An application example of shallow seismic reflection technique for geological-geotechnical mapping in the urban area of the city of São Paulo, Brazil

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This paper was prepared for presentation at the 9th International Congress of the Brazilian Geophysical Society held in Salvador, Brazil, 11-14 September 2005.

Abstract

We evaluate the potential of shallow seismic reflection for a geological and geotechnical research in noisy urban environments with a paved surface. The field tests were made at the Sedimentary Basin of São Paulo, in the urban area of the city of São Paulo. It was verified that a sledgehammer and 100 Hz geophones provide the most suitable equipment. An interpretation of the CMP section, interpolated by the well information, demonstrated a high potential for mapping geological structures with numerous details and good continuity. The information obtained from the final seismic section revealed various sediment strata of the São Paulo Basin and several bedrock structures. The results characterize the shallow seismic reflection method as a flexible tool that can be adapted to the objectives of the proposed research. The latter can be accomplished by defining appropriate acquisition parameters as well as through perceptive processing.

Introduction

The use of the seismic reflection method began in the 1920s. Since then its use for deep hydrocarbon exploration has constantly grown. The first registered attempts to use high-resolution shallow seismic reflection were made in the 1950s and 1960s (Pakisser et. al, 1954). However, due to the large cost and amount of work required, considering the absence of digital processing, the attempts were abandoned. Only in the late 1970s did the high-resolution shallow seismic reflection find its place among the geophysical methods of geological-geotechnical shallow investigation, that is, up to approximately 100 m (Knapp & Steeples, 1986). The increasing application of the method was caused mainly by the progress in the computer industry, which made the seismograph cheaper and more efficient. This success was reinforced in the 1990s, when, for the first time, the technique called the optimum offset (Pullan et al., 1990) was applied, in which one selects from preliminary tests an appropriate distance between the shot point and the geophone in order to determine a section consisting of traces of common offset, and a section of the common-depth point (Mayne, 1962), which is typically used in the oil industry for deep seismic reflection profiling, since it proves to be an efficient technique even in regions with a low signal/noise ratio. This technique became the most effective one in the last decade in studies with high-resolution shallow seismic reflection (Knapp & Steeples, 1986; Black et al., 1994). At the workshop on shallow seismic held in Berkeley (California) in 1996 (Steeples et al., 1997), having among the participants the most prominent experts in the subject at that time, a number of novel applications were presented, such as characterization of bedrock, detection of geological faults, stratigraphical delineation, profiling changes in near-surface facies, etc.
With a great number of geological-geotechnical problems to which the reflection seismic method can contribute, it is employed in urban environments where the underground is continuously used for many different tasks (tunnels, water flood reservoirs, conduits for electrical wires and optical fibers, etc.).
At the same time, the challenge of applying the shallow reflection seismic method in an urban environment is related to several aspects degrading or complicating the acquisition and analysis of seismic data, such as small and restricted work areas and altered superficial strata (landfill and asphalt), in addition to the background produced by high-voltage transmission lines and the vibrational noise of traffic.
With the aim of investigating the accuracy and potential of the shallow reflection seismic method in the described conditions, a study has been performed, applying the method with the CMP (Common Mid-Point) technique in an area of the city of São Paulo, more precisely, inside the São Paulo University campus, which, in addition to being a typically urban region, has already been the object of geological-geotechnical research, using photo-interpretation, surface mapping, as well as an execution of several wells (Azevedo, 2002). Nowadays, in the same surroundings a tunnel is being excavated to give passage to a subway line.
In this work, we present and discuss our results on the applicability of the shallow reflection seismic method as an efficient tool for geological-geotechnical studies in an urban area, using an appropriate acquisition parameter and careful processing.

Location and geological context of study area

The test area was chosen inside the Cidade Universitária of USP (Figure 1), located at the west side of the city of Sao Paulo, on the left bank of the Pinheiros river. The choice was motivated by several factors: i) the existence of wells in the surroundings of the test locations; ii) the possibility of performing a simultaneous acquisition over the asphalt layer and over the soil; iii) the site is located in a typically urban environment with a heavy vehicle and human traffic.

