasil Gandolfo - Instituto de Pesquisas Tecnológicas de São Paulo - IPT
Tiago de Jesus Souza - American Tower do Brasil
Paulo Aoki - American Tower do Brasil
Paulo Scarano Hemsi - ITA - Instituto Tecnológico de Aeronáutica - Divisão Civil



This paper was prepared for presentation during the 14th International Congress of the Brazilian Geophysical Society held in Rio de Janeiro, Brazil, August 3-6, 2015.



## Abstract

**This paper presents the results of a seismic test of recent application in Brazil, called parallel seismic. This test is intended to determine the maximum depth of a foundation element. Its application has been tested on a large diameter caisson foundation and the results were very satisfactory.**

## 1. Introduction

The parallel seismic (PS) test, used in some foreign countries, is a geophysical technique a bit similar to the downhole test. In Brazil, there are no reports of its use.
The objective of the PS test is the determination of the unknown depth of a pile foundation. It is a frequent problem in civil engineering that arises from the non-availability of blueprints, undocumented foundation project or from existing, but unreliable information.
The geophysical surface methods are generally unsatisfactory to solve this problem.
The PS data acquisition requires a borehole positioned very close to the foundation to be investigated and, therefore, is able to provide more accurate and reliable results.
The length of the foundation pile is an important parameter to evaluate their loading capacity, in the case of reusing the structure for other purposes. For example, when subjected to higher loads.
In this paper will be presented the result of a PS test to determine the unknown depth of a large diameter caisson foundation of a phone tower, located in São Paulo-SP, Brazil.

## 2. Parallel seismic test

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 exposed top, if it is accessible) Elastic waves, predominantly of the compressional type (P-wave), are produced and propagate through the pile.

Due to the high elastic properties contrast between the ground and the material that constitutes the foundation (concrete, in general), seismic waves are refracted and received by three-component geophones (or hydrophones) placed in a cased borehole very close to the pile (within 1.5 meter) and recorded on a seismograph (Figure 1).

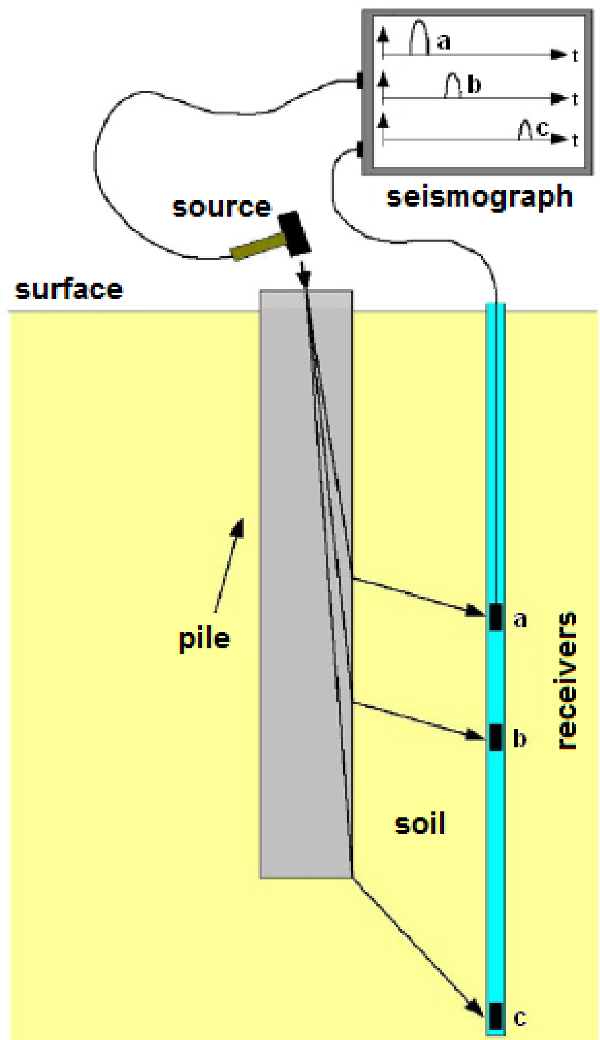


Figure 1 - Parallel seismic testing
(modified from Niederleithinger, 2012).

