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COMPARISON BETWEEN RESULTS OF SEISMIC REFRACTION AND STANDARD PENETRATION TEST (SPT) TO STUDY SHALLOW GEOLOGICAL SUBSURFACE IN AN URBAN AREA OF BRASÍLIA, BRAZIL

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ABSTRACT. The most common procedure for an engineering project/construction is the use of direct survey, borehole and Standard Penetration Test (SPT). This provides punctual information of the geology at the site, and many boreholes are necessary along the construction site, representing a significant amount of the budget for the construction and to help develop a better geological understand/map of the site. The use of geophysical methods allows to study the subsurface by indirect means, with low cost, and enable to cover large areas if compared to direct surveys. Geophysical methods are increasingly being used in engineering works, however, in Brazil the use in engineering projects is still scarce. In this work was used shallow seismic refraction method to study the shallow subsurface in an area along the future track of the subway system of Brasília, Brazil. The refraction results (P-wave) were compared with previous existing data from Standard Penetration Test (SPT), and soil profile description. The seismic was used to study the subsurface geology, and SPT data were used to compare the seismic results. We observed a good correlation for the depths obtained through each method, mostly in the north portion of the line, when the SPT was near the line, indicating that its results are influenced by the same mechanical parameters, related to soil strength. Our results motivate the use of seismic refraction as a tool to optimize the direct investigation methods for better geotechnical characterization of the medium.

Keywords: shallow seismic refraction, standard penetration test (SPT), geotechnical study.

RESUMO. O procedimento inicial mais comum em um projeto de engenharia é o uso de pesquisa direta, por meio de sondagens e Índice de Resistência à Penetração (SPT, em inglês). Estas ferramentas fornecem informações pontuais acerca da geologia local, sendo necessárias diversas sondagens para desenvolver um bom entendimento geológico/geotécnico da região, fazendo com que as sondagens representem uma quantidade significativa do orçamento da obra de engenharia. O uso de métodos geofísicos permite estudar a subsuperfície por meio indireto, com baixo custo, e possibilita cobrir grandes áreas, quando comparado ao uso exclusivo de sondagens diretas. Métodos geofísicos estão sendo cada vez mais utilizados em obras de engenharia, no entanto, o seu uso em projetos de engenharia no Brasil ainda é escasso. Neste trabalho foi utilizado o método de sísmica de refração rasa para estudar a subsuperfície em uma área ao longo do futuro trecho do sistema de metrô de Brasília, Brasil. Os resultados de refração (onda P) foram comparados com os dados pré-existentes de SPT e descrição do solo. A sísmica foi empregada para estudar a geologia da subsuperfície, os dados SPT foram utilizados para comparar com os resultados sísmicos. Observou-se uma boa correlação para as profundezas obtidas através de cada método, principalmente na porção norte da linha, região em que o SPT está mais próximo da linha, indicando que os seus resultados são influenciados pelos mesmos parâmetros mecânicos, relacionados com a resistência do solo. Nossos resultados motivam o uso de refração sísmica como uma ferramenta para aperfeiçoar os métodos de investigação direta, com objetivo de gerar uma melhor caracterização geotécnica do meio.

Palavras-chave: sísmica de refração rasa, índice de resistência à penetração, estudo geotécnico.

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INTRODUCTION

In the beginning of engineering works the knowledge and the conditions of the subsurface is crucial because the geological structures can be a complex factor. A typical approach is to study the subsurface in a direct way, using boreholes and Standard Penetration Test (SPT) (Hettiarachchi & Brown, 2009). Generally, direct survey provides high quality information, however, represent punctual information. Several surveys are necessary to have a greater understand of the geology, increasing the cost of the work. Direct surveys are “invasive techniques”, where the study area can be permanently affected, and at some cases, limit the application at urban areas (McDowell et al., 2002). Several methods, such as resistivity, ground penetrating radar (GPR) and seismic can be used combined with direct geotechnical surveys to reduce its quantity and cost (McDowell et al., 2002; Consenza et al., 2006).

