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TRIDIMENSIONAL GPR MAPPING IN THE UPSTREAM FACE OF AN RCC DAM

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Abstract. *Mapping with geophysical techniques such as the Ground Penetrating Radar (GPR) is based on the propagation of electromagnetic waves and has a wide range of applications in civil engineering. This work presents a non-destructive investigation with GPR in the conventional concrete face of a roller compacted concrete (RCC) dam. The objective is the identification of subsurface anomalies, such as niches of higher porosity in the conventional concrete, whose thickness is not greater than 50 cm. The acquisition of radargrams was carried out with a 2 GHz antenna with dual polarization, which allowed assembling a three-dimensional subsurface image from a single direction reading path. The images were treated with a specific package of filters for concrete surveys. After this post-processing, the group of images was integrated to form a block diagram. The interpretation of the whole block was performed with a controlled thickness slicing procedure for identification of anomalies within sound concrete. A general view of the investigated area is presented with the indication of anomalous regions which may require a localized repair.*

1 INTRODUCTION

The integrity, load capacity and service life of concrete dams is directly correlated to the quality of constituent materials and construction methods. The common practice of investigation of concrete in civil structures uses invasive methods to extract samples for laboratory tests. Besides being destructive, these methods cannot consistently reveal abnormalities within the analyzed structure.

Civil engineering has recently started using non destructive geophysical techniques for the inspection of hydraulic structures. However, investigation of anomalies such as niches of higher porosity, cracks and damaged areas within concrete is not trivial. With geophysical surveys one can determine concrete conditions, detecting anomalous areas and mitigate the damage.

The Ground Penetrating Radar (GPR) is a geophysical tool whose principle is based on the propagation of electromagnetic (EM) waves. It is a non destructive method of investigation used for different purposes, such as to detect the thickness of slabs[1], the integrity of masonry structures[2], the integrity of reinforcement in bridge decks[3], buried

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pipes[4], archaeological surveys[5] and others. In particular, it has been used to detect embedded objects and voids in concrete[6] with high resolution.

Although the use of GPR is widespread in geological and geotechnical areas, this tool is not yet a usual practice in concrete dams or other hydraulic concrete structures. Thus, the present study is also an initial survey, which will form the basis for the definition of EM parameters for a better acquisition in future studies.

This paper presents a tridimensional high resolution GPR mapping of a selected area in the upstream face of the RCC dam of Santa Clara in Paraná state - Brazil. The study aimed to identify the possible presence of anomalies in the subsurface layer of the conventional concrete, whose thickness is less than 50cm. The mapping was carried out with a 2 GHz dual polarization antenna allowing the direct formation of a 3D subsurface image from single direction reading path. The tridimensional images were integrated after post-processing the read sections with a specific package of filters for concrete surveys.

Interpretation of the images was performed after the analysis of each section radargram with centimetric slicing, searching for possible subsurface anomalies within sound concrete.

2 GPR – GROUND PENETRATING RADAR

The Ground Penetrating Radar non destructive technique consists in the continuous emission of electromagnetic waves and receiving reflected signals to obtain subsurface images of the structure.

The equipment used in the present survey is shown in Figure 1. It has an interesting feature such as a dual polarized antenna (see Figure 2), which allows performing the data acquisition in only one direction. The 2 GHz frequency antenna allows a high resolution investigation, but with limited range, up to 50 cm in concrete.

An electronic distance meter EDM was attached to the antenna, which is basically a wheel acting as a trigger for the emission of equidistant electromagnetic pulses, allowing a regular data acquisition.

Figure 1: GPR with dipole 2 GHz antenna.

2.1 Radar wave propagation in concrete

One of the most important points in an investigation with EM radar waves is the choice of frequency. This definition is complex and involves a "choice" between capacity of penetrating the material and signal resolution for identifying characteristic targets[7].

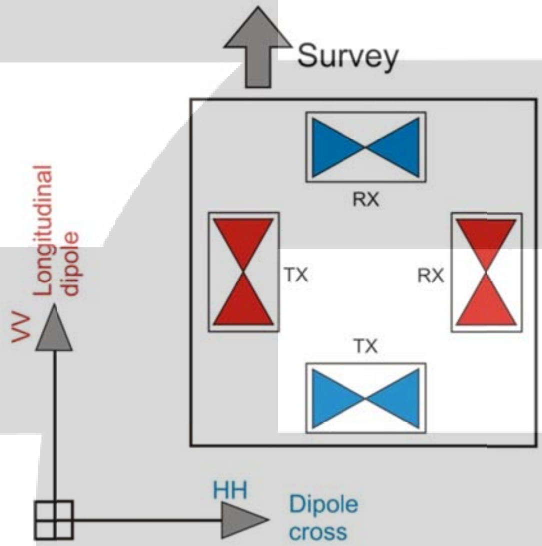

Figure 2: Layout of receivers (RX) and transmitters (TX) in a dipole antenna.

