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GPR APPLIED TO RIGID PAVEMENT FROM SANTOS DUMONT AIRPORT, RJ

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ABSTRACT. This paper presents the results of a research performed by using Ground Penetration Radar (GPR) to evaluate the structure of the rigid pavement of Santos Dumont Airport in Rio de Janeiro, Brazil. The GPR data profiles were acquired with 250 and 700 MHz shielded antennas. The geophysical investigation was performed along of 6 profiles, totaling 1432 meters of GPR sections. For calibration of the speed of propagation of electromagnetic wave were drilled three boreholes until the depth of 1.8 m. The results of GPR allowed the precise delineation of reflectors related to geotechnical interfaces (pavement thickness – concrete slab and macadam) and geological (sand/embankment soil), showing the efficiency of this method in this case study.

Keywords: GPR, concrete, rigid pavement, Santos Dumont Airport.

RESUMO. Este trabalho apresenta o resultado de uma pesquisa desenvolvida usando *Ground Penetrating Radar* (GPR) para avaliar a estrutura do pavimento rígido do pátio de manobras de aeronaves do Aeroporto Santos Dumont, no Rio de Janeiro, Brasil. Para isso foram usadas antenas blindadas com frequências de 250 MHz e de 700 MHz. Os dados de GPR foram adquiridos no modo *common offset*, ao longo de 6 perfis que totalizam 1432 metros de investigação. Para a calibração da velocidade de propagação da onda eletromagnética foram executados três furos de sondagem até a profundidade de 1,8 m. Os resultados de GPR possibilitaram o delineamento preciso de refletores relacionados a interfaces geotécnicas (espessura do pavimento – revestimento de concreto e do macadame) e geológicas (areia/aterro com entulho), mostrando a eficiência da aplicação deste método neste estudo de caso.

Palavras-chave: GPR, concreto, pavimento rígido, Aeroporto Santos Dumont.

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INTRODUCTION

The continued Brazilian economic development requires investment in terrestrial, nautical, and aviation infrastructure to maintain its balance. Regarding aviation, Empresa Brasileira de Infraestrutura Aeroportuária (INFRAERO) exposes a critical overview for Brazilian airports and emphasizes the necessity and urgency of upkeep, reform and expansion of its physical infrastructure. The landing runway, maneuvering areas and parking lots of aircrafts are essential for the operation and function of an airport (Oliveira & Nobre Jr., 2008).

In Brazil, the main problem with aerial transportation is insufficient landings, runways, and maneuvering areas for aircraft. The high impact loads resulting from takeoff and landing of the aircraft are supported by an appropriate structure of the pavement, which transmits a compatible stress resistance to subgrade. Although there are significant differences in the cross sections of road pavement and airport runways (Yoder & Witczak, 1975), the pavement can be generally defined as a multilayer structure of finite thickness, built on the end surface of earthworks designed, technically and economically, to resist stress arising from vehicular traffic and weather, and to provide better transit conditions to users with comfort, economy, and safety (Bernucci et al., 2006).

To fulfill its functions of safety, comfort, and to also resist horizontal shear stress, pavement must have its superficial layer consisting of cohesive material (TAC, 1997). Pavement is classified basically into flexible and rigid.

The flexible pavement are those wherein the surface is comprised of a mixture consisting of essential aggregates and asphalt binders capable of resisting the traffic directly to the actions and transmit them at a reduced force to the lower layers, which are usually made of granular bases and sub-bases. Since the rigid pavement is constituted by Portland's cement concrete slabs which has a high rigidity in relation to lower layers and therefore absorbs virtually all shocks from the applied load (DNIT, 2006). Thus, in rigid pavement, the concrete slab is at the same time the base and cover layers, which typically sits on a layer of granular sub-base or roller compacted concrete.

The aircraft's landing and takeoff pavement are commonly built with flexible pavement because of the best tire to pavement grip and greater rolling comfort. The shunting yard and parking of aircraft is constructed with rigid pavement due to the rheological behavior of asphalt layers, which may have increased permanent deformation when subjected to long static charges.

The knowledge of pavement structure and the deformation of the surface layer of aircraft pavement is very important for the maintenance and rehabilitation against premature wear, such as fatigue of tarmac materials due to the excess load, bad design, or inadequate construction (Shahin, 1994). Only a precise and efficient evaluation allows the creation of an expressive database, to provide management with a proper support of the tarmac.

The knowledge of the prior pavement structure requires a good report at the end of construction ("as built"), as well as a permanent and detailed record of all interventions done on the pavement during its service life. Unfortunately this record is not available in most cases and it is necessary to resort to direct or indirect methods of sampling to determine the composition and thickness of the pavement layers.

On direct sampling methods, you must dig a trench or extract a sample of the pavement (core) to measure the thickness of layers. Although this method provides an accurate measurement, it is destructive, time consuming, and does not provide a continuous representation of the thickness of layers, since it is a specific inquiry. With indirect methods of sampling the physical parameters can be obtained on the surface in places where there are restrictions for excavation and drilling. The main indirect method of investigation is geophysics which uses the physical properties to study the environment. According to Telford et al. (1990), there are various geophysical methods that allow the detection of subsurface structures (gravimetry, magnetometry, radiometry, electromagnetometry, seismic and resistivity), however, for the study of pavement, the ground penetrating radar (GPR) was highlighted in recent decades (Hugenschmidt, 2002; Lahouar & Al-Qadi, 2008).

In Brazil, studies realized by Lima-Filho et al. (2004) and Gomes (2008) used GPR to identify causes of deformation and to evaluate the pavement structure on landing, takeoff, runway and maneuvering areas of aircraft at airports. Gomes (2008) noted that non-destructive methods do not completely eliminate the use of destructive methods, which apply in a complementary way and in smaller numbers and are markedly more expensive than non-destructive. In his research Gomes (2008) concluded that joint and systemically in both devices implementing the Falling Weight Deflectometer (FWD) and GPR is a valuable tool for managing pavement, to get to know its structure.

Work performed by Barrile & Pucinotti (2005), Hugenschmidt & Mastrangelo (2006), Loizos & Plati (2007), Lahouar & Al-Qadi (2008) and Chang et al. (2009), show that GPR is a method which enables us to understand many aspects of the structural elements investigated in the evaluation of hard surfaces, such as thickness, homogeneity, defects, presence and number of longitudinal and transverse steelbars.

This work aims to show the efficiency of the use of GPR, associated with conventional methods, the investigation of the structure of rigid pavement Patio Maneuvering Aircraft, the Santos Dumont Airport in Rio de Janeiro/RJ.

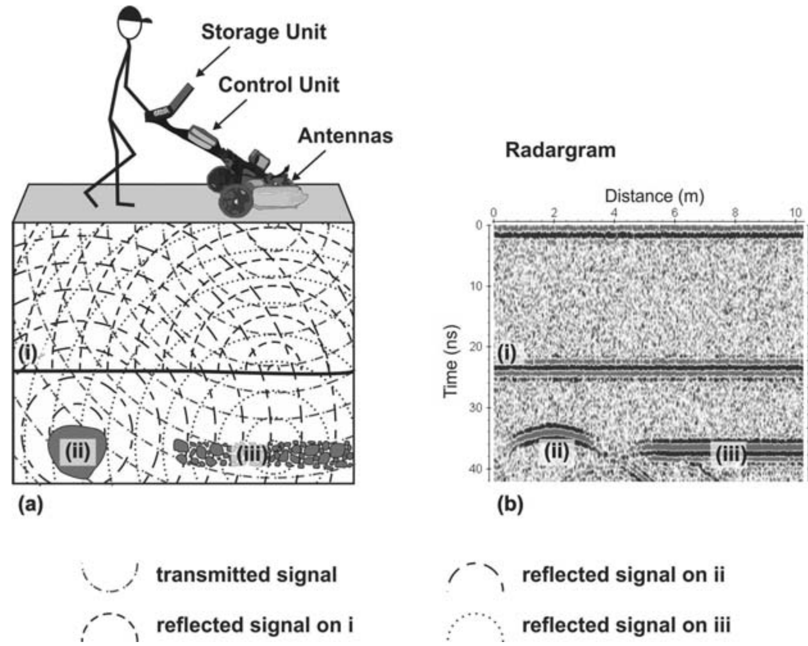

Figure 1 – Schematic diagram of the GPR data acquisition process (a) and radargram (b).