The main characteristic of geophysical methods is to provide information by indirect means, covering both large and small areas, and in different scales. The cost of geophysical surveys is considerably smaller when compared to the exclusive use of direct survey, usually spending less time to be done.

The SPT is a common method used in engineering projects to define soil strength. The number of blows needed per depth for the STP can be related to vertical resistance to ground penetration (Yagiz, 2008; Alves, 2009). Several authors use both seismic refraction and SPT to define soil conditions such as, type of soil, rippability and liquefaction (Basarir & Karpuz, 2004; Basarir et al., 2008). Generally, SPT data is compared with shear wave (V_S) measurements, providing better results, since shear wave propagation is not affected by the water content of the medium (Hasancebi & Ulusay, 2007; Anbazhagan & Sitharam, 2008). However, in this work, due to equipment restrictions, the SPT data was compared with primary wave (P-wave).

The seismic refraction is one of the main geophysical techniques used in geotechnical problems (e.g. Khalil & Hanafy, 2008). Among the most common applications of seismic refraction in a geotechnical context is to measure the depth of the bedrock, for the construction of large and tall buildings, dams and highways (Telford et al., 1990). There are some examples of the use of seismic refraction in Brazil (Prado, 2000; Martínez & Mendoza, 2011). For more information about application of geophysical methods in Brasília, see Seimetz (2012).

In this work, we used shallow seismic refraction to study the subsurface for a future subway station in Brasília, Brazil (Fig. 1). The main objective was to generate a geological model based on shallow seismic refraction results, in order to understand the shallow geological structure in the study area and also compare the geological model, seismic results, with the Standard Penetration Test (SPT) data.

METODOLOGY

For the data acquisition of shallow seismic refraction, were used 48 receivers spaced 2 meters apart (Fig. 2). The seismic source used was a hammer with 8 kg, struck 15 times against a metal plate placed on the ground. A total of six seismic sections were acquired, all with 94 meters in length (Fig. 3), composing a seismic line with 564 meters (Figs. 1 and 3). The positions of the source for each line were at: –2, 47 and 94 meters, from the first geophone. The data was acquired by using the Geode (Geometrics) seismograph and for the data processing was used the program package SEISIMAGER 2D. The technique used to process the data was the time-term inversion.

The SPT is a classic geotechnical method used to measure mechanical properties of the medium. A sample tube is driven into the ground using a standard weight, which is dropped freely from a standard height. According to international standards (ASTM, 2008), the number of blows required for this tube to penetrate 15 cm into the soil is recorded and resulting a graph of blows quantity with respect to depth. This graph can be related to variations in the strength of the material in the subsurface, since the blow counts are related to density of the ground (Brown & Hettiarachchi, 2008; Murley & Hettiarachchi, 2011). For the region of Brasília, when the SPT blow count is higher than 50, the material is considered impenetrable. Meaning that, from this depth on, the soil provides good ground stability for engineering purposes (Alves, 2009). This was the definition used in this work to underline the depth of the impenetrable. We selected the eight SPT probing most close to the seismic line. These eight SPT data where separated in three groups, according to soil description and depth of the impenetrable level. Group 1 includes SPTs numbers 935, 938 and 940 (yellow circles in Fig. 1), Group 2 contains SPT numbers 952 and 953 (orange circle in Fig. 1). Group 3 includes SPTs 985, 986 and 993 (Red circles in Fig. 1). The SPT data used in this work were acquired by engineering companies with the supervision of the Department of Civil Engineering (ENC) of the Universidade de Brasília (UnB).