The PS test can be performed in concrete foundations, steel, masonry and wood.
The borehole should extend at least 3 to 5 meters below the expected maximum depth of the foundation element.
The borehole preparation should follow the guidance set out in the crosshole or downhole testing standards (ASTM D4428, D7400). It must be drilled as vertical as possible, cased with PVC pipe and capped at the bottom. The annular space between the casing and the borehole wall should be grouted, ensuring a good coupling with the surrounding ground.
If hydrophones are used, the borehole should be filled with water. If geophones are used, the borehole must be dry.
The seismic traces are recorded at each position corresponding to the traveltime from source (seismic wave generated by the impact of the hammer on the surface) to the receiver (geophone inside the borehole).
This procedure is performed, starting at the bottom of the borehole to the surface, usually at regular intervals of 50 cm or 1 m. The test result is a seismogram containing the seismic traces recorded at different depths.
Picking the first arrivals, a straightline can be fited, which provides the P-wave velocity ($V_P$) in the material foundation (usually concrete, which has a high value for $V_P$) and in the surrounding soil (usually with a $V_p$ smaller then the foundation one). The depth at which it can be observed the inflection point is taken to be the depth of the foundation.
The advantages of PS test are the possibility to be performed on foundations made of several kinds of materials and when the pile head are not accessible in some sites.

### 3. Description of the test site

The PS test, which result is presented in this paper (IPT, 2014), was performed in a site where there was a phone tower installed on caisson type foundation (2.3m in diameter) under a concrete block (3.0 m x 3.0m x 1.6m) and maximum depth previously unknown (Figure 2).
The borehole for the PS test was drilled as close as possible to the foundation element, lying 1.5 m to 15 m. It was cased with a PVC pipe of 85 mm in diameter and capped at the bottom. The annular space between the case and the borehole wall was grouted (Photo 1).

### 4. Geological and geotechnical characteristics

The phone tower site lies in precambrian terrain of the Embu Complex. Schists, phyllites, migmatites, gneiss, lenticular bodies of quartzites and amphibolites are the predominant rocks.
Soundings carried out in the area show the presence of a clay-sandy silt soil, micaceous, variegated, with growing resistance throughout its depth. It features a soft consistency in the first meters and reaches medium consistency to 10 meters, with $N_{SPT}$ over 10. The water level was found at 19.6m depth.

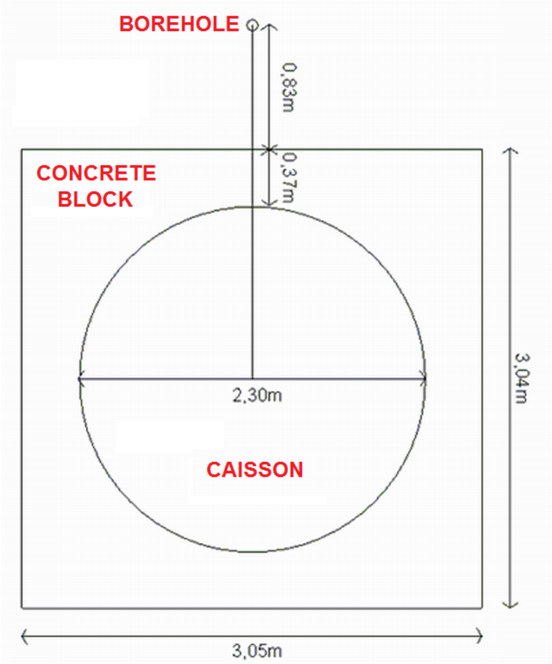

Figure 2 - Sketch of the foundation and the position of borehole used in the test


Photo 1 - Detail of the borehole for PS testing.