Three major factors determine the choice of frequency for the survey: spatial resolution, cluttering and depth of penetration. These factors are influenced by basic characteristics of the material as conductivity (σ), permittivity (ε) and heterogeneity.

Concrete is a dielectric material and can behave as a conductor or insulator of EM waves. The dielectric (constant) permittivity of concrete varies from about 5 to 12. Normally, concrete is not conductive[7] and the attenuation of EM signals is given by,

$$\alpha = 1640\sigma\varepsilon^{-0,5}(dB/m) \tag{1}$$

The conductivity is directly proportional to frequency (f) of the waves. Therefore, the attenuation is higher as the frequency increases.

Since the radar provides the time of the EM wave propagation between transmitter and receiver, it is important to know the wave speed in order to estimate the depth of a detected target. The equation of the EM wave velocity is given by[7],

$$v = c\ \varepsilon^{-0,5} \tag{2}$$

where c = 0,3 m/ns is the speed of light. For radar frequencies wave velocity can be considered constant. Assuming a permittivity ε = 8, one has v = 0,106 m/ns.

It is argued that for a good vertical resolution (r) for a reflected EM pulse, the wavelength (λ) should be[7]

$$r > \lambda/4 \tag{3}$$

As $\lambda = v / f$, then,

$$f > 0{,}0264 / r \quad (\text{GHz}) \tag{4}$$

Therefore, theoretically, to have a resolution of 2,64 cm in the image, frequency must be greater than 1 GHz. To minimize noise in the radar image, the dominant wavelength of the EM pulse should be at least 4 times larger than the characteristic size (h) of heterogeneity[7],

$$\lambda > 4h \tag{5}$$

Thus,

$$f < 0{,}0264 / h \quad \text{(GHz)} \tag{6}$$

For example, for h = 1,2 cm, the frequency must be less than 2.2 GHz. Finally, an aspect that should not be overlooked is that when the antenna is brought into contact with a surface area for survey the pattern of the EM field changes considerably, and reduces the frequency of the transmitted signal. The equation below was suggested to estimate the effective frequency (f_r) signal in a material such as concrete,

$$f_r = f\,[2\varepsilon/(1+\varepsilon)]^{0,5} \tag{7}$$

3 CONTROLLED FIELD TEST

Before applying the GPR system in Santa Clara dam, a controlled test was performed to evaluate its capacity for detecting anomalies of different sizes embedded in concrete.

The construction plan consisted of a concrete block built in two steps with a minimum size for the GPR readings. The block was 5,20 m long, 1 m wide and had thickness of 0,50 m. Eighteen anomalies were inserted in a symmetric configuration, as shown in Figure 3. The anomalies had different areas and thicknesses and consisted of empty spaces filled with aggregates size 1 and 2, which were covered with a plastic film to ensure its higher porosity. The sizes of the anomalies were printed in the concrete using regular molds, as shown in Figure 4: Placement of the anomalies in the concrete block.

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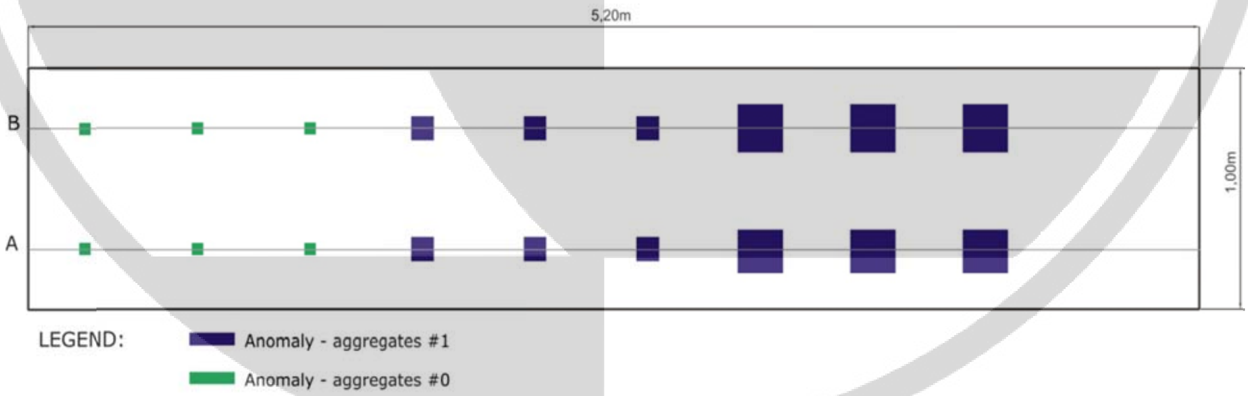

Figure 3: Schematic plan of the concrete block with the anomalies layout.

