G.Re.T.A. Solution to Monitor the Integrity of Tailings Dams

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ABSTRACT

The increasing number of tailings dams' failures in the recent decades highly demands to set up reliable systems to monitor the stability of these structures. Appropriate design, efficient operation and continuous monitoring are key solutions to guarantee the stability of earthen embankments including tailings dams.

Electrical resistivity tomography (ERT) is widely used in the mining industry for mineral exploration, groundwater studies, characterizing mine wastes and monitoring acid mine drainage. We present the capability of an Italian geo-electrical monitoring system (developed by LSI Lastem with the scientific support of Politecnico di Milano) for permanent monitoring of tailings dams. G.Re.T.A. (Geo Resistivimeter for Time-lapse Analysis) is an autonomous ERT system including a remotely controlled resistivity-meter with two cables connected to 48 stainless steel electrodes. The protected cables can be buried in shallow trenches along the embankments. The system can be powered by solar panels or power grid. Datasets of resistivity sections and acquisition parameters are available on a cloud platform. Site-specific algorithms for time-lapse data analysis and visualization of resistivity differences for any desired measurement period are available online to monitor the subsoil in real-time. An automatic control algorithm can detect if changes have approached pre-set thresholds and send alarms about anomalous changes to the customer.

The advancement of G.Re.T.A. is that it can be implemented as a long-term system to underline the internal heterogeneities of the tailings dams based on changes in resistivity values. The efficiency of the system has been proved in pilot sites for monitoring the internal conditions of river levees and through laboratory tests for shallow landslides. One G.Re.T.A. system was also installed in 2020 in a tailings dam in Chile to monitor underseepage. The system is capable of being used to monitor the inner properties of mine wastes, heap leaching facilities and tailings dams.

INTRODUCTION

In the period 1915-2020 (data available until 6 July 2020) 351 tailings dams failures occurred, of which 10 were classified as very serious accidents occurred from 2010 to 2020. For this and other reasons, dam monitