Identificación y Evaluación de Fractura mediante Tomografías Eléctricas, en las proximidades del eje de la Represa Huamantana – Lima - Perú,

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1 INTRODUCTION

To perform the Geophysical Investigation using Electrical Tomographies, near the axis of the Huamantana dam, located in the city of Lima to identify the fracture that is escaping the water that is being dammed. For the fines of the case has been made up to three trips to the problem zone, conclude that there are trends that perform the resistivity measurements using Electrical Tomography, at the edge of the geo-membrane. With this purpose, it was necessary to provide strong contrasts of resistivity, dissolving 200 kilos of salt in the pool of water where the water leak occurred. For a suitable sensation of the sensation of the stains of the nature, a first campaign of the measurements of the resistivity in the natural conditions reced which was done on the day 29 12 2016, this day in the afternoon has dissolved the 200 kilos Of salt in the water pool Inside the reservoir. Subsequently in the following days the resistive measurements began, tracing the salt water route. This phase of the study was carried out without major setbacks, with information being initiated a process. The result of the two campaigns was integrated, resulting the corresponding illustrations, which is described in an integrated way. The first campaign was done without salt, and all day along with salt water, as shown in the illustrations. To develop the necessary study for the following investigations that complement the investigations developed and that are mentioned below:

I. Geophysical Prospecting using TME or Electrical tomography.

II. Process and Interpretation of the resistive values of the SPD, then correlate these results with the geology of the area under investigation.

Know the achievement Obtain detailed information of the stratigraphy in the study area and the identification of georeferenced anomalies caused by the tectonism of geological faults, which are reflected as zones of low resistivities or anomalies.

2. MATERIALS AND METHODS

For the present work of investigation was used the technique of Tomography electrical for which was used equipment of last generation such as:

• French 10-Channel Syscal Pro Resistivity Meter - IRIS Instruments.
• Reels with 100 m of cable for SEV.
• Cable configuration for SPD with spacing of 10 meters.
• Power supply 800 DC.
• 30 Stainless steel electrodes (Dipoles) and 04 Steel (AB)

The field work was done without major setbacks, except the drizzle that disturbed the readings and mobilized, as the photographic panel shows.

There were also problems with the owners of the agricultural lands where the cables were stretched, which did not allow passing through their properties, problems that were solved explaining them about the objectives of the paper.

3. METHOD

Geophysical prospecting is an indirect method to know the surface structure of the earth's crust, in some cases it is necessary to study up to 3000 meters deep in hydrocarbon exploration. In groundwater exploration and mining, they do not exceed 100 meters in depth. In geotechnical studies, 90% of the studies do not exceed 300 meters in depth, usually less than 100 meters. For the purposes of the present study the required 30 meters.

In geotechnical investigations the best results are the electrical methods in its variants Vertical Electrical Probing (SEV), Electric Panels (CE) and Poles Dipole Probes (SPD) Electrical Tomographies. Also of great importance is the seismic prospecting of Refraction with its variants of Mas W, REMI, Down Hole, H / V among others.

For the objectives of the present project, they have required the study by means of the electrical resistivity method, applying the electrode distribution to the Poles Dipole Soundings (SPD), in order to be able to identify the fracture of the rock where there is leakage of the waters that are being stored In the dam of Huamantanga. The ones we will explain below.

The earth is a good conductor of the electric current, by its content of metallic minerals, degree of humidity and mineralization of the water that occupy the interstitial spaces of the rocks and sedimentary formations; The temperature also influences the electrical conductivity of the rocks. These are the most important characteristics that define the resistivity of the physical environment. In geological formations such as those observed in the investigated area, the resistivities vary from Ω-meter units for wet to saturated soils, with different degrees of mineralization, to higher mineralization, lower resistivity and vice versa, when the soil or rocks is found without metallic minerals And without moisture.