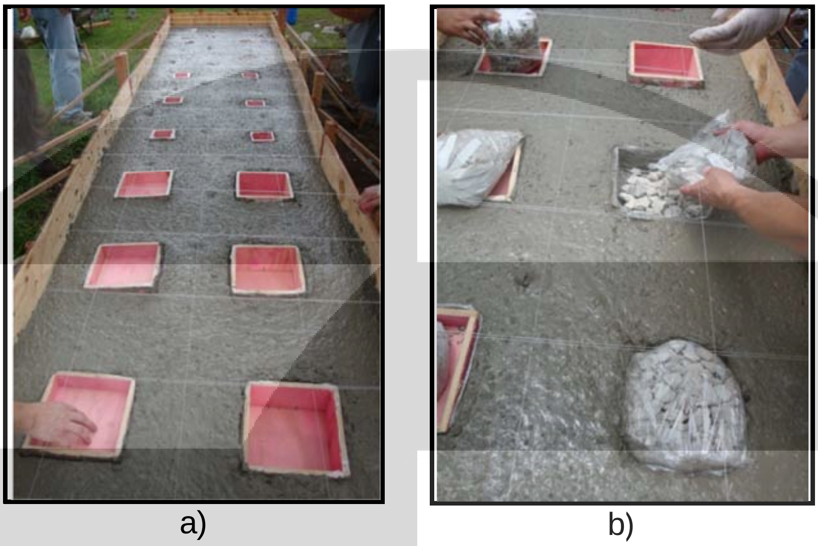

Figure 4: Placement of the anomalies in the concrete block.

After the GPR readings, the radargrams were post-processed with a package of filters: high and low pass bands in the vertical and horizontal directions, background removal and recovery gains.

Two radargrams are shown in Figure 5 and Figure 6 along with a section view of the block at the reading line. The presence of all anomalies could be detected and are indicated by yellow arrows in each figure.

Larger anomalies show very strong hyperbolic signals in the images. Small anomalies are still detectable, but the signals are not so evident, especially from the less thick ones. In general, thicker anomalies show stronger signals.

Although in the initial plan all anomalies were placed 10 cm in depth, during construction some deviations occurred, as indicated by the radargrams.

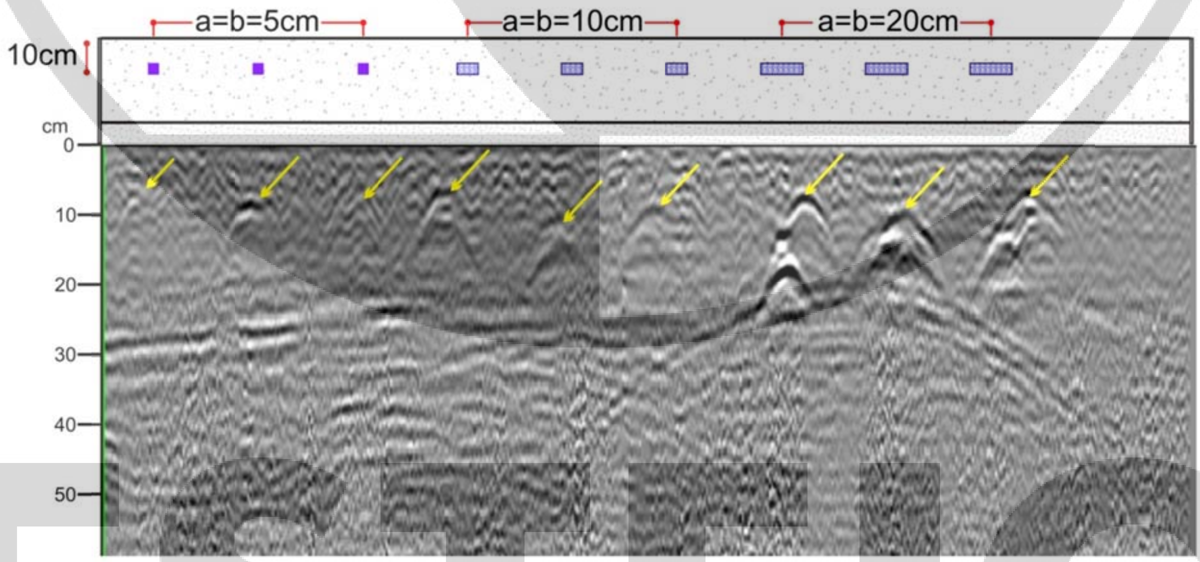

Figure 5: Radargram of section A with 5 cm thick anomalies placed at a depth near to 10 cm.

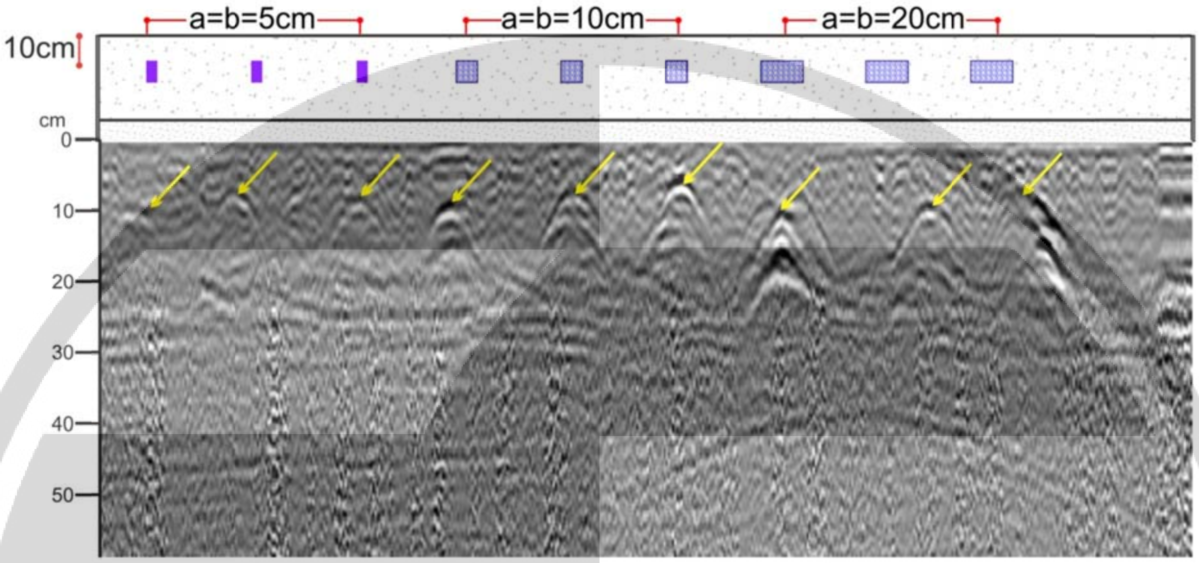

Figure 6: Radargram of section B with 10 cm thick anomalies placed at a depth near to 10 cm.

4 APPLICATION OF GPR IN THE UPSTREAM FACE OF SANTA CLARA RCC DAM

The GPR survey in Santa Clara was performed in a limited area of the upstream face of the dam (Figure 7), in order to evaluate the condition of the conventional concrete.

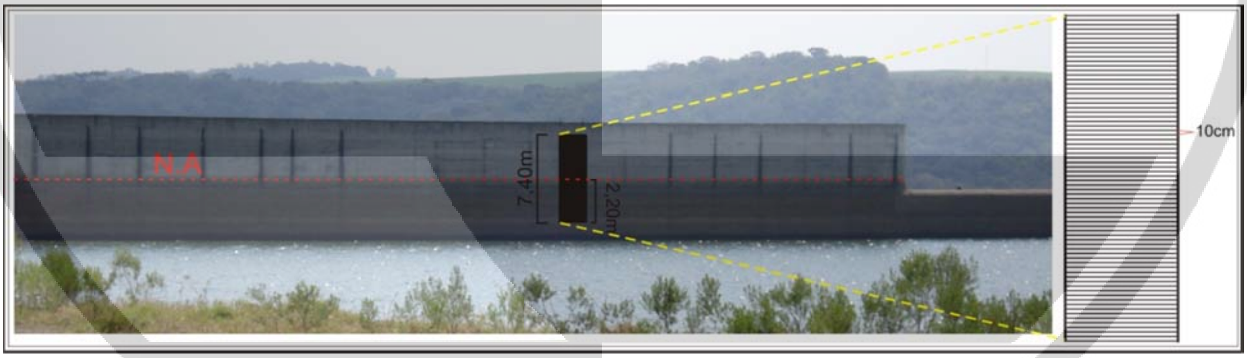

Figure 7: Location in the upstream face where the GPR survey was carried out – reading paths in the right side.

The selected area was discretized with 75 lines, 2,20 m long each one, with a 0,10 m spacing. Once the lines were marked, the GPR readings were done sweeping the antenna over each line, always in the same direction (Figure 8).

