Geotechnical Engineering in the XXI Century: Lessons learned and future challenges
N.P. López-Acosta et al. (Eds.)

doi:10.3233/STAL190125

A Comparison of Geophysical Techniques and Analysis to Evaluate the Geotechnical Parameters of the Riparian Environment of Moquegua - Peru

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Abstract. Generally, civil works are exposed to the dynamics of the process of evolution of the earth, trying to understand it to elaborate projects in harmony with the environment, only in this way sustainable projects will be obtained from the society. The work of river defense understood as a walk that runs parallel to the bank of the Osmore River, also protecting an adjacent avenue, was severely affected by the dynamics of the river, even eroding part of the double path. Procuring the measures to restore the affected areas, an extensive program of field and processing of the obtained data was developed, with this objective the corresponding analyzes were carried out, so that the new design of the river defense has the technical solids to resist the maximum floods from the river. Initially a revision of the geological information and mechanical pits existing in the previous studies was developed; In the second stage, geological-geotechnical research was carried out, where geophysical studies were developed using seismic refraction tomography to identify the geoseismic strata based on the speed of the seismic waves and the geo-resistivity strata based on the electrical resistivities of each stratum identified through high-resolution electric resistivity tomography. The geophysical results integrated to the other investigations with direct methods, allowed the integral geotechnical understanding of the researched area, which led to pose the ideal solution to the imminent risk of dynamic river force, knowing in detail the morphology of geophysical differentiated strata. Two geophysical methods were used to improve the forensic geotechnical analysis, resulting in multiple methodologies increasing the certainty of the characterization of the study area, in terms of physical and mechanical properties.

Keywords. Riverbank protection structure, seismic refraction survey, electrical resistivity tomography, seepage flow, erosion.

1. Introduction

Periodically in the region of Moquegua, located in southern Peru, there is a significant increase in the fluvial flow and also a revealing increase in the flow that shows that the

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riverbank defense is not prepared to support it, manifesting vulnerability and the need to develop a better verification technique that allows avoiding material losses. Historically it has been recorded that in the rainy periods the water level of the river increases naturally, however, there are years where rainfall is copious and the risk increases exponentially due to the overflowing increase in water level generating a collapse of the riparian defense system, as it happened in the month of February 2015.

The objective of this research is to present a case study where the joint use of two geophysical techniques and geotechnical analysis allow a solid study of the advantages and disadvantages and propose the geophysical application, several studies have been carried out based on stability models for avoiding a rupture of the riparian protection considering different parameters [1], [2], [3], [4] and [5]. The seismic refraction method is one of the best for a characterization of the site under study [6], [7] and [8], while to complement this information the electrical method provides sensitive physical properties [9], such is the case of electrical tomography with different configurations [10], [11] and [12]. The combination of both techniques has shown the achievement of results with a superior quality for the interests of geotechnics and engineering, being that its application has been giving successful conclusions, being one of them in concrete structures of works of great relevance for engineering, where cement generally seems more conducive to electricity than the surrounding materials [13] and [14].

2. Methodology

2.1. Data collection procedures

In order to achieve the objectives of this research work, it was necessary the participation of a field brigade. The activities carried out during this stage were carried out considering the work on seismic lines and tomographic lines, with a total of seven sectors for each, which covered the entire area of interest to know the stratigraphic characteristics as shown in Figure 1. During the phase of the field the biggest problem that had to be solved was the constant seismic noise, caused by the passage of vehicles and the draining of the river that cause small vibrations of the ground; Impacted impaction giving a greater number of blows with the hammer, until obtaining a clear seismic signal in the seismograms.

Figure 1. Research zone by geophysical prospecting.

2.2. Applied Geophysical Prospecting Methods

The geophysical prospecting is an indirect method to know the interior of the earth's crust, and does not alter it in any way, taking advantage of one of the many physical properties of the material under study, such as those that were applied to know the geology of the zone between the El Tucumán Bridge and El Rosado Bridge of the Mariscal Nieto Avenue in Moquegua.

2.2.1. Seismic Survey by Refraction

This method allows to know the stratigraphic sequence of the subsoil, based on the time it takes to travel the seismic waves, for a determined geological stratum, this travel time is subject to the physical characteristics (hardness of the soil or rock) of the physical environment, greater hardness of the rocks greater is the frequency and greater the speed of the seismic waves, and vice versa for soft soil minor is the frequency, greater the amplitude of the seismic waves and lower speed, characteristics known as the elastic behavior of the rocks. Studies carried out applying the seismic wave method in the soil for its characterization for geotechnical engineering applications, such as for road projects, proved to provide an effective characterization of the subsoil obtaining the geotechnical and physical parameters [15] and [16].