METHODOLOGY

The ground penetrating radar (GPR) is the general term applied to the geophysical method that uses radio waves, typically in the frequency range 10-2600 MHz to map geological structure and objects buried in the soil (Annan, 2001).

In this method the electromagnetic waves are radiated into the subsurface through a transmitting antenna. The contrast between the electrical properties of the subsurface cause the signal to be reflected back to the surface and continue to spread. This reflected signal is received by a receiving antenna and recorded and stored in a control unit. The continuous collection of this data along a surface enables the lateral stacking traits comprised of one radargram, representing a high resolution image of the subsurface (Fig. 1).

The investigated area was the aircraft maneuvering runway of Santos Dumont Airport, located in the Plaza Senador Salgado Filho, downtown of Rio de Janeiro/RJ (Fig. 2).

For the GPR data acquisition used the equipment Detector Duo (Ingegneria Dei Sistemi – IDS), which consists of three modules interconnected by cables. The first module consists of a set of shielded antennas (central frequency of 250 MHz and 700 MHz); the second module by a control unit; and the third module comprises a data storage unit (Fig. 3).

The data acquisition parameters were: spacing between the traces of 2 cm; time window of 64 ns; 256 samples per trace and temporal sampling interval of 0.25 ns.

Data were acquired over 6 lines named L1, L2, L3, L4, L5 and L6 (Fig. 4). Lines 2 and 6 were segmented into smaller lines of approximately 100 meters, depending on the activities in the aircraft maneuver runway during data acquisition, thus being named in L2A, L2B, L2C, L2D, L2E and L2F (L2) and as L6A, L6B, L6C, L6D, L6E and L6F (L6).

RESULTS

The electromagnetic velocity of each geotechnical interface was obtained with the aid of information extracted from 4 boreholes. From the survey it was possible to identify materials and the following layers: coating/concrete based on Portland cement board; sub-base in macadam (stone hand and stone powder); natural subgrade soil (fine to medium sand or silty sand). It also determined thicknesses of these layers in the survey region, thus allowing to correlate reflectors with the geotechnical and/or geological interfaces, given that, knowing the actual depth of these reflectors as well as related, we obtain the interval velocity of propagation of the wave the electromagnetic environment (V_i), using the equation of the transit time of a wave where the incidence of it is perpendicular to the reflector (zero offset section) according to (Eq. 1).

$$V_i = \frac{2z_i}{t_i} \tag{1}$$

where z is the layer thickness, and t is the double transit time of electromagnetic wave in the subsurface.