The first GPR profile (0,00 m) was read at the level of the crest of the dam, in the same height of the concrete pavement. The last profile (7,50 m) was read 2,20 m below the normal reservoir water level.

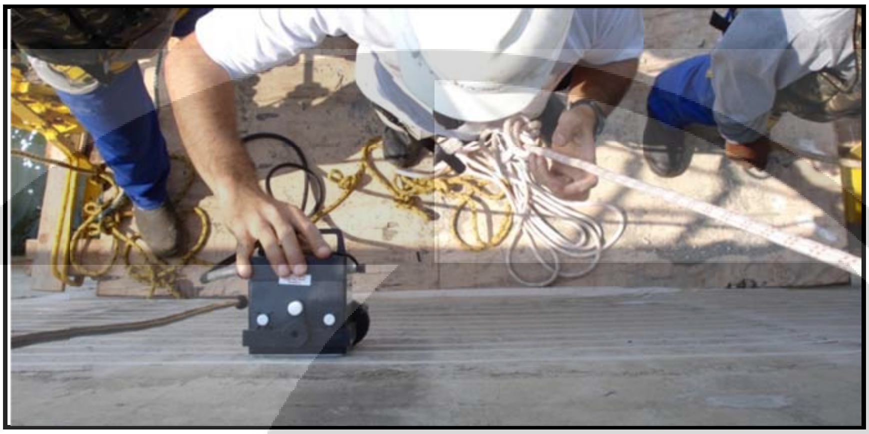

Figure 8: GPR survey in the upstream face with a 2 GHz dipole antenna.

4.1 Results

Almost all profiles showed the presence of faint irregular and truncated reflectors, which are normally associated with surface irregularities in the concrete surface and the medium heterogeneity.

The first two profiles at the levels 0.0 and 0.10 m show striking reflectors in the form of regularly spaced hyperboles. This is a clear evidence of the concrete reinforcement at the pavement level (Figure 9).

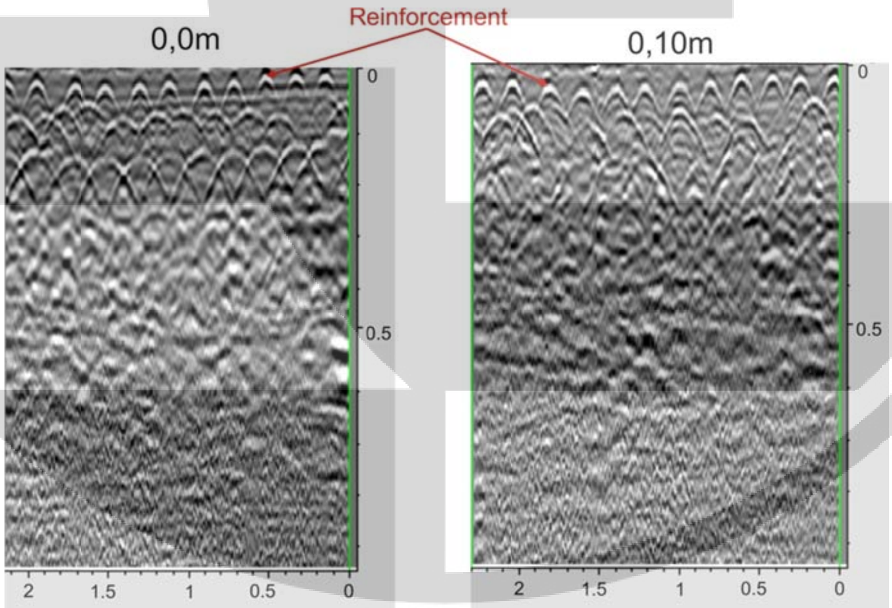

Figure 9: Radargrams at the pavement level in the crest of the dam.

It is noticeable that beyond the depth of 0,50 m the signal quality is poor due to the high attenuation of the 2.0 GHz EM waves in the concrete. Beyond this depth noise masks the presence of reflectors, making data interpretation even more difficult (see Figure 10). Coincidently, this depth is also associated to the transition between the conventional concrete and RCC.