The geology of the area consists of Tertiary sediments of the Itaquaquecetuba Formation of the Sedimentary São Paulo Basin, lying over a Precambrian bedrock. The description of the production well PP1 (Figure 1), located close to the test site shows the following information on the main lithofacies present: (1) sands up to the depth of 25 m; (2) conglomerate from 25 m to 35 m; sands from 35 m to 52 m; (4) clays from 52 m to 70 m; (5) granite gneiss basement. In the crystalline basement, there are families of NNW-SSE sub-vertical joints, originated from traction, the result of the last tensions over the rock mass (Azevedo, 2002). Such structures constitute large lineament systems affecting the whole drainage system in the surroundings of the Cidade Universitária (Figure 2).

Method/Problem investigated

Initially, examining the information from well PP1, we obtained the geological model 1D (Figure 3a) and, from this model, some synthetic seismograms were generated using the algorithm Triseis from the software Seismic Unix (Stockwell & Cohen, 1998) in order to estimate the path-time for waves reflecting in the present interfaces (Figure 3b).

Then several walkaway noise tests were performed. The main goal was to compare the responses of different geophones under different couplings and seismic wave sources, attempting to establish the ideal equipment and parameters which could improve the efficiency and resolution of the shallow reflection seismic method.

The comparative analysis of all walkaway noise seismograms, after processing, showed that the best results came from 100Hz geophones with a spike of 0.18 m long and a sledgehammer-plate system as the seismic source. The final seismogram concatenated and processed revealed three distinct reflections at 50 ms, with respect to the top of the conglomerate, 75ms, associated to the top of the clay, and 100ms, related to the basement (Figure 3c).

Having defined the appropriate parameters and equipments (Table 1), we performed a survey using the high-resolution shallow reflection seismic method with a modification of the CMP technique, termed by Diogo (2004) as acquisition through "fixed base CMP survey". The goal of this procedure is to reduce the time of execution for the field survey, which depends on a limited number of seismograph channels. To reach the 12 fold acquisition with 24 available channels, the procedure consists in keeping fixed the geophones array and moving the shot point toward the array (the distance between shots being the same as that of the receptors). After covering 12 shot points (equivalent to half the number of registered channels), the first 12 geophones are shifted to the end of the array, and a new set of 12 shots is performed.

Table 1 - Acquisition parameters used in the survey performed with the modification of the CMP technique called "fixed base"

Number of chanels	24
Minimum offset	36 m - 47 m
Maximum offset	59 m - 70 m
Receiver spacing	1 m
Geophone type	100 Hz
Source type	sledgehammer - 6 kg
Coupling	spike - 0,18 m
Sample rate	0,25 ms
Recording time	200 ms
Pre A/D low cut filter	3 Hz
Coverage fold	12

To the CMP survey 164 shots, 1 m apart, were acquired. As a consequence of this procedure, there is a variation of the minimum offset during the acquisition, ranging from 47 m to 36 m. The 1 m distance between consecutive geophones and between shot points produced for the stacked seismic section, a coverage of 1200%.

Results

The data processing in shallow seismic is characterized by the necessity of preserving high frequencies and the most of shallow reflections. Unlike in conventional seismic, here, most of the time, the superficial waves superimpose to the desired reflections. To avoid losing the details, which would be the case in a conventional processing, a high level of interaction with the processing algorithms is required. For instance, in the NMO corrections, the seismic trace stretch muting should be applied in a much more rigorous way than for the conventional seismic data (Miller, 1992). A special attention is also required: the use of the F-K filter, which can generate artifacts, and static corrections.

The basic processing flow varies depending on the characteristics of the data, that is, all available treatments might be employed, but only those giving the best results for the final section are chosen.

For these data, after including the geometry, editing the traces and performing a spectral analysis, we decided to apply a band pass filter (30 – 250 Hz) resulting in an enhancement in the identification of reflection events as well as in the S/N ratio. Then we performed a velocity analysis, through a joint observation of semblance and NMO panels, NMO corrections, and stacking. As the analyzed data, after stacking, showed a good S/N ratio and three supposed distinct events, thus satisfying the random reflectivity function condition, and in order to verify whether the identified events were not periodic (multiples or ringing), we chose to apply predictive deconvolution. A prediction lag of 20ms and a 150ms operator lag were employed. In this case, additionally eliminating the periodic events, we also enhanced the vertical resolution. Deconvolution was successfully applied and contributed to the final geological interpretation (Figure 4b). And, finally, in order to distribute the energy of the trace, making the image homogeneous, an automatic gain (AGC), with a 80ms time window, was applied.