## 5. Data acquisition

To carry out the PS test were used the following equipments: a) SmartSeis 12-channels seismograph (Geometrics); b) triaxial borehole geophone (8Hz), with pneumatic clamping mechanism; c) 1.8kg sledgehammer with a trigger switch (Photo 2).

Photo 2 - Geophysical equipments used for the PS test: seismograph (above, on the left); sledgehammer with trigger switch (above, on the right); triaxial borehole geophone (below, on the left); equipments in the site (below, on the right).

The impact of the hammer was applied directly against the central portion of the concrete block on the caisson (Photo 3).The signal received by the borehole geophones was recorded at regular intervals of 50 cm, starting at the maximum depth reached by the sensor (14.5m) and ending nearby of the ground surface (0.5m).

Photo 3 - PS test being performed in the telephone tower foundation.

## 6. Results

Figure 3 shows the resulting seismogram of PS test, obtained by registering the seismic traces for one of the horizontal components of the borehole triaxial geophone.

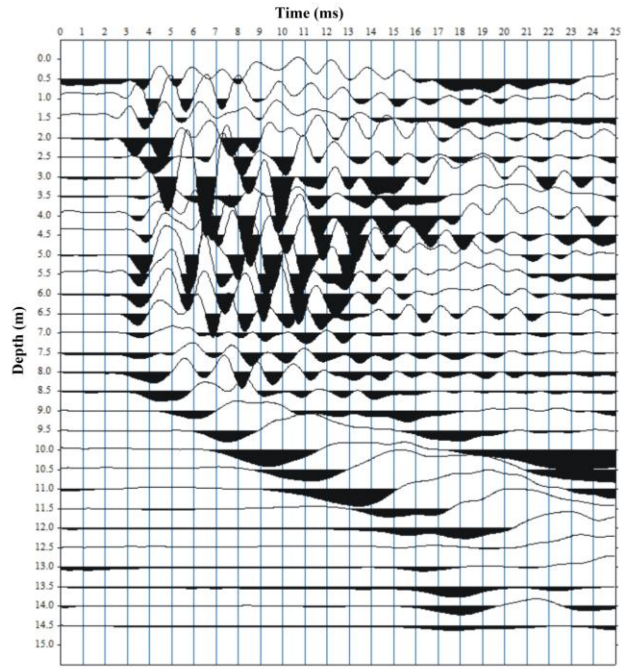


Figure 3 - Seismogram obtained from the PS test.

Due to the high contrast of the velocity in concrete (V1) and the velocity of surrounding soil (V2), the seismic rays will emerge at an angle of nearly 90° from caisson/ground interface, according to Snell's refraction law. Under these conditions, the horizontal components of the triaxial borehole geophone (Hx and Hy) will register the seismic signal efficiently (Figure 4).

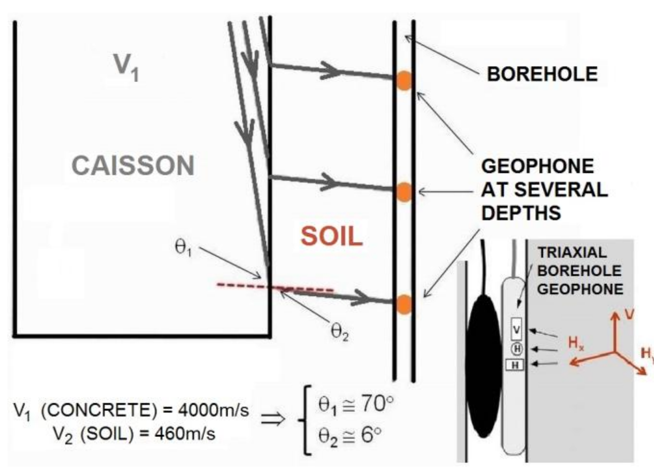


Figure 4 - Seismics raypaths in a PS test.