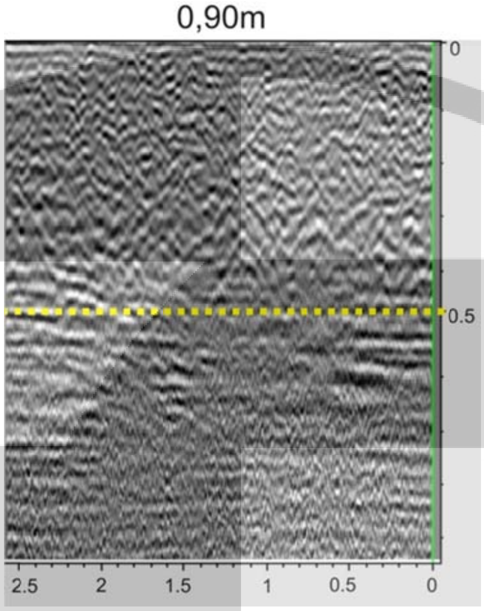

Figure 10: Radargram showing noisy data beyond the depth of 0,50 m.

In some profiles it was noticed the presence of isolated hyperboles of small amplitude, which are associated with the occurrence of metallic fragments inside the conventional concrete as shown in Figure 11.

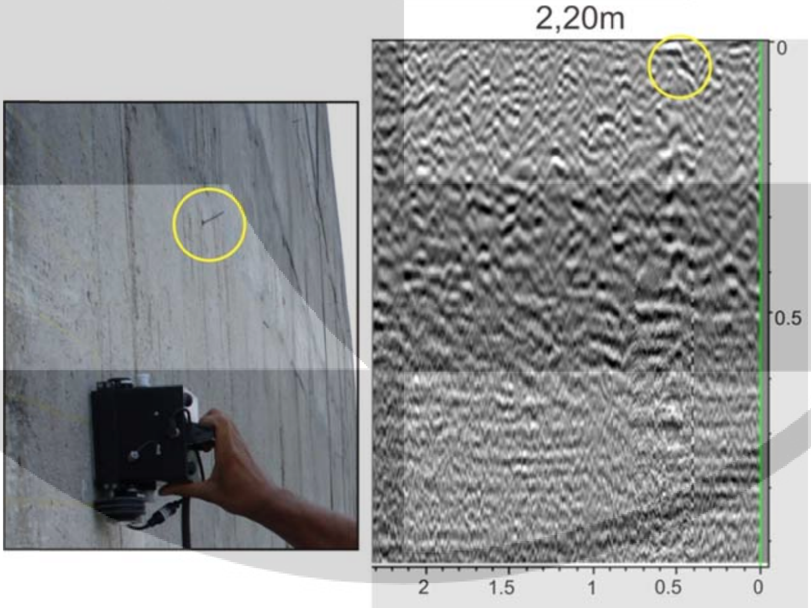

Figure 11: Presence of metal fragments in the face of the dam.

In specific radargrams there was the occurrence of striking hyperboles of greater magnitude, which are related to the presence of metal elements used to fasten the climbing forms during the concrete work. The forms are shown in Figure 12 alongside the radargram of the corresponding level.

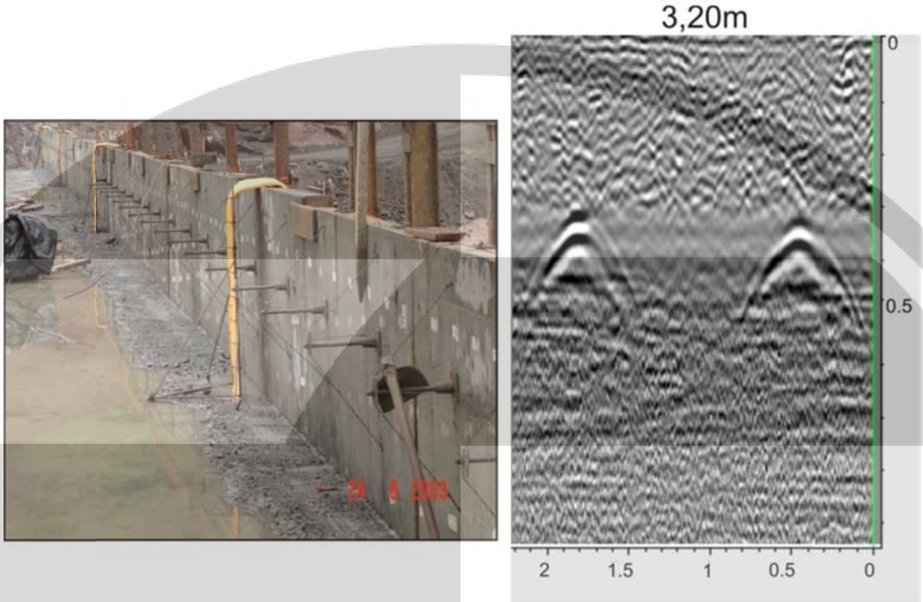

Figure 12: Example of striking hyperboles (right) resulting from metal elements used to fix the forms (left) which were left embedded in concrete.