Interpretation and discussion of the results

During the interpretation of the final stacked seismic section, we were able to identify three interfaces (Figure 4b), consistent with previous results based on the noise analysis (Figure 3c) and with the available geological information for the well PP1, corresponding to: (1) top of the conglomerate, 25 m deep (yellow); (2) top of the gray-blue clay, 52 m deep (green); (3) crystalline basement constituted of gneiss rocks, 70 m deep (red). In the crystalline basement, we were also able to identify sub-vertical discontinuities, probably related to the NNW-SSE structures which shape the whole drainage system in the surroundings of the Cidade Universitária and neighborhoods (Figure 2). Such structures enlarge the fractures of the rock mass, forming zones of high permeability (Azevedo, 2002), accounting for the importance of its identification in the design and execution of underground works.

Conclusions

Our seismic survey, using the CMP technique, however laborious, proved to be valid for the terrains of the Sedimentary Basin of São Paulo, in the urban area of the city of São Paulo. An interpretation of the final section demonstrated a high potential for continuous structural and stratigraphical mapping, being a powerful tool in interpolating 2D profiles on the basis of information obtained from drilled holes.

As a future study, the results presented in this work open the prospect of obtaining other CMP profiles with larger covered areas for an improved definition of basement structures.

Acknowledgment

We would like to thank CNPq for financial support; IPT for providing geophones of 100Hz and a seismic rifle; Ernande Costa Santos for assistance and friendship, as well as for valuable advice during the data acquisition at the test location.

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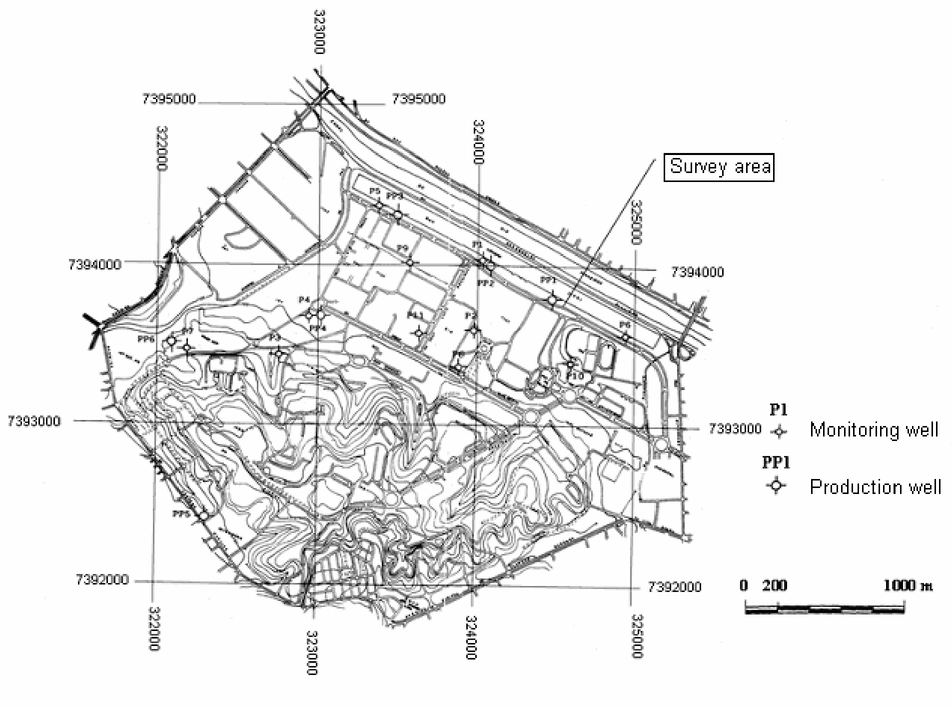
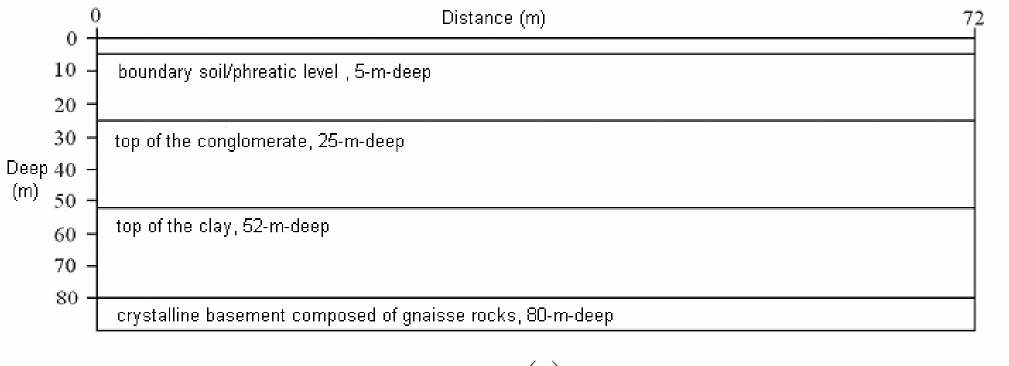
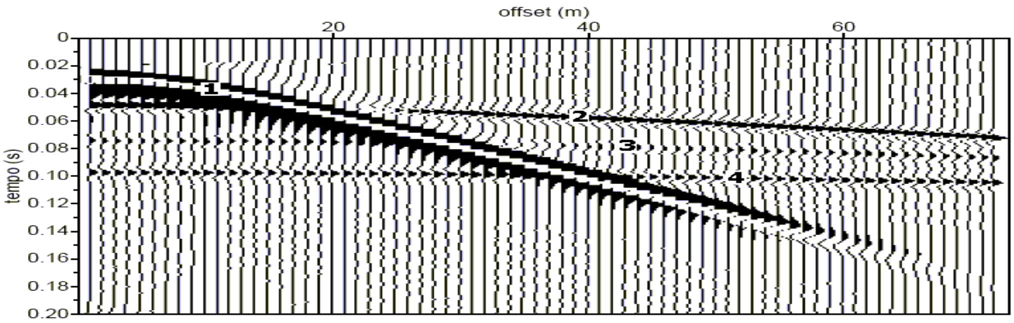