RESULTS

Figure 2 shows an example of a seismogram obtained by the method of shallow seismic refraction. In the y-axis is the time, and the x-axis represents the geophone offsets. It is observed that for the geophones more distant from the shot point (where

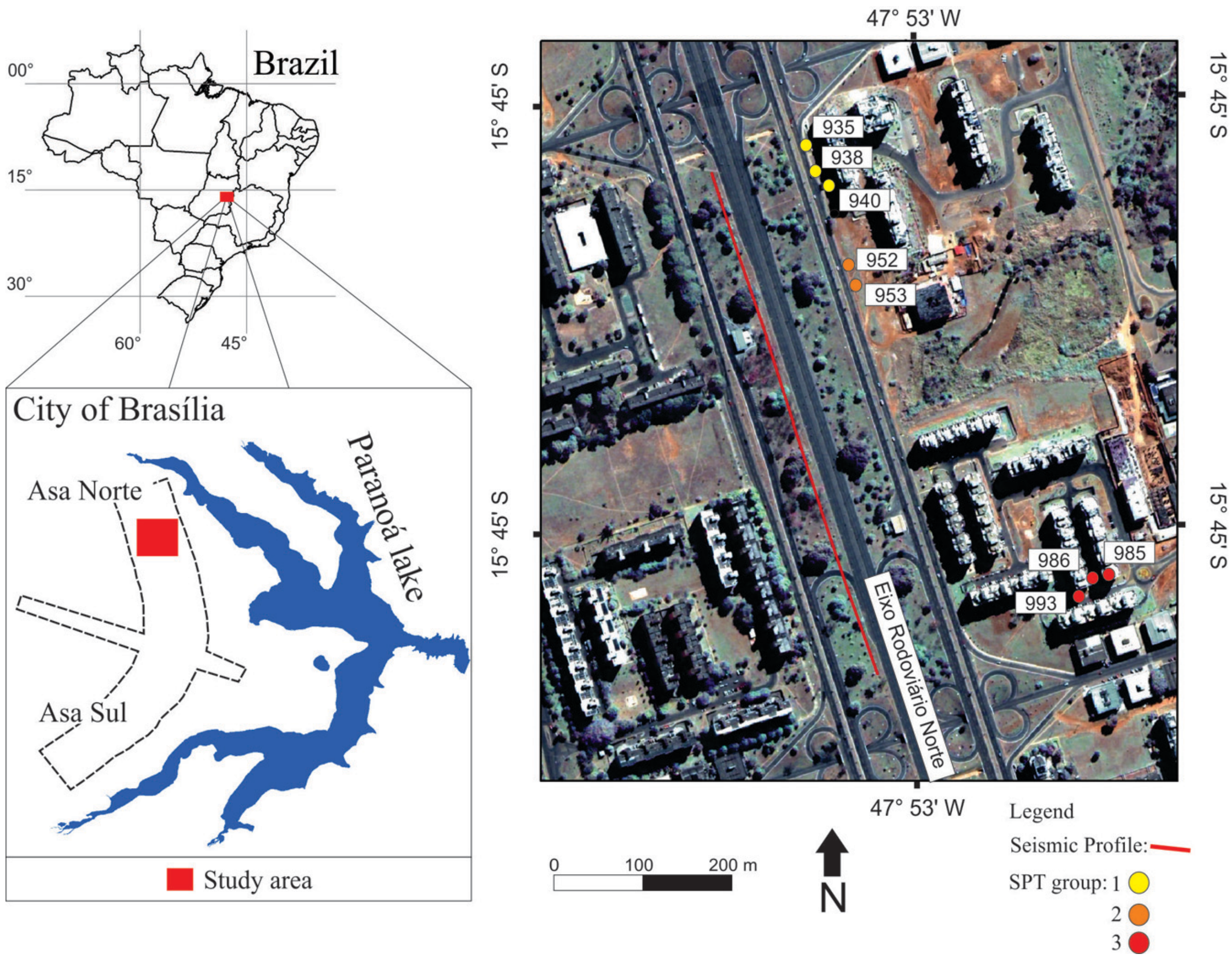

Figure 1 – Study area on the Asa Norte region of Brasília, between the blocks 112 and 113. The red line is the seismic profile. The SPT data (color circles) were separated by groups (different colors) related to their distance from the seismic line, depth of the impenetrable layer (from SPT results) and soil description.