For this case artificial earthquakes have been provoked with a hammer blow with 20 pounds of weight, the geophones are connected to a flute cable that conducts the signals of the geophones to the seismograph, where the current signals are amplified up to levels where the waves Arrival seismic observations are properly observed as shown in Figure 2. Seismic Refraction Survey (SRS) has been applied in recent years, showing a quality superior to traditional technique [17] and [18].

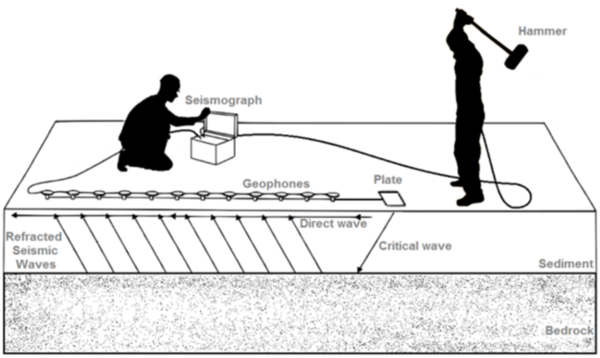

Figure 2. Field distribution of the geophones in the seismic refraction survey according to [19].

2.2.2. Prospecting for Electric Resistivity

It is an indirect method to know the underground geology, with results quite close to the reality of the field. They consist of sending electrical current to the ground, by means of steel electrodes and receiving other non-polarizable electrodes, the electrode configuration can be symmetric linear tetraeletrodic (AMNB), trielectrodic or bielectrodic, the most used in Peru is the tetraeletrodic device devised by Schlumberger, and the Measures with multichannel equipment also known as electrical tomography, several studies carried out by this method [20] and [21].

Electrical resistivity tomography is a method of multielectronic resistivity, based on 2-D modeling of soil resistivity, using numerical techniques such as finite elements and/or finite differences. Currently, progress is being made in 3-D modeling. The appearance of the present method has involved a spectacular qualitative leap with respect to conventional resistivity methods, techniques that have still been used for several decades in the study of water leaks; its limited 2-D resolution means that they are considered a secondary method versus electrical resistivity tomography. According to [22] to perform an electrical tomography with a Pole-Dipole (PD) configuration, relationships between the data sets based on the triple potential method, the reciprocity theorem and the additive properties of the electric potential must be known which has been normalized by the injected current. The configuration and distribution of the electrodes used according to the pole-dipole method in the field works are shown in Figure 3.A. For the presentation in 2D model, the measurements were recorded variations of lateral and vertical resistivity of the subsoil, which allows building graphically what is called a "pseudo" as seen in Figure 3.B. That is, seeks to increase the number of measurements of the field that commonly occur in the form of pseudo-sections of apparent resistivity.

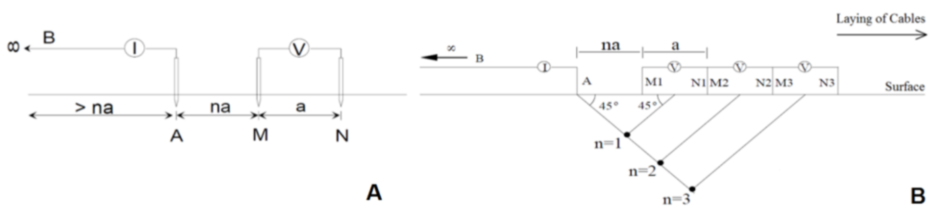

Figure 3. A. PD configuration; B. Representation of pseudosections through the PD technique.

3. Results

3.1. Field Results of the Seismic Survey

This phase the prospecting was performed with a seismograph Geometrics of 24 channels, 25 Geophones of 4.5 Hz with spacing between geophones of 2.5 meters for the seismic lines transverse to the river, while for the longitudinal lines to the river were 5 meters. The seismic lines were executed from the El Tucumán Bridge to the El Rosado Bridge, as shown in Figure 1. In order to better manage the cartography of the study area, it has been divided into 7 sectors comprising a number of seismic surveys, and a total of 39 Seismic Refraction Survey (SRS) whose results are shown in Figure 4, with different lengths whose total sum is 4012.5 linear meters as shown in Table 1.

Table 1. Volume of Geoseismic Research.