The Electrical Resistivity method is applied by means of a double electrode dipole. The first dipole is the electric current transmitting circuit, from a source of direct current that can be current accumulator, current generator, solar panel or other forms, by means of electrodes (A - B) made of metal at most Resistant to penetrate hard floors, in this circuit is measured the electric current (I) that is sent to earth. The second dipole is the receiver or potential circuit formed by the impalelectable electrodes MN, where the potential or fall of electric voltage (DV), created by the flow of the electric current, is measured.

For the distribution of the AB and MN electrodes there are several schools, such as those devised by Wenner, Lee, Schlumberger (can be symmetrical or asymmetrical) among others; Being the one of greater application in Peru the one devised by Schlumberger, because this one that gives better results in soils with strong lateral anisotropy and / or rugged topography.

The electrolytic distribution of Schlumberger is characterized by being linear, symmetrical and / or asymmetric, which allows investigating the depth required by the study, in the central part of the electrode distribution.

There are other distributions such as Dipole - Dipole, Polo - Polo, Polo - Dipole. For this distribution of electrodes, equipment with 10 to more simultaneous measuring electrodes is used. They are characterized by providing horizontal and vertical information.

We will now describe the electrode distribution used:

2.1 POLE DIPOLO POLE OR ELECTRICAL TOMOGRAPHY

They allow to investigate in a horizontal and vertical form the subsoil, information of great importance to define the geotechnical characteristics of the area under study. The configuration and distribution of electrodes used with the Polo Dipole method in the field work is shown in Fig. 1.

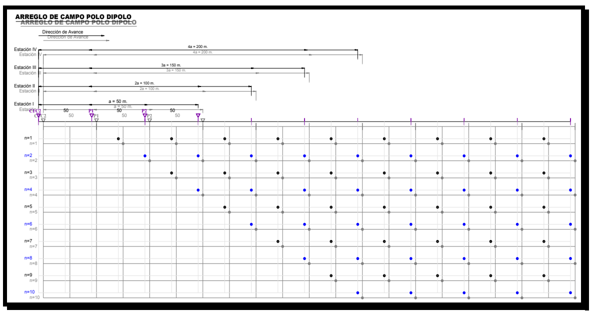

Figure 1 - *Configuration Polo - Dipole*

These measurements are made with sophisticated equipment designed for this purpose, such as the 10-channel Syscal Pro Resistivimeter, which allows us to perform 10 continuous readings in less than 30 seconds, and the data is stored or recorded by the equipment, and then downloaded in a CPU and proceed to processing.

This configuration of the geoelectric devices, allowed to register the lateral and vertical variations of the subsoil.

The measurements made it possible to record the lateral and vertical resistivity variations of the subsoil, to present in 2D model, which allow to construct graphically what is denominated a "pseudo" as seen in Fig.2.

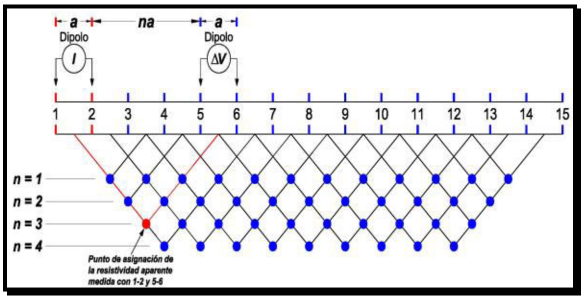

Figure 2- *Representation of the pseudo-domains with device Polo Dipole*

To begin with the readings the current electrodes are positioned in positions 1-2 of the scheme, while the potential ones occupy positions 3-4, so that the separation factor of the device dipoles will be n = 1. The intensity I and potential ΔV are measured and introduced in the expression:

$$\rho_a = \pi \cdot n(n+1)(n+2) \cdot a \frac{\Delta U}{I}$$

This gives the value of ρa corresponding to the pair of positions 1-2 and 3-4. From the center of these positions are drawn lines at 45 °, so that at the point where they are cut, the value of the measured apparent resistivity is assigned.

