Study of seasonal variation of the P-wave velocity and porosity estimation using seismic refraction

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Abstract

This work shows results of seismic refraction in an area within the University of Brasilia, Campus Darcy Ribeiro, during dry and rainy seasons in the years 2010 and 2011. The main objective was to show the variability of seismic velocity with respect to seasonality, related with the water content in the ground. The results showed seasonal changes in the velocity of the first and second layer of the studied profile. With these results it was possible to estimate the porosity of the first layer.

Resumo

Este trabalho apresenta resultados de sísmica de refração em uma área dentro do Campus Darcy Ribeiro, na Universidade de Brasilia, durante as estações de chuva e de seca nos anos de 2010 e 2011. O principal objetivo deste trabalho foi mostrar a variabilidade da velocidade sísmica com respeito à sazonalidade, relacionada com o conteúdo de água no solo. Os resultados mostraram mudanças nas velocidades da primeira e da segunda camada do perfíl estudado. Com estes resultados foi possível estimar a porosidade da primeira camada.

Introduction

The seismic velocity is one of the most important physical properties used in the geological characterization of a medium. Within certain limits, the values of velocity of seismic waves can be related to specific types of rock, allowing discriminating layers with different elastic characteristics. Some works used geophysical methods to evaluate the seasonal variations in the physical properties of the medium related with the moisture content of the soil (e.g Doser et al., 1998, 2003).

According to the equations of seismic velocities, they have an inverse dependence with the density. However, what usually is observed in the results of seismic studies is an increase in seismic velocity with increasing density. This can be explained by the fact that the elastic parameters K (incompressibility) and μ (rigidity modulus) are also dependents of the density and vary more rapidly than this. Thus, density is a key factor to regulate the velocity of the seismic waves in the medium.

The main factors that can cause variations in density are porosity and fluid contents in the pores (Han and Batzle, 2004). The P wave velocity varies drastically from one dry medium to a saturated, because the P-wave energy can propagate through the matrix material and also through the interstitial fluid.

Generally, igneous and metamorphic rocks have low porosity and the velocities of waves depend mainly on the elastic properties of rock forming minerals. Sedimentary rocks and unconsolidated sediments have pore spaces between grains which may contain fluid or solid materials such as clays. In these cases, the velocity is more dependent on the porosity and pore filling material.

We carried out three surveys of seismic refraction, during dry and rainy periods of the years 2010 and 2011, on the campus of the University of Brasilia (Figure 01) next to the Science Central Institute (ICC in portuguese). Our objective was to observe the variation of the P-wave velocity due to water saturation of the medium. The study area is located in the Paranoá Group. Details of the geology of the study area can be founded in the works of Alves (2009), Blanco (1995) and Martins (2000).

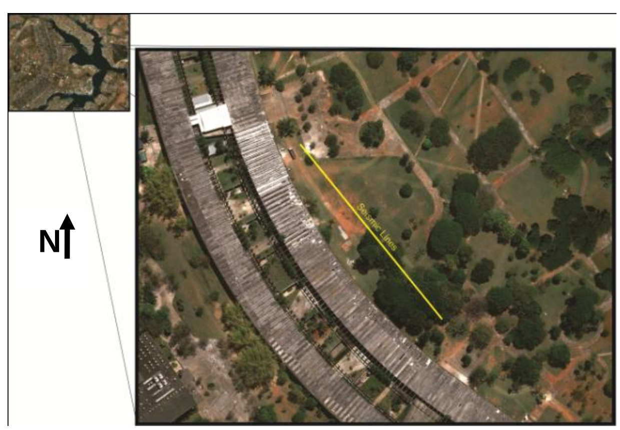

Figure 01 – Study area. The position of the seismic lines is showed in yellow. (Source: Google Earth, 2010).

Seismic Refraction

The seismic refraction method is one of geophysical methods more used to obtain the values of the velocities of the medium. This method is based on the propagation of mechanical waves generated by artificial sources, such as hammer, seismic rifle, among others. These waves are detected by receivers (geophones) laid on the ground, and its propagation time is used to calculate the velocity and thickness of the material through which they pass.

Here, the refraction data acquisition occurred during the practical lessons of discipline Field Geophysics of course of Geophysics, University of Brasilia. Three surveys were conducted at different times of the years 2010 and 2011 (Figure 02). The first survey took place on 07.10.2010 during the drought period. The second occurred on 30/10/2010, approximately one month after the start of the rainy season. The third occurred on 02/04/2011 several months after the onset of the rainy season.

As the surveys were conducted during the practical lessons, we not used the same acquisition geometry. For the first profile (10/07/2010), were used 24 geophones with dominant frequency of 14 Hz, spaced 5 meters between them, and the shot points were at positions -50, -2.5, 57.5, 117.5 and 160 meters from thee first geophone. For the second profile (30/10/2010), were used 24 geophones with dominant frequency of 40 Hz, spaced of 4 meters between them, and the shot points were at positions -30, -4, 46, 96 and 122 meters from the first geophone. For the third profile (02/04/2011), were used 48 geophones with dominant frequency of 14 Hz, spaced 2 meters between them, and the shot points were at positions -20, -2, 47, 96 and 116 meters from the first geophone.