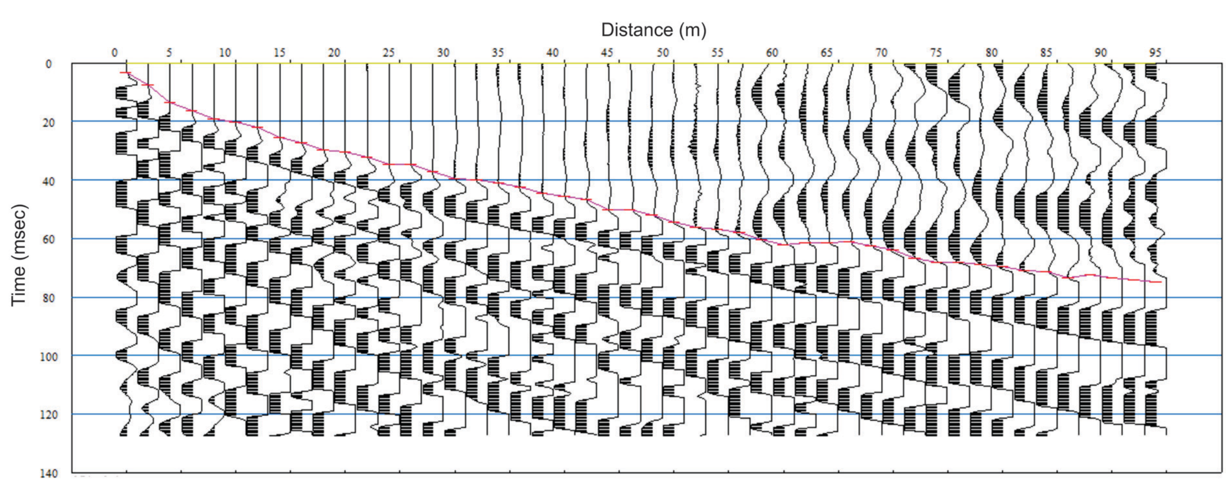

Figure 2 – Example of seismograms acquired in this study. In this case, the source position was –2 meters related to the first geophone. The purple line represents the marking of first breaks.

Table 1 – Summary of information obtained with the methods of seismicrefraction and SPT.

SPT number	Position on seismic line (m)	Distance from seismic line (m)	Thickness – seismic (m)	Thickness – SPT (m)
935	17	105	3,5	4
938	47	106	4	6
940	66	112	5	6
952	155	106	7,5	9
953	179	106	7,5	8
986	541	267	11	22
985	543	253	11	23
993	557	229	10	21

the arrival of the wave occurs later) the signal/noise ratio is lower. This is probably due to the decrease of the seismic signal energy far from the source, which makes the record more susceptible to the effects of pedestrian circulation nearby the geophones, cars passing on roads nearby and the influence of trees when the weather started to get strong winds at the study site. However, it was possible to identify the first arrivals at all geophones.

The comparison between the results obtained from seismic refraction and SPT are shown in Figure 3. A summary of information obtained from these results is presented in Table 1.

Six velocity models (one for each sub-section) were generated for the study area (Fig. 3B), where two layers were observed with different velocities, according to the time-distance curves generated from the picking of the first arrivals (Fig. 3C). The velocities obtained for the first layer varies from 402 to 540 m/s, and the velocity for the second layer varies from 1519 to 1791 m/s.

SPT data and soil description were compared to parts of the seismic line (Fig. 3A). The SPT graph is represented in yellow lines, where the abscissa represents the number of blows (from 0 to 60 blows) and the ordinate axis represents the depth. The soil description is represented by the square blocks. Their composition varies from embankment, originated from construction works, clay and siltstone.