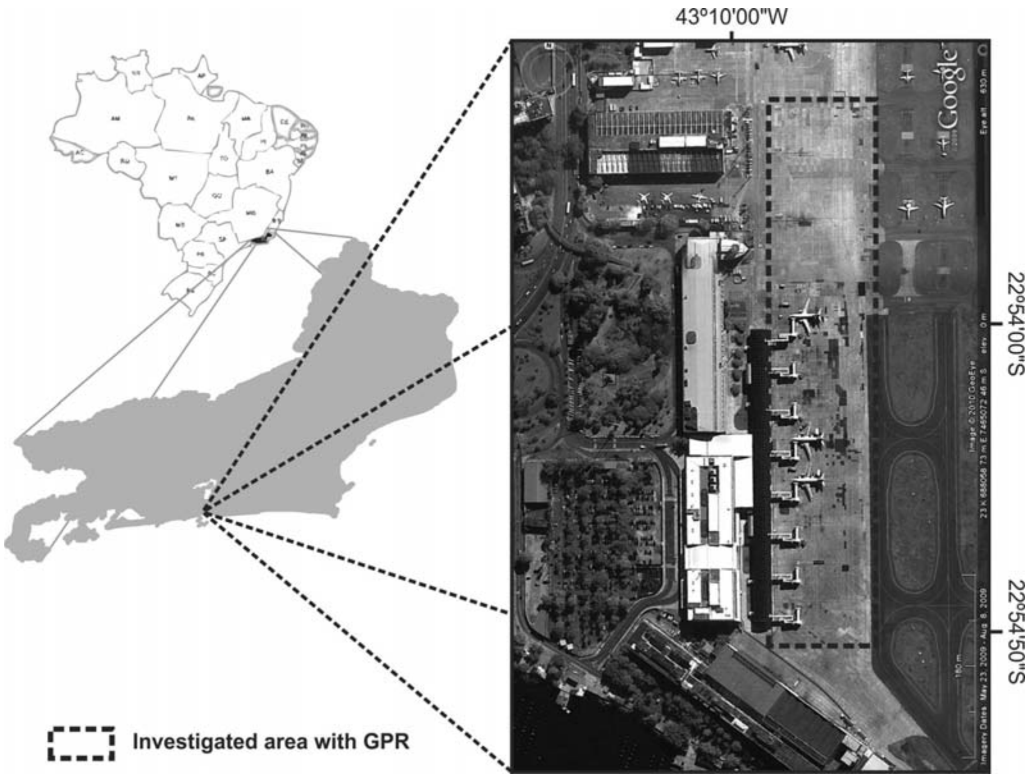

Figure 2 – Location of investigated area with GPR at Santos Dumond Airport, Rio de Janeiro/RJ.

Figure 3 – Photos show the GPR data acquisition in part of the Santos Dumond Airport, Rio de Janeiro/RJ.

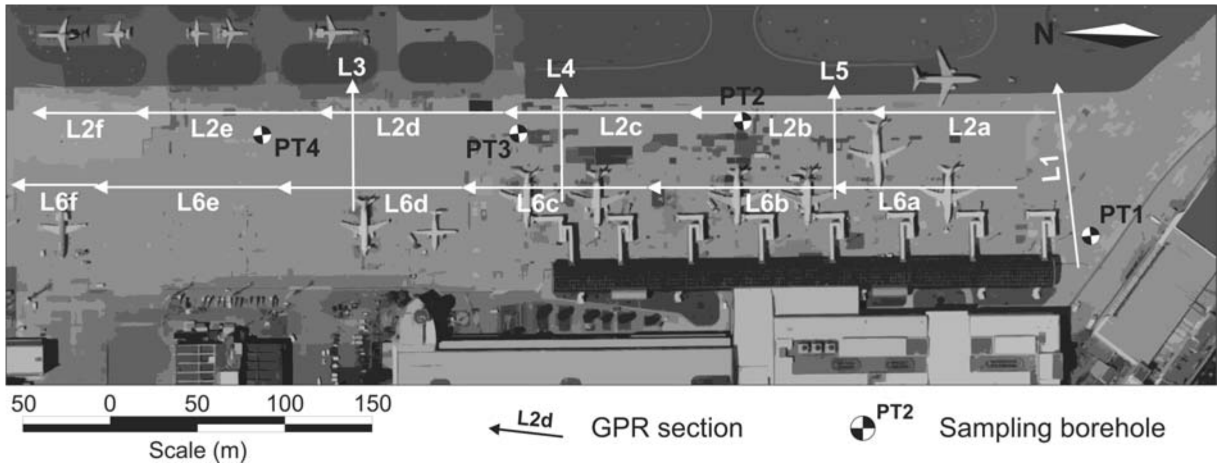

Figure 4 – Sketch with the position of the GPR profiles and boreholes sampling conducted in the Santos Dumond Airport, Rio de Janeiro/RJ.

Table 1 – List of thicknesses, transit time of electromagnetic wave and velocities of geotechnical interfaces found in the boreholes and correlated with the GPR data.

Borehole	Layer					
	Concrete			Sub-base		
	Thickness (m)	Double Time of reflection on layer (ns)	Velocity (m/ns)	Thickness (m)	Double Time of reflection on layer (ns)	Velocity (m/ns)
PT01(1)	0.20	4.82	0.083	0.31	10.50	0.109
PT02(1)	0.23	5.60	0.082	0.57	16.33	0.106
PT03(2)	0.27	6.48	0.083	0.38	14.90	0.090
PT04(2)	0.28	6.91	0.081	0.32	13.80	0.093

(1) Base constituted for macadam. (2) Base constituted for gravel.