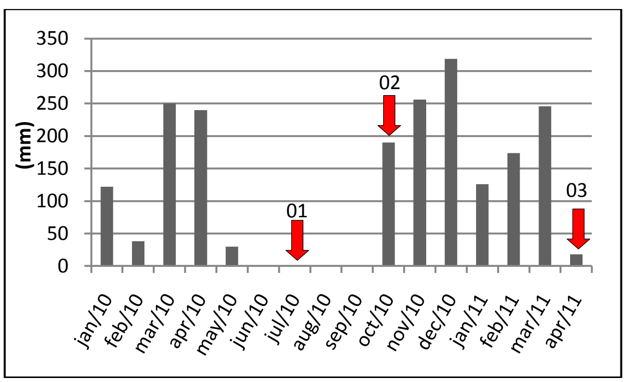

Figure 02 – Monthly accumulated precipitation in millimeter. Red arrows indicate de data of seismic surveys. (Source: Inmet, 2011).

Porosity Estimation

In order to derive porosity from velocity, one needs to know the velocity in fluid, in the solid part of the medium and in the saturated medium. Many researchers have worked on the relation between seismic wave velocity and porosity, such as the relation developed by Wyllie et al. (1956, 1958):

$$\frac{1}{V_g} = \frac{\phi}{V_f} + \frac{(\phi - 1)}{V_m} \tag{1}$$

where V_g is the velocity of the compressional wave in the saturated medium, V_f is the velocity in the fluid, V_m is the velocity in the solid part of the medium and ϕ is the porosity.

We used the Equation 01 to estimate the porosity of the medium. As the velocity of the solid part (V_m), we used the velocity obtained in the dry period and as the velocity of the saturated medium (V_g), we used the velocity obtained in the rainy period. The value used as velocity of the fluid (water) was 1450 m/sec.

Results

Seismic Refraction

The results of seismic refraction are shown in Figure 03. The colors indicate different layers with different velocities. The observed velocities can be considered as the average velocity for each layer. There were three layers in all the surveys. The interfaces are observed approximately plane parallel, and the velocity of the medium increases with depth.

Figure 03a is the result of a survey conducted on 10/07/2010. The first layer has a velocity of 376 m/sec and an average thickness of 8 meters. The second layer has a velocity of 1805 m/sec and an average thickness of 13 meters. The base of this layer was found at a depth of about 22 meters. The third layer has a velocity of 3071 m/sec.

Figure 03b is the result of a survey conducted on 30/10/2010. The first layer has a velocity of 516 m/sec and an average thickness of 11 meters. The second layer has a velocity of 1810 m/sec and an average thickness of 10 meters. The base of this layer was found at a depth of about 21 meters. The third layer has a velocity of 3006 m/sec.

Figure 03c is the result of a survey conducted on 04/02/2011. The first layer has a velocity of 481 m/sec and an average thickness of 10 meters. The second layer has a velocity of 1631 m/sec and an average thickness of 11 meters. The base of this layer was found at a depth of about 21 meters. The third layer has a velocity of 3061 m/sec.

Porosity Estimation

The results of the Porosity estimation are showed in the Table 01. The velocity of the fluid used on the calculus was 1450 m/sec.

Layers	Vg (m/s)	Vm (m/s)	ϕ (%)
01	516	376	37
02	1631	1805	44

Table 01 – Results of the porosity estimation based on seismic velocities.

Discussion

With these results, we observed a change in velocity of seismic waves with respect to the period of acquisition in all layers. We interpret that the cause of these variations is the saturation degree of the medium has changed in the dry and rainy periods.

As seen in Figure 02, the first survey (10/07/2010) occurred in the midst of drought period. Probably the most superficial layers was very low saturation degree (perhaps zero), which justifies a lower velocity for the first layer in comparison with those observed in other surveys. The velocities observed in this survey could be taken as reference, i.e. as more representative to the characteristics of the material which forms the layers.

The second survey took place about a month after the onset of rains (Figure 02), which explains variations in the velocity only in the first layer, because the water of the rain may haven't had time to percolate throughout the second layer, affecting only its top.

The third survey took place about six months after the onset of rains (Figure 02), giving more time for the second layer has been saturated, justifying the change in the velocity of this layer.

The first layer may be formed by a mixture of soil and landfill deposited during the construction of the building of the ICC. Due to this construction, as well as pedestrian traffic, and possibly vehicle, this layer must have a high compaction degree, and consequently a lower porosity when compared with the original soils of the region.

The second layer, because of its velocity, should be related to the saprolite. According to the results of the first survey, the velocity of this layer, when not saturated, is higher than the velocity of water (1450 m/sec). The saturation effect, as the results of the third survey, made its velocity decreases, suggesting a significant porosity for this layer.

The third layer can be interpreted as the bedrock. The variation of its velocity is proportionally very small, and must be related to the error of the method.