Figure 1 - Map of the campus of the USP presenting location of the survey area with localization of the wells (adapted from Iritani, 1993).

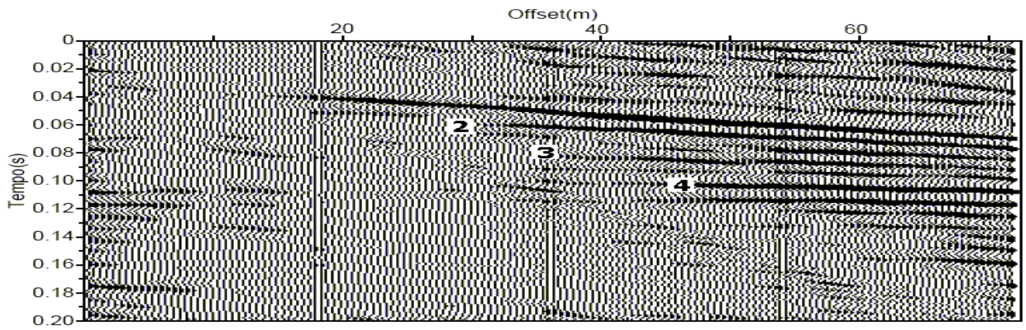
Figure 2 – Large lineament systems (generated from photo-interpretation) which affect the whole drainage system in the surroundings of the Cidade Universitária (adapted from Azevedo, 2002)



(a)



(b)



(c)

Figure 3 – (a) geologic model generated from the information of the production well PP1; (b) synthetic seismogram generated from the description of the production well PP1. Event 1: boundary soil/phreatic level, 5-m-deep, V_{int}=0,4 km/s; event 2: top of the conglomerate, 25-m-deep, V_{in}=1,7 km/s; event 3: top of the clay, 52-m-deep, V_{in}=2,1 km/s; event 4: crystalline basement composed of gnaisse rocks, 80-m-deep, V_{in}=2,4 km/s; (c) seismogram of the walkaway noise test interpreted with an application of the corresponding events to the synthetic seismogram;