In the seismogram can be observed that the traces exhibit a lower frequency at depths below 8m, compared to that ones which are above this depth.

The break in the slope of the two straight line segments, V1 (P-wave in the concrete foundation) and V2 = 455m/s (P-wave in soil) was taken to be the depth of the foundation (Figure 5), evaluated at 8 meters

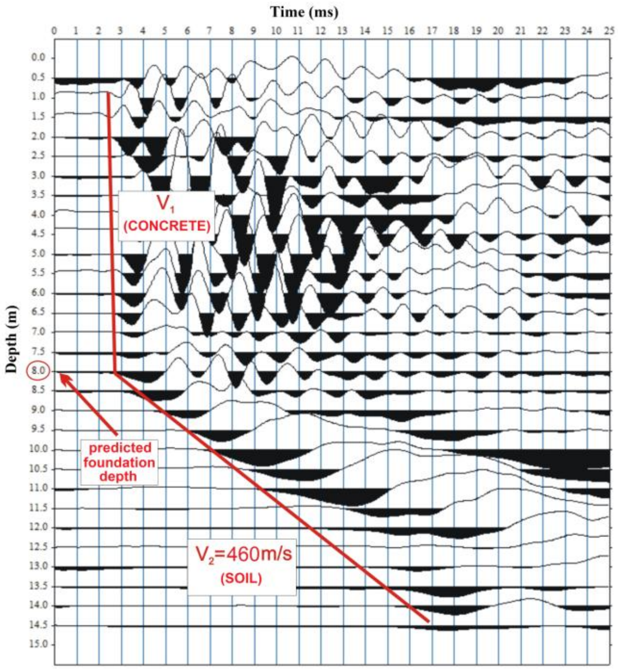


Figure 5 - Interpreted seismogram, with the evaluated depth of the caisson.

For evaluation of the results obtained, was performed a 2D numerical simulation using a synthetic model. The following parameters were used: the caisson diameter of 2.3m; depth of the base equal to 8 meters; velocity of P-wave in the soil equal to 460m/s and 4000m/s in the foundation (concrete); distance from the borehole to the foundation block equal to 0,83m. Figure 6 shows an illustration of the proposed model.

It was built a time x depth graph (Figure 7) from the arrival times of the P-wave obtained from the seismogram. In this particular field test, the velocity of P-waves in the foundation (V1) had not been well defined. Then, we adopted a typical velocity for the concrete, equal to 4000m/s.

It was calculated the theoretical times of the rectilenear raypaths shown in Figure 6, that correspond to traveltime from the source (point of impact in the center of the foundation element) to each of the geophone positions in the borehole.

The results of theoretical traveltimes and the P-wave arrival times obtained from the seismogram are presented in the graph of Figure 8.

It can be observed a good agreement between the measured data and the calculated values , reinforcing the assumption that the maximum caisson depth would be about 8 meters deep.

The information of the foundation project, available after the completion of the field test, confirmed the correct depth of 8 meters for the caisson (Figure 9) proving the effectiveness of the methodology for the test performed in this type of foundation.