The velocities obtained for materials were: 0.082 m/ns for concrete, 0.1075 m/ns for the macadam, and 0.0915 m/ns for the gravel. Depending on the speed difference found for the macadam and the stone powder (0.016 m/s), and the similarity between the patterns of reflections of these layers, a propagation speed of electromagnetic wave of 0.1 m/s was used for both layers. As for the concrete a velocity conversion time to depth of 0.082 m/ns. Table 1 summarizes the values of layer thickness, as well as the times and the propagation velocities correlated to data in different boreholes.

DISCUSSION

By correlating boreholes, with reflectors identified on GPR radargrams (Fig. 5) it was possible to identify the main geological interfaces, geotechnical structures and various interferences present in the area of lines of data acquisition. Throughout the mapped area distinct patterns of reflection were observed in GPR sections which can be related to different types of materials.

Continuous reflectors represent the geological and/or geotechnical interfaces on site ground (concrete slab, macadam and gravel bases and pack the landfill subgrade). These reflectors are commonly straight, which may present as continuous sub-horizontal or incline correlated with textural and compositional variations of the materials (Fig. 6).

The point reflectors, characterized by hyperbolic reflections (Fig. 7), may be related mostly to interference buried in the subsurface. Such features can be found throughout the extent of the area of clear and striking shape and at different depths from representing various types of pipes (gallery rainwater) to blocks of rocks.

After the correlation of continuous reflectors with geotechnical interfaces was realized an interpretation using REFLEXW software (Sandmeier, 2011), with the tools *picking* and *layer show* was held. The *picking* allows you to select each reflector related to geotechnical and/or geological interfaces, allowing the layers to sort by speed variation. On the other hand the *layer show* tool