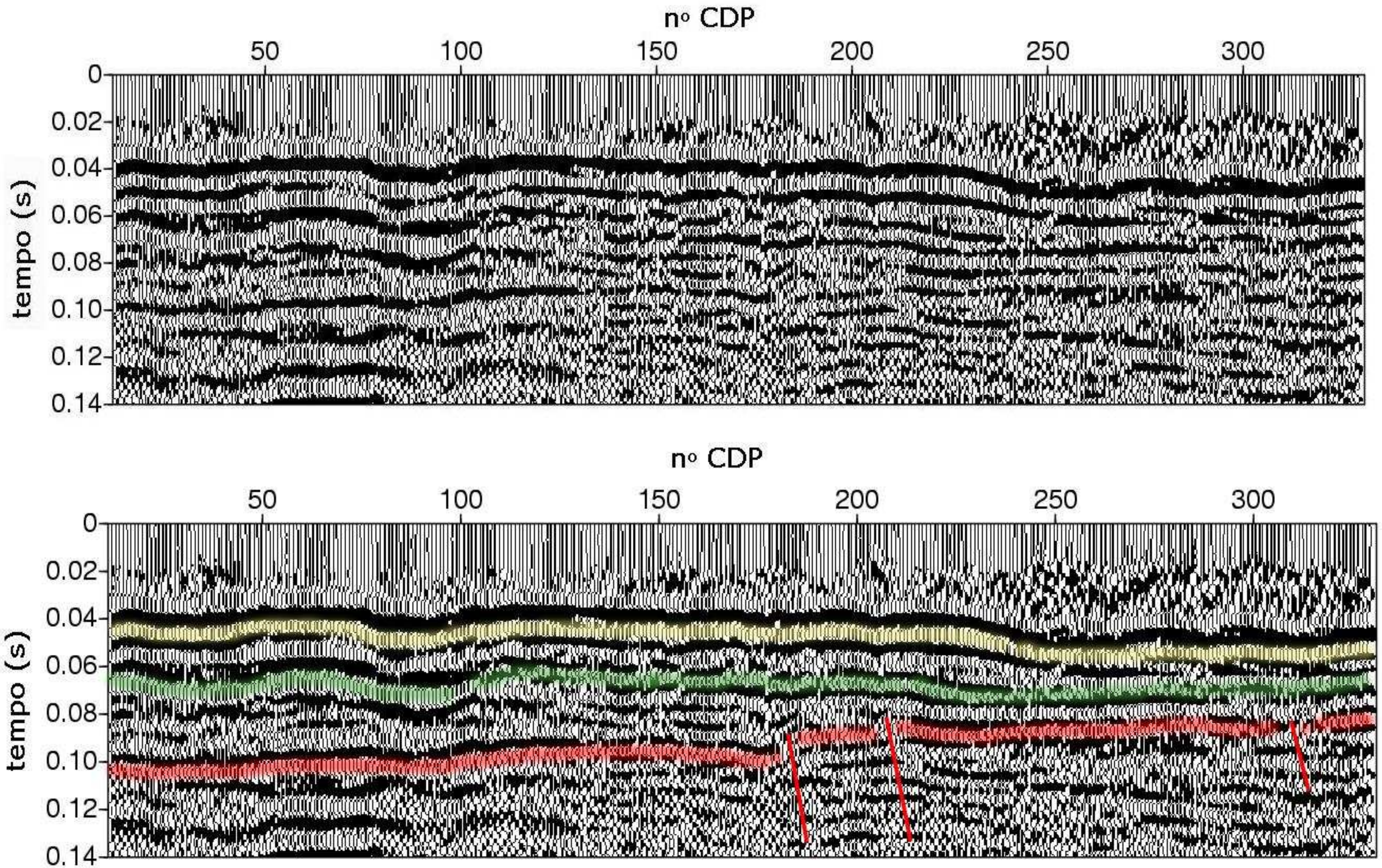


Figure 4 – Final stacked seismic section: (a) without interpretation; (b) with interpretation;