Sectors	Sector 1	Sector 2	Sector 3	Sector 4	Sector 5	Sector 6	Sector 7	TOTAL
SRS	01 a 08	09 a 15	16 a 19	20 a 22	23 a 29	30 a 36	37 a 39	39
Length in m	875.0	750.0	375.0	312.5	675.0	725.0	300.0	4012.5

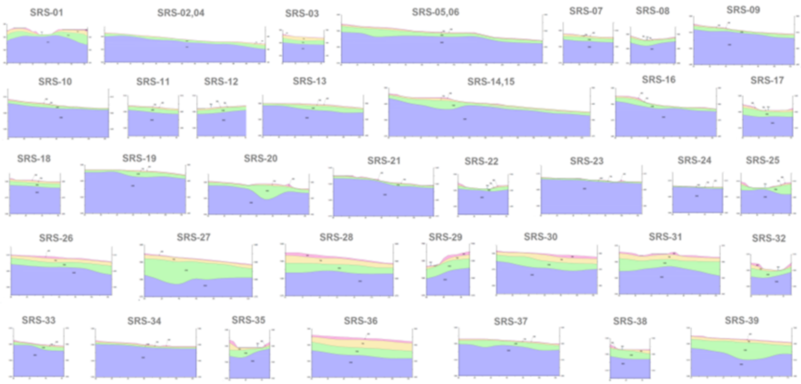

Figure 4. Seismic Refraction Survey.

3.2. Field Results of the Electric Prospection

The ERTs were executed from the El Tucumán Bridge to the El Rosado Bridge, as shown in Figure 1. In order to better manage the cartography, the study area under study has been divided into 7 sectors, each sector comprising a number of electricity lines as shown in Figure 5. For the electrical tomography survey was used a Syscal Pro Resistivimeter of 10 channels, cable configuration for PDS (Pole-Dipole Sounding) with space of 10 meters, in total 43 ERTs have been made with different lengths, whose total sum is 4210.0 linear meters. Table 2 shows in detail their respective lengths and to which sector they belong.

Table 2. Volume of Geoelectric Research.

Sectors	Sector 1	Sector 2	Sector 3	Sector 4	Sector 5	Sector 6	Sector 7	TOTAL
ERT	01 a 10	11 a 20	21 a 24	25 a 28	29 a 33 + 01.1	34 a 40	41 a 43	43
Length in m	980.0	960.0	380.0	390.0	580.0	640.0	280.0	4210.0

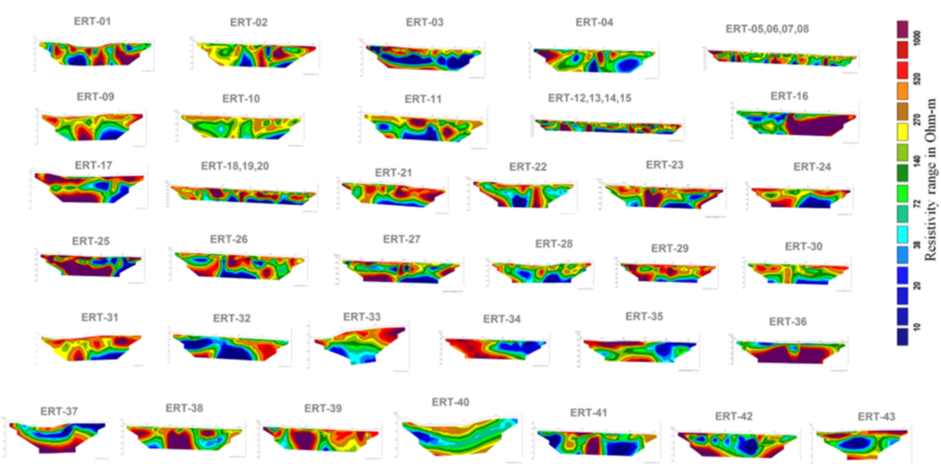

Figure 5. Electrical Resistance Tomography.

4. Discussion

4.1. Results of the seismic refraction survey

The 39 seismic lines were processed by 3 programs, the first software was SIPIK program developed by RIMROCK Geophysics of U.S.A., to identify the time of the first waves arriving at each sensor as shown in Figure 6.A.

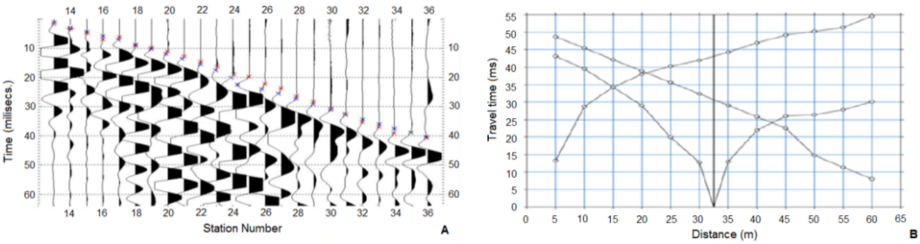

Figure 6. A. Record of arrival times of seismic waves to sensors; B. Dromochrones of the seismic line.

Then the Seis Opto Imager software was used to obtain the dromochrones (space-time diagrams with the arrival times of the refracted seismic waves, distributed in straight lines) as shown in Figure 6.B. Finally, it was processed and analyzed using the Seis-Imager software to obtain a one-dimensional shear wave velocity distribution (Vs), which are presented in the geoseismic sections in different shades of colors.