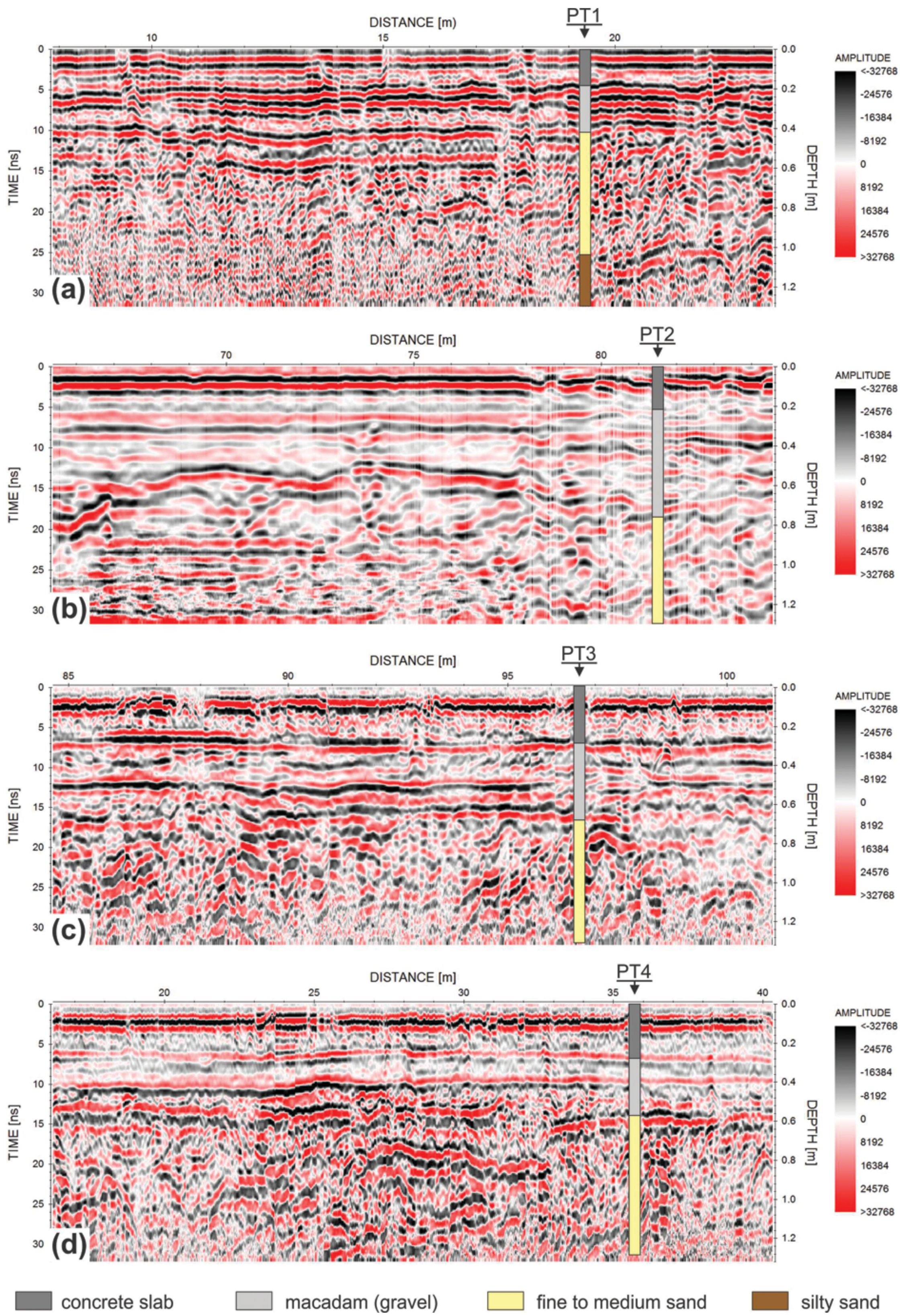

Figure 5 – GPR sections with geological and/or geotechnical information superimposed. (a) L1 with PT1. (b) L2B with PT2. (c) L2C with PT3. (d) L2E with PT4.

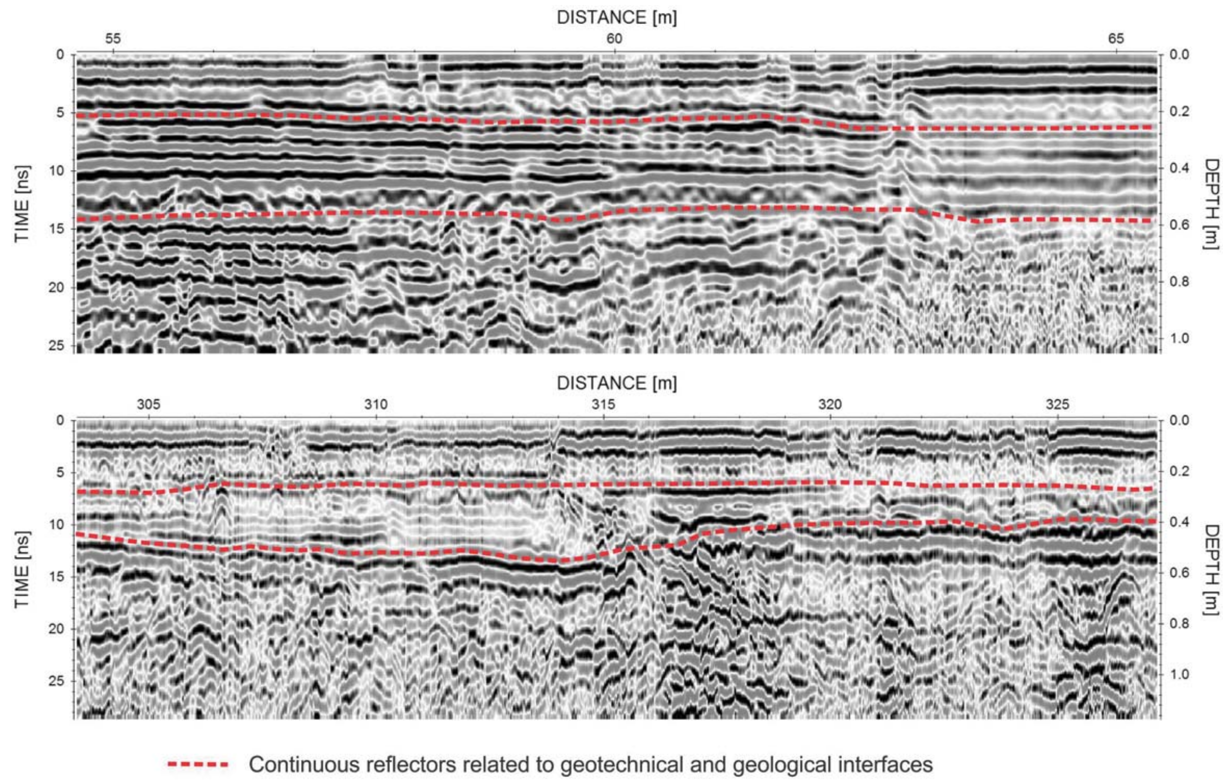

Figure 6 – Examples of GPR sections with reflection patterns characteristic of the geological and/or geotechnical interfaces present in the area.