The values found for the porosity of the first and second layer are consistent. The original soils of the region have porosities between 50% and 70% (Carvalho et al., 2004). As the first layer no longer has the original soil, and must be mixed with landfill, and, probably as this layer was compacted during construction of the ICC, it is likely that its porosity is smaller than the typical values of soils in the region. The third layer was interpreted as being the bedrock and therefore its porosity must be very low.

Unfortunately, we could not obtain measurements of porosity using conventional techniques to validate our results before submission of this work.

Conclusions

The seismic refraction method was effective in studies of seasonal variation of the velocity structure of the medium. We observed changes in elastic characteristics of the layers due to their saturation with rainwater from velocity measurements using the method of seismic refraction.

The estimated porosity is consistent with the conditions of study area, but may contain large errors due uncertainties in the velocity values, and also, due the velocity-porosity conversion expression not be the best for this case. There is the need for measures of porosity using conventional techniques to validate the results.

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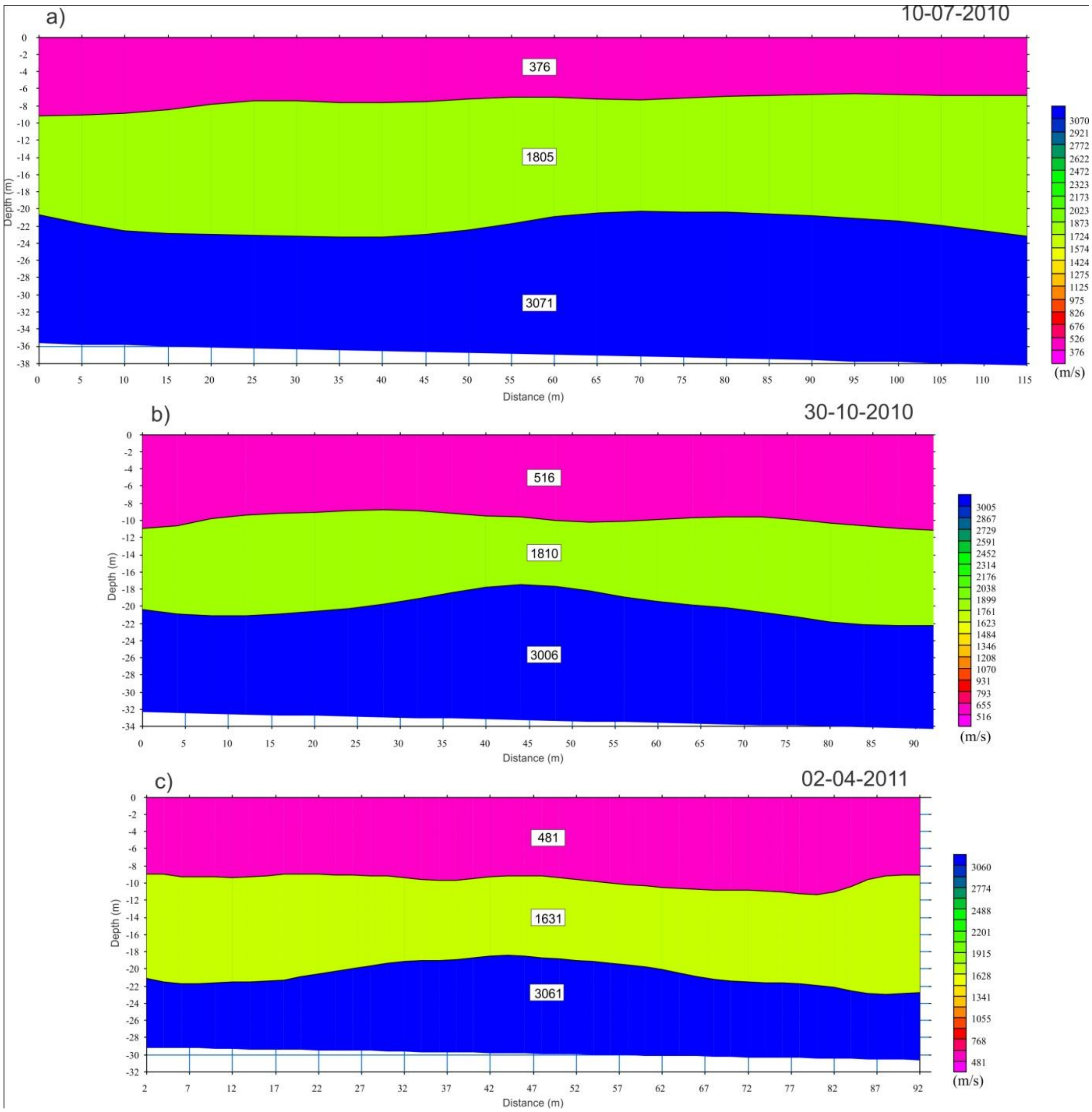

Figura 03 – Velocity models obtained using the method of seismic refraction. (a) Model for the data acquired on 10/07/2010. (b) Model for the data acquired on 30/10/2010. (c) Model for the data acquired on 02/04/2011.