Then the measurement is performed for the pair of positions 1-2 and 4-5, plotting the corresponding point. Following this process a pseudo-resistivity of the whole subsoil is drawn, the representation of which is generally in the form of a trapezoid.

It is very important to emphasize that this pseudosection procedure is only a graphic convention, and in no case implies that the depth of investigation of the device is given by the intersection of the two lines at 45 °.

The pseudosection gives a very approximate image of the distribution of resistivities in the subsoil. However, the image they provide is distorted.

4. RESULTS

The present item corresponds to the measurement phase of the georesistive parameters, such as the current sent to earth and the difference of potentials created by it; Work done in the field stage and pre-processing of the data, the research was carried out with spacing between electrodes of 5 meters, which will allow to know from 25 to 30 meters depth, necessary for the project objectives.

For an adequate evaluation of the area, 4 tomographic lines have been made, distributed as shown in illustration Nº 2. In each line the readings whose graphics are being presented in illustrations 2.1 to 2.4 have been repeated.

Considering the fundamental objective of the study, which is to delineate the areas where the rock is fractured, it has been found desirable to increase the electrical conductivity of the water by dissolving salt or sodium chloride in the standing water.

For an adequate identification of the areas of fractured rock, a first campaign of resistivity measurements in natural conditions was carried out, which was carried out on 29 December 2016, resulting in profiles 01A, 02A and 03A. At the end of these measures, the 200 kilos of salt was dissolved in the water well (photo No. 01 of item 1.1) inside the reservoir. On the 30th of December, 2016, the readings were repeated in each line or profile of electrical tomography performed the day before, resulting in the geoelectric profiles 01B, 02B, 03B and 04B, as shown in Figures 3, 4, 5 and 6.

The processing of the investment began with the ordering of the field data, then they were processed using the X2IPI software, these results are being presented in the illustrations from 3 to 6.

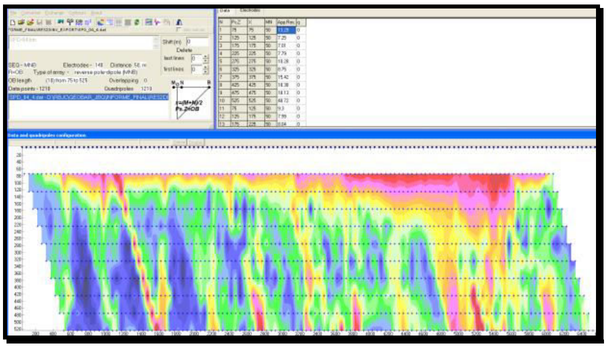

***Figure 3 -** Data Visualization X2IPI (Moscow University & IRD)*

After verifying the information as well as its data, we proceeded to export the information to the Res2dinv software and in which we were able to observe the block diagram for the 3 lines as shown in fig. 4

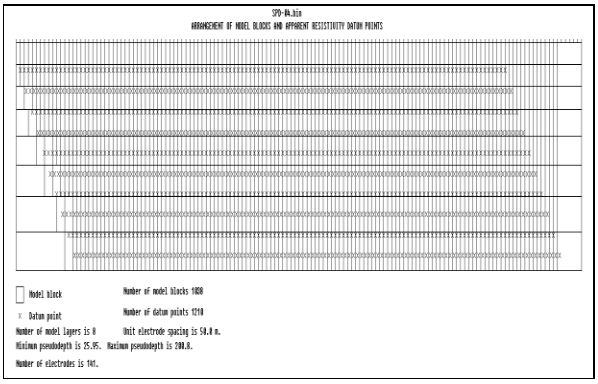

***Figure 4 -** Blocks diagram*

The investment model, to make the investment model, was chosen the method of finite elements as a method for the solution of equations and the inversion by least squares, results that are shown as the image shown in fig. 2.5.