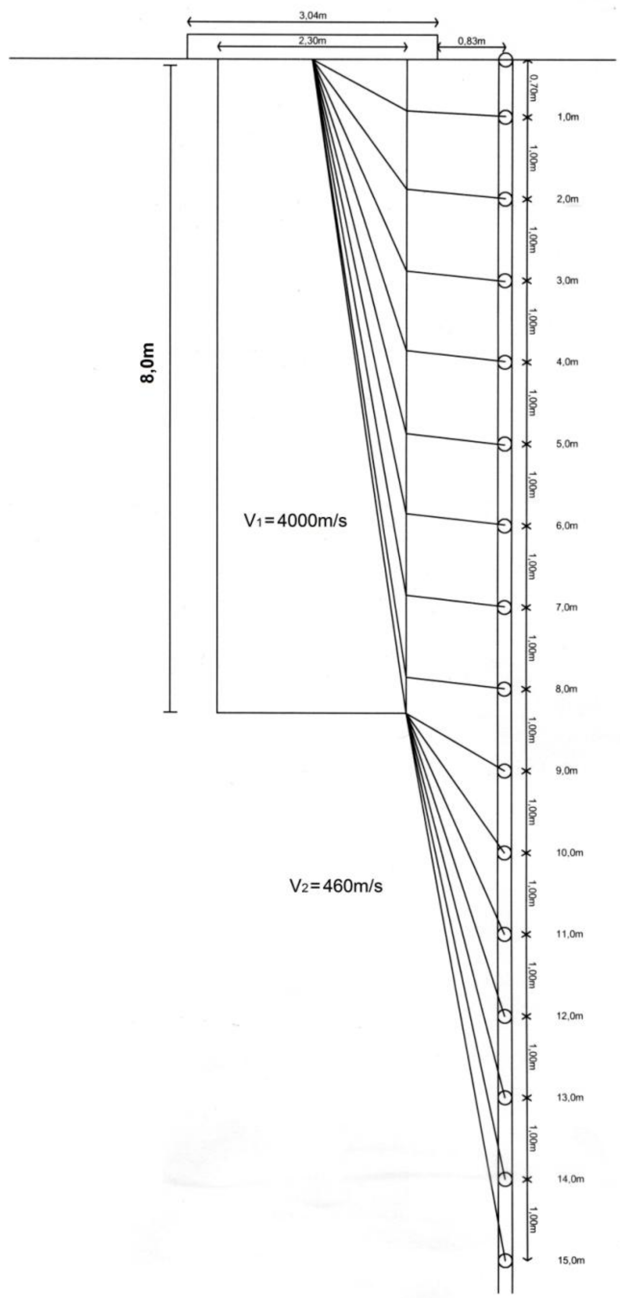


Figure 6 - Model used to calculate the theoretical traveltimes of the P-wave in the PS test.

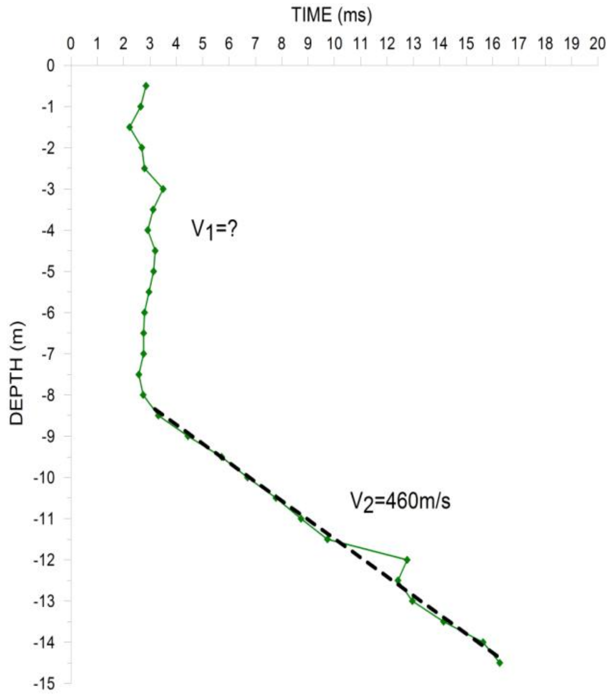


Figure 7 - Time x depth graph with the arrival times of the P-wave obtained from seismogram.