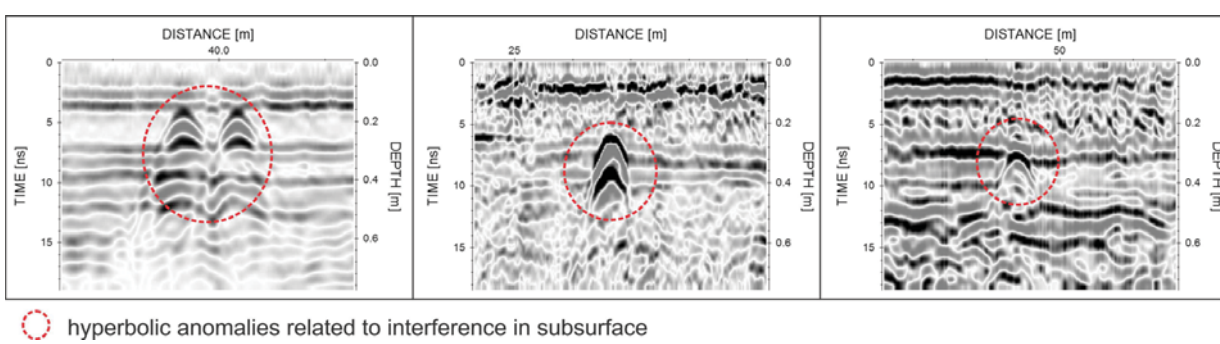

Figure 7 – Examples of GPR sections with hyperbolic reflection patterns (diffractions) related to interferences (pipes and/or stones) present in the pavement.

uses data from the *picking* to generate an interpretive model with the adjusted depths (Fig. 8).

As the coating showed a constant speed horizontally, its thickness was calculated at all traces of the profiles. These data enabled the creation of a histogram of the frequency distribution of coating thickness at each point of the pavement investigated (Fig. 9). The analysis shows that the histogram of the concrete coating ranges from 19 cm to 32 cm, with a mean of 25$\pm$1.8 cm. The values obtained confirm that the plates of rigid pavement of the aircraft manuever runway of Santos Dumont Airport, are within international standards (12.5 to 30 cm) for general aviation airports (Kohn & Tayabji, 2003).

CONCLUSIONS

The geophysical investigations with GPR enabled the lineation of continuous reflectors associated with geotechnical interfaces (thickness of concrete slab and macadam/gravel base) and geological (sand and embankment).

The results confirmed the efficiency of the antennas of 250 MHz and 700 MHz to measure the thickness of layers of concrete pavement at aircraft runway of Santos Dumont Airport.