The GPR profiles along the lines just below the normal reservoir level showed increased presence of irregular and truncated reflectors, due to the irregular concrete surface with showing aggregates. Wear in this area is particularly high due to the water level fluctuations (Figure 13). None of these hiperboles detected in the radargrams are an indication of internal flaws.

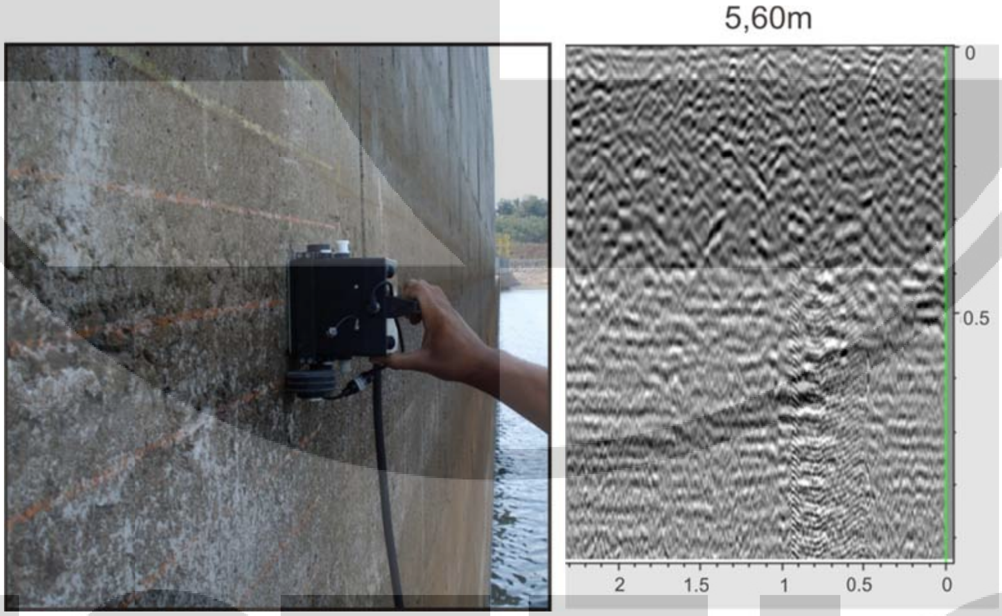

Figure 13: Normal water level zone showing greater wear.

For a better visualization of the profiles at different depths from the mapped area a specific processing procedure called C-Scan was performed[8], consisting of a data interpolation based on positive and negative peaks of the electromagnetic reflectors generated by the GPR.

The product of this interpolation is a block, which after a 5 cm slicing, allows the identification of highly conductive areas, depicted in warm colors, and highly resistive areas in blue (Figure 14).

The metal elements used for fastening the climbing forms are clearly shown at well defined and equidistant spots of high conductivity between 40 cm and 45 cm depth.

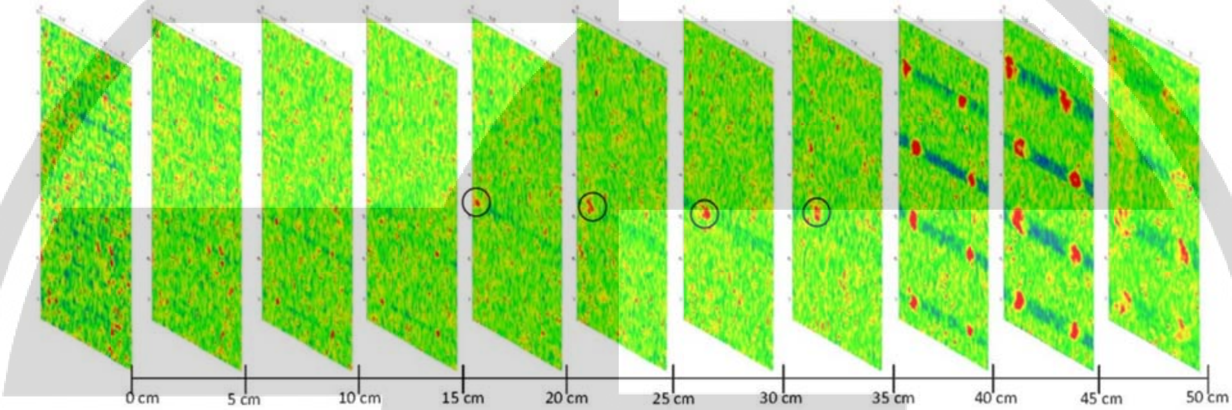

Figure 14: 5 cm C-Scan of the mapped area. The circled areas indicate anomalies at various depths.