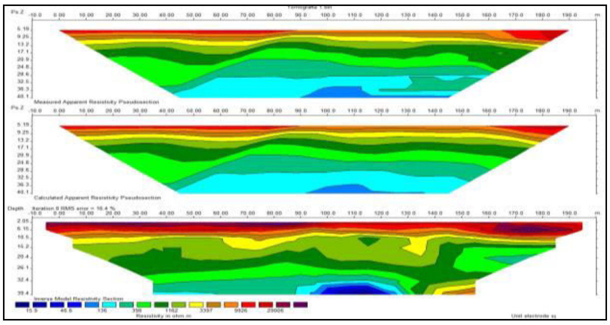

***Figure 5 -** Investment model for lines 1*

The topography inversion model has been applied to the 3 tomographic lines, using the software Res2dinv, for the same we use the method of finite elements for the approximation of the data observed with the inverted, 2.6 shows the topography inversion model applied to profile 1 as the image shows.

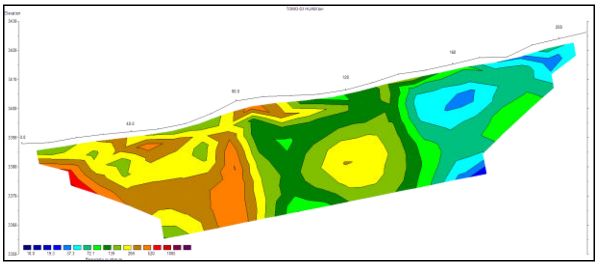

***Figure 6 -** Topography investment model for line 1*

INTERPRETATION OF TOMOGRAPHIC PROFILES AND CORRELATION WITH HYDROCHEMISTRY AND GEOLOGY OF THE PLACE

The information of the SPD or Electrical Tomography lines made in the probable zones of the water leaks were distributed as shown in illustration 2.0:
The First Profile parallel to the axis of the dam inside of glass.
The Second Profile 10 to 15 meters upstream of the first profile.
The Third Profile on the slope outside the glass.
The Fourth Profile approximately 10 m above the eye or water spring.

In this way, the resistivity measurements were performed for each of the 04 lines of Tomographic Electrical - TME,

Considering the fundamental objective of the present study, for an adequate identification of the fractured rocks where the water of the dam escapes, a first campaign has been carried out on the tomographic lines shown in fig. 3.0 and in greater detail the illustration No. 02, measuring the resistivities under natural conditions, which was carried out on 29/12 2016, resulting in the profiles 01A, 02A and 03A. After completing these measures, in the afternoon after 16 hours the 200 kilos of salt were dissolved in the reservoir (photo No. 01 of item 1.1), in order to increase the electrical conductivity of the water ,
In this way have strong contrasts of resistivities, which will allow us to properly identify the areas of influence that have fractures of the rocks.

On December 30, 2016, from the first hours the readings were repeated in each line or profile of electrical tomography performed the day before, resulting in the geoelectric profiles 01B, 02B, 03B and 04B.

These readings were made to adequately contrast resistivities without salt and salt, thus clearing doubts about the areas of influence of rock fracture. That the profile of the fracture through which the water is filtered and the profile of the water that is being filtered upstream of the dam is shown in profile 4B.

This information was interpreted using the Res2dinv software, resulting in images showing tomographic illustrations No. 2.1 to 2.4, where the color changes represent changes in the physical chemical characteristics of the geological environment, which will be interpreted in geological terms.

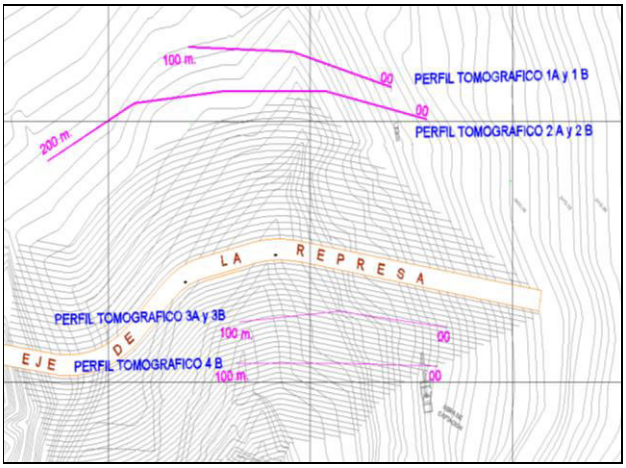

Figure 7 *- Lines of the Profiles of Electric Tomographies Done*

PHYSICAL CHARACTERISTICS OF WATER WITH AND WITHOUT SALT

Ph Measures
Measurements have been taken of the PH of the water before it is infiltrated, taking values from 7.2 to 7.4 in the water stand, and at the outlet by the spring the indicated values are maintained.
Electric Conductivity
Its EC value was also taken before the first run of resistivity measures without salt, and gave values of 90 mmohos at the entrance or lagoon and 100 mmohos at the source or outlet.
The readings after the second measure of resistivity the water already had salts, and measured values of 180 mmohos in the entrance or lagoon and 180 to 190 mmohos in the spring or exit .
As will be seen if there has been increased EC after adding the salts to the water.

INTERPRETATION OF TME AND HYDROGEOLOGICAL CORRELATION

The information obtained from the Electrical Tomography (TME) lines were interpreted using the software Res2dinv, resulting in the images shown in illustrations 3 to 6, where the color variations represent changes in the physical and chemical characteristics of the hydrogeological medium, which Continuations will be interpreted in terms of resistivity and its influence with fractured rocks. For this purpose we will first describe the range of resistivities found for the study area.

Range of Resistivity

For a suitable interpretation of the resistive values found in the study area, a range of resistivities has been established as follows:

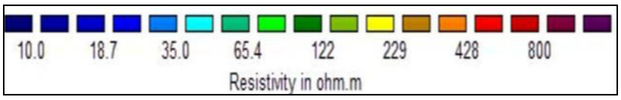

Figure 8 *– Color for Range of Resistivity*

- Resistivities of 10 to 30 Ω-meters in color Blue to Celeste
  These resistive values would correspond to fractured and saturated rocks.
- Resistivities from 30 to 300 Ω-meter in color Green to yellow
  In the study area these values corresponded to the clay formations with little content of fine and slightly compact sands to little compacts.
- Resistivities Greater than 300 Ω-meter in color Red Orange to Dark Purple
  They represent very compact sediments or healthy rocks.

TOMOGRÁFIC PROFILE TME-01 A y 01 B
It has been drawn from east to west as shown in illustration 2.0 in plan, with a length of 200 linear meters. In Fig. No. 9 and with better resolution in illustration 3, the results interpreted in 2D are presented, in it are shown two zones where the rocks are fractured:
I ZONE.- It corresponds to rock fractures the most important, identified by the TME 01 A between the progressive 53 to 67 m. Fracture that is presented in vertical form, where at present water is found and infiltrated to give rise to the source water downstream of the dam.
The profile of the TME 01 B was made after 12 hours that it was put salt to the water, in order to increase its degree of electrical conductivity, and we can have greater contrast of resistivities to differentiate the fractures of the rocks. In illustration 3 TME 01B, two branches are observed, one in blue color the main fracture identified between the progressive ones 52 to 60 m, and the other in green to celestial color that apparently does not have continuity in depth, identified between the progressives of 75 to 90 meters and a depth of 16 to 18 meters.
The main areas of fracturing of the rock are between the progressive ones of 50 to 70 meters, that must have a special treatment for its waterproofing.
Observing in more detail the main leaks of the water would be giving by two specific points, in the delimited plane with celestial strip with a width of 01 meter for both cases. They are points where you must have the greatest care or care for waterproofing.