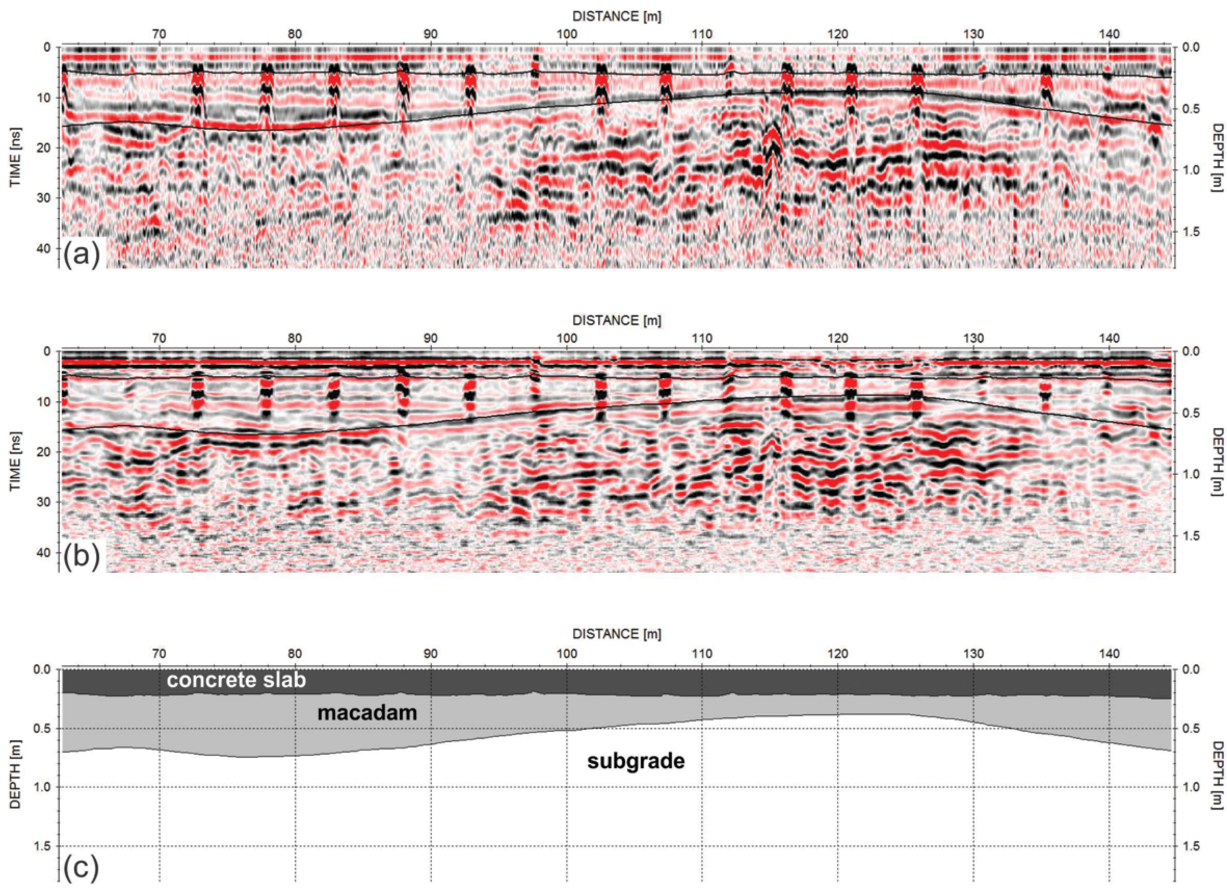

Figure 8 – GPR sections of L2E, obtained with antennas of (a) 250 MHz and (b) 700 MHz, with geotechnical interfaces model superimposed. (c) Geological and geotechnical model obtained after the interpretation of the GPR sections.

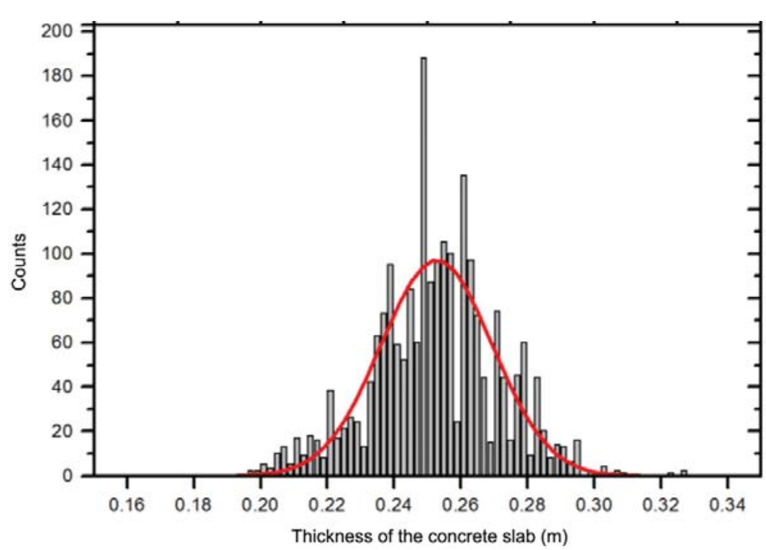

Figure 9 – Histogram of frequency distribution of concrete pavement thickness obtained with the GPR data from the Santos Dumont Airport. It is evident a Gaussian distribution with a mean at 0.25 m.

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