DISCUSSION

The seismic line was separated in three different regions: North, Center and South regions, according to soil description data, N-SPT values, seismic velocities data and the depth of the seismic refraction interface. The North, Center and South regions are related to SPT groups 1, 2 and 3, respectively (Fig. 1). Each region was correlated with a different seismic section; the North region includes only section 1. The Center region of the line includes sections 2, 3, 4 and 5, and the South region is related with section 6. This division was mostly based on the depth of the seismic interface and the velocity of the second layer. The velocity of the first layer was not considered as a factor for this division because can be highly affected by engineering works, as adding embankment or removing original soil.

In all of the three regions, we assume that the depth of the impenetrable SPT level is related to the interface between the two layers in the seismic model, since both methods rely on soil strength (Basarir & Karpuz, 2004; Basarir et al., 2008). The comparison between the seismic section and SPT data from group 3 is more susceptible to mistakes because of the distance between them (260 m).

In the North region, the soil has a first layer of about 2,5 to 3 m of embankment, followed by a layer of clays until the depth of about 10 m. There is no presence of siltstone. The SPT impenetrable level depth is shallow, about 4 to 6 m, suggesting that the clay is responsible for the impenetrable level. Section 1 of seismic, showed that the velocity for the first layer (433 m/s) is related to embankment, and the velocity of the second layer (1519 m/s) is related to clay. The second layer has the lowest velocity in all of the six seismic sections. The depth of the seismic interface showed good correlation to the depth of the impenetrable level of SPT data.

The soil description of the Center region showed no layer of embankment, the first layer is associated with clays, with a thickness of 6 m, followed by a layer of siltstone until a depth of 13 m. The SPT impenetrable level was found at a depth of 8 m, within the layer of siltstone. In this case, it was not the change of material from clay to siltstone that resulted in the impenetrable layer, it was the strength of the siltstone layer that increased in depth. The velocity of the first layer (402 to 524 m/s, in sections 1 to 5) is related to clay and siltstone, the velocity of the second layer (1620 m/s to 1791 m/s) is related to siltstone. The seismic interface was found at depth of about 7,5 m, similar to the depth found with the SPT method.