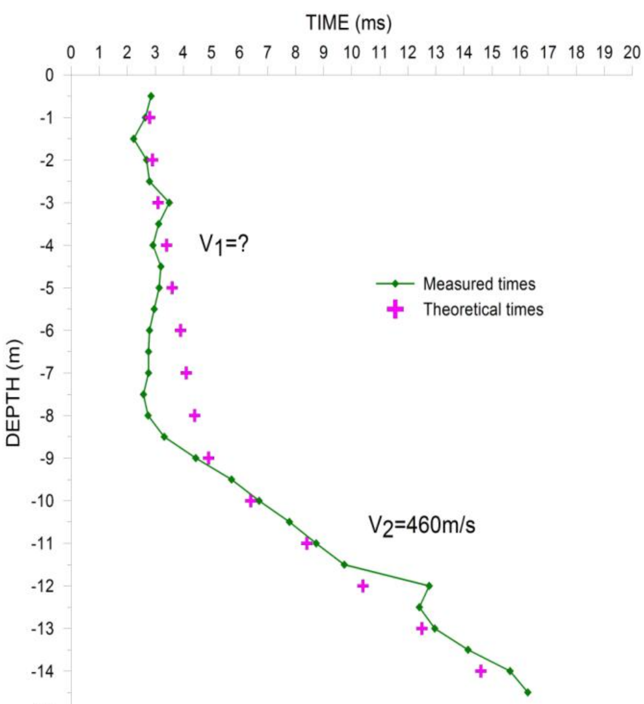


Figure 8 - Time x depth graph with the measured and theoretical travel time calculated from the model of Figure 6.

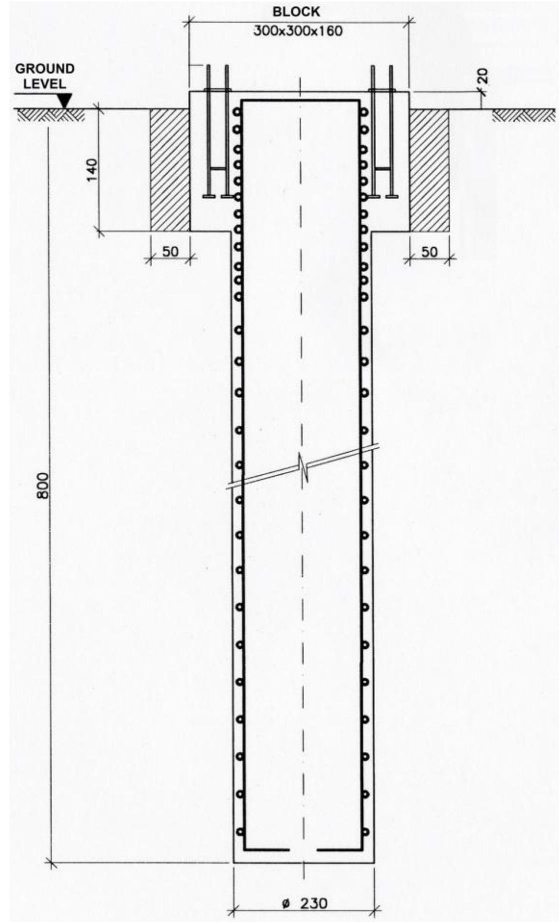


Figure 9 - Foundation design showing the depth of 8 meters for the caisson.

## 7. Conclusions

The PS test presented in this case study, where the foundation consisted of a caisson of 2.3 m in diameter, provided a very satisfactory result.
As it is still a pioneering application technique in Brazil, it requires some methodological improvements.
The technique should be used in other of foundations types, in terms of its building material, geometry, dimensions, diameters, etc. for a more thorough evaluation of the strength of this promising technique and improvement in its operational procedures.

## 8. References

IPT. 2014. Ensaio Sísmico Paralelo realizado no site SPO063SS, situado na Rua João de Santana, 393 - Jd. São Luiz, município de São Paulo-SP. RELATÓRIO IPT Nº 140.905-205, 28p.

Niederleithinger, E. 2012. Improvement and extension of the parallel seismic method for foundation depth measurement. Soils and Foundations, v.52, n.6, p.1093-1101.