The interpretation of the seismograms has differentiated the range of speeds shown, where each color represents a geoseismic layer and considering the geology observed in the field and the little variation in speed, it has been considered convenient to group them into four strata that are: speeds of 300, 700, 1500 and 3000 m/s, the description is shown in Table 3.

Table 3. Summary of the lithology found in the 39 SRS.

Stratum	VP m/s	Geoseismic Lithology
1^{st}	300	Soft soils of anthropic origin located on the riverbank protection track and farmland; Of alluvial origin in the river bed, in both cases chaotically distributed.
2^{nd}	700	Fine to coarse sands, and rounded pebbles, with little clay and/or silt, slightly compact.
3^{rd}	1500	Fine to coarse sands, with boulder and little clay or silt, slightly more compact than the previous stratum.
4^{th}	3000	Fine to coarse sands, and pebbles with very compact clays and/or silts.

4.2. Electric Resistivity Prospecting Results

In the research area, 43 ERTs have been drawn along the 6500 linear meters. Most of the tomographic lines coincide with the seismic lines, which will be integrated at the end of the study. For ease, proximity and similar geological- geomorphological characteristics of the study area, the ERTs were grouped considering the Sectors of the geoseismic investigation; the tomographic lines made are shown in Table 2, and the description is shown in Table 4.

Table 4. Summary of the lithology found in the 43 ERT.

Stratum	Resistivity Ω-meter	Geoseismic Lithology
1st	10 - 50	Sand and gravel sediments of fine to coarse grains, with a considerable content of clays and/or saturated silts.
2nd	51 - 250	Fine to coarse sands, gravels, rounded edges, by sectors it is very likely to find clays and/or silts, these sediments are chaotically settled and wet to saturated.
3rd	250 - 700	Fine to coarse sands, gravels, rounded edges, by sectors it is very likely to find clays and/or silts, slightly more compact than the previous stratum.
4th	700 - 1000	Fine to coarse sands, gravels, rounded edges, by sectors it is very likely to find clays and/or silts, better compacted than the previous stratum.

5. Conclusions

This document presents a case study of the protection structure of the banks of the Osmore river, the geophysical research carried out for forensic geotechnics in order to be able to rehabilitate and improve riparian protection due to an engineering failure, allows us to indicate that the physical characteristics of the geoseismic strata are the same in the 6500 linear meters investigated, what vary are the thicknesses of the strata, which will be highlighted for all the geo-seismic sections traced. For the first stratum correspond to soft soils of anthropic origin, identified outside the main bed of the river in the lines made in the gardens or sides of the riparian protection trail. By sectors they are conformed by agricultural lands and in the bed of the river they correspond to alluvial sediments. The second stratum is made up of sands, fine to coarse gravels, rocks or sub-rounded stones, by sectors clay and/or silt are present, these sediments are chaotically distributed. The third stratum is made up of sands, fine to coarse gravels, rocks or sub-rounded stones, clay and/or silt are present in sectors, these sediments are chaotically distributed, and they are found with a greater degree of compaction than the previous stratum. The last stratum would be made up of sands, fine to coarse gravels, rocks or sub-rounded stones with a larger size than the previous stratum; by sectors there are clays and/or silts, these sediments are chaotically distributed, with greater compaction.

After having analyzed through forensic geotechnics and having a detailed geology, it can be indicated that the defense of the river bank suffered a collapse due to the failure of erroneous calculations of the protection structure, one of the main factors being the flow of water that entered In the strata of the soil and considerably modified its behavior, another factor that intervened was the strong water currents during the rainy period which caused the weakening of the foundation and the excavation of the natural slope in front of the protection of the riverbank, generating a failure in structure. This indicates that it must be taken into consideration for the control of the water level during the rainy seasons creating some type of drainage, and avoiding the erosion of the soils where the foundations of the riparian protection are located, to avoid faults for in the rehabilitation process.

In particular, we observed that the combination of SRS and ERT gives rise to an infallible tool for interpretation. However, the execution of the seismic method is relatively complicated because it has a more complex procedure and is therefore recommended for investigations with large specifications. While the electrical method demonstrates rapid fieldwork, good performance must be maintained during the analysis phase of the longitudinal and transverse sections, which is generally one of the most difficult points during interpretation.

Acknowledgments

We would like to thank the Mariscal Nieto Provincial Road Institute for the financing of the research as part of its Rehabilitation and Improvement project of Mariscal Domingo Nieto Avenue. We are also grateful to the Nucleus of Geotechnics of the Federal University of Ouro Preto for the help in the work with the precious discussions and theoretical contributions, and to the CAPES (Coordination for the Improvement of Higher Education Personnel) which allows us to improve the research.

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