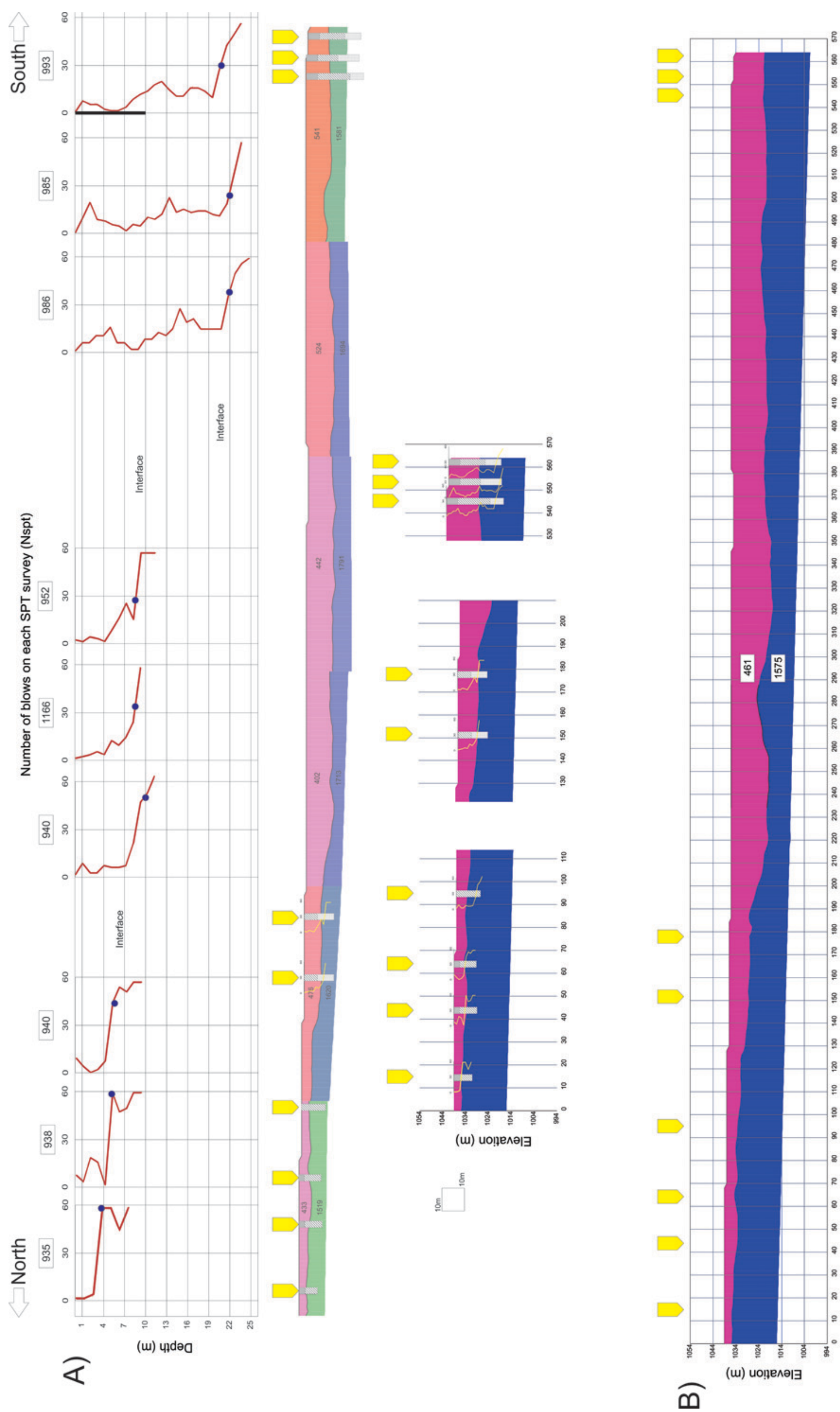

Figure 3 – Comparison between results of: A) SPT, soil description and seismic refraction. B) The six seismic sections together, with the velocity of each layer from each section in m/sec. C) Travel-Time curves, obtained through the marking of the first arrivals on seismograms.

The South portion of the line is where the correlations between seismic and SPT does not match, because of the distance from the seismic line (260 m), and different geotechnical context. The soil description shows a layer of embankment of about 5 m, followed by clay and siltstone. The interface between the clay and siltstone varies from 14 to 19 m deep. The SPT impenetrable level was found at a depth of about 22 m, in the siltstone layer. The first seismic layer (velocity of 540 m/s) is related to the embankment and clay layers, and the second seismic layer (1580 m/s) is associated to siltstone. The seismic interface seems to relate with change in soil strength of the siltstone layer. Although there is great difference between the depths found with the SPT (22 m) and seismic (11 m), both method show increase in the depth from north to south.

The analysis of the SPT data and the seismic results has shown that neither of the methods could be used exclusively to define layers in terms of their material composition. On most of the SPT data, the impenetrable layer was not related to direct change in composition, but change in soil strength, defined by factors such as density, compaction and porosity.

CONCLUSIONS

For the study area there was a good correlation between the results of seismic refraction and SPT, which showed an increase in thickness of the shallow layer toward the South, although STP from group 3 could not be directly correlated.

The seismic model showed that the depth of the interface between the two layers is about 4 m in the northern part of the line, increasing to 11 m in the south. The depth of the seismic model is compatible with the SPT data in the center and north portion of the line.

For the study area, the correlation between seismic and SPT showed that for seismic velocities greater than 1500 m/s, the SPT blow count is higher than 50, outlining the impenetrable strata.

As expected, the variations in the velocity of seismic waves should be related to variations in material resistance as observed with the data from SPT, since seismic refraction is an efficient geophysical method to determine soil compactness (Sturaro et al., 2012). Furthermore, seismic results and SPT do not relate exclusively on lithology, but other factors such as density, compaction and porosity.

These results provide arguments to increase the joint employment of geophysical and geotechnical methods, following the examples of Fonseca et al. (2006) and Sudha et al. (2009), specially for bigger engineering projects.

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