Voids or niches of higher porosity with high water quantity would also be indicated with red colors. In the surveyed volume the circled red spots detected from depth 20 cm to 35 cm, slightly above the 5,00 m level, is an evidence of one or more anomalies.

Looking at the radargrams between levels 4,60 m and 4,80 m, in Figure 15, the presence of a continuous plane anomaly in a diagonal position with respect to the face of the dam can be observed. The anomaly goes from 15 cm to 35 cm depth (Figure 14 and Figure 16 detail).

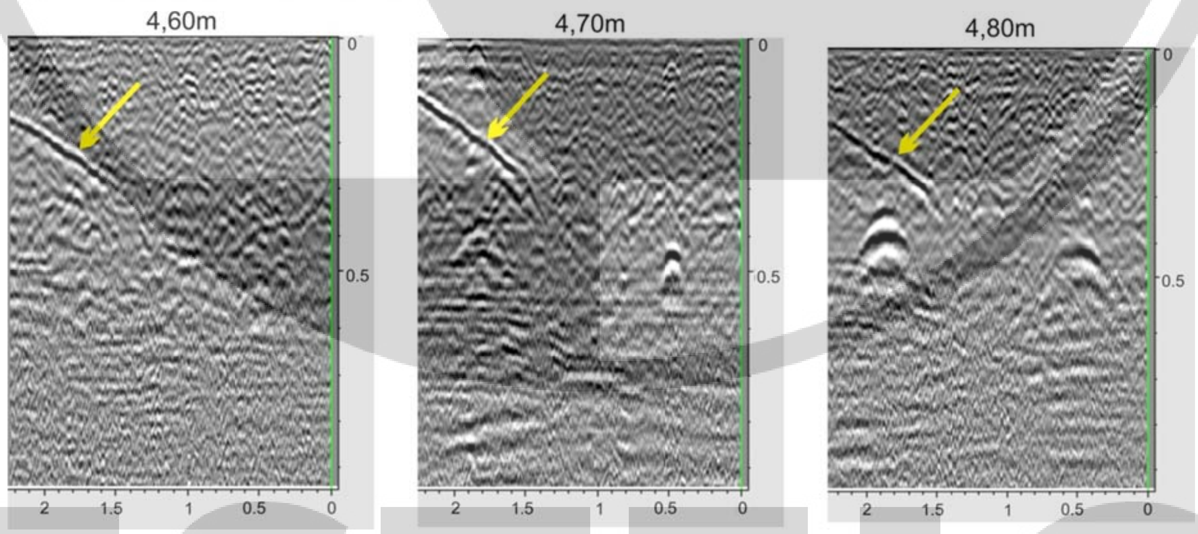

Figure 15: Radargrams at levels 4,60 m, 4,70 m and 4,80 m with the anomaly indicated.

A closer look at the C-scan shows the anomaly in detail, which is over 80 cm long and ranges from depth 15 cm to 35 cm.

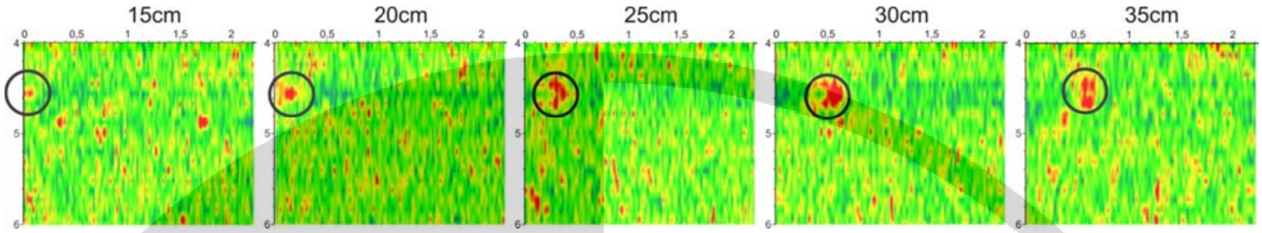

Figure 16: Detail of the C-scan with identified anomaly.

5 CONCLUSIONS

The GPR has proved to be a useful complementary non destructive tool for the investigation of the upstream face of concrete dams, allowing the identification of internal anomalies with high precision and resolution.

It is a relatively quick method of data acquisition, which can be applied to large areas or for investigation of specific areas with single or periodic assessments.

In the examined area of the upstream face of Santa Clara RCC dam, the GPR profiles revealed the presence of a plane anomaly inside the conventional concrete. Its location is above the normal reservoir level and the implementation of a refined inspection or corrective intervention was not justified.

The GPR radargrams also revealed the presence of metal elements inside the conventional concrete zone, regularly spaced in vertical and horizontal directions, which were used for fastening the climbing forms during the dam construction.

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