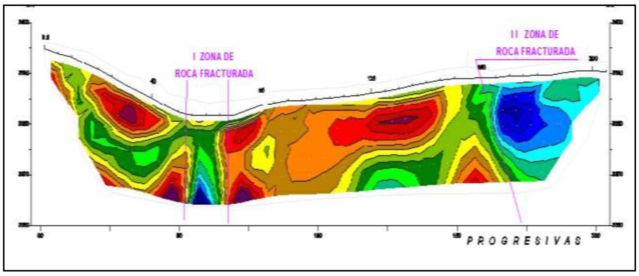

Figure 9 - Tomográfic Profile without Salt

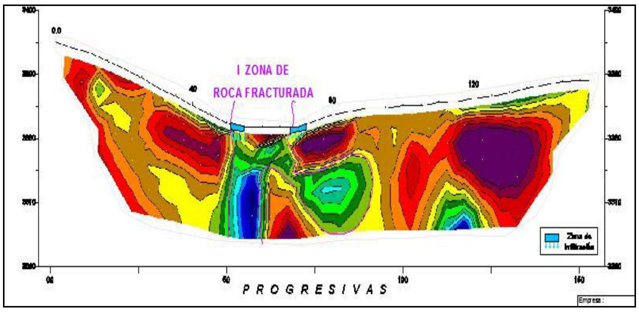

Figure 10 - Tomográfic Profile with Salt

I I ZONE.- Corresponds to rocks fractures identified by the TME 01 A, between the progressive 160 m. At the end of the scan. Due to the shape of the blue color the fractured rock is not deepened as in the I Zone. For security, we suggest applying to this zone also the waterproofing that is given to the first zone.

TOMOGRÁFICO PROFILE TME-02 A and 02 B

It has been drawn from east to west as shown in illustration 2.0 in plan, with a length of 100 linear meters. This TME 2 is approximately 10 to 20 meters from the previous TME. The main hydrogeological characteristics observed are as follows.
The TME 2A and TME 2B are very similar, where the color brown to orange has a stratification parallel to the surface, indicating that in this sector the rock is healthy. The anomaly or fracture occurs only in the vicinity of the geomembrane placed in the dam.

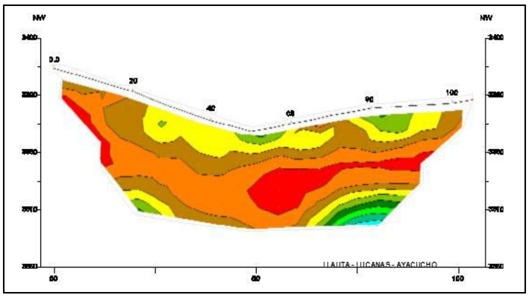

Figure 11 - Tomográfic Profile without Salt

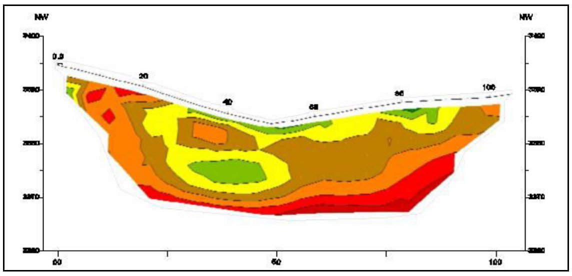

Figure 12 - Tomográfic Profile with Salt

TOMOGRÁFIC PROFILE TME-03 A y 03 B

It has been drawn from east to west as shown in illustration 2.0 in plan, with a length of 100 linear meters. In Fig. No. 12 and with better resolution in illustration 2-3, the results interpreted in 2D are presented. It is the first TME traced water down the dam shaft, practically on the body of the dam.
The TME 2A and TME 2B are similar, where there are no marked abnormalities as in the first two tomographies, indicating that the geological formation is very homogeneous up to 25 meters depth investigated.
The characteristic of the very homogeneous stratification found with this TME, indicates or explains that the water that flows from the dam, must be flowing through very fine cracks, for this reason with the present method it is impossible to be able to identify it.
In Figure 5 TME-03B, a light blue spot is observed in the progressive 13, to correlate it with the water pipe, where there must be some water leakage.

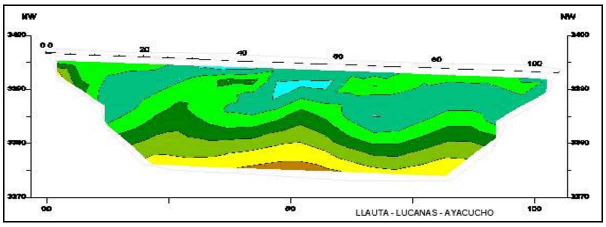

Figure 13 - Tomográfic Profile without Salt

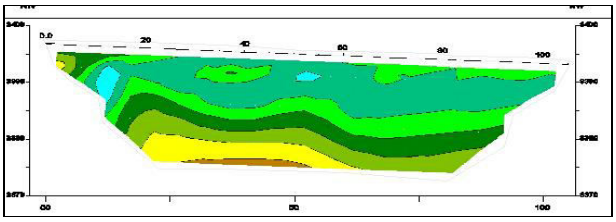

Figure 14 - Tomográfic Profile with Salt

TOMOGRÁFICO PROFILE TME 04 B

It has been drawn from east to west as shown in illustration 2.0 in plan, with a length of 100 linear meters. In Fig. No. 3.2.4 and with better resolution in illustration 2-4, the results interpreted in 2D are presented. This profile is very close to the spring originated by the waters that infiltrate the dam.
For the present case, the TME has only been drawn with salt water, the results of which show the TME 4B. The image in Figure 2.4 shows a saturated stratum along the TME, with an outcropping of water between the progressive 84 to 94 meters, which would be related to the water spring or eye to be waterproofed, the width involved 3 m and the main flow is given by a width of 01 m.

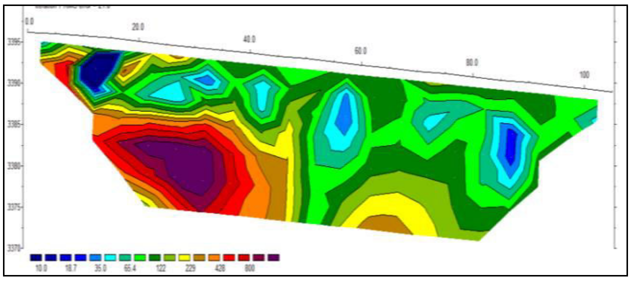

Figure 13 - Tomographic Profile TME 04 B

5 CONCLUSIONS

By means of the present study two zones of weakening or fracturing of the rocks have been identified that are:

I ZONE.- It corresponds to rock fractures the most important, identified by the TME 01 A between the progressive 53 to 67 m. Fracture that is presented in vertical form, where at present water is found and infiltrated to give rise to the source water downstream of the dam.
The profile of the TME 01 B was made after 12 hours that it was put salt to the water, in order to increase its degree of electrical conductivity, and we can have greater contrast of resistivities to differentiate the fractures of the rocks. In illustration 2.1 TME 01B, two branches are observed, one in blue color the main fracture identified between the progressive ones 52 to 60 m, and the other in green to celestial color that apparently does not have continuity in depth, identified between the progressives of 75 to 90 meters and a depth of 16 to 18 meters.
The main areas of fracturing of the rock are between the progressive ones of 50 to 70 meters, that must have a special treatment for its waterproofing.
Observing in more detail the main leaks of the water would be giving by two specific points, in the delimited plane with celestial strip with a width of 01 meter for both cases. They are points where you must have the greatest care or care for waterproofing (See conclusion figure).

I I ZONE.- Corresponds to rocks fractures identified by the TME 01 A, between the progressive 160 m. At the end of the scan. Due to the shape of the blue color the fractured rock is not deepened as in the I Zone. For security, we suggest applying to this zone also the waterproofing that is given to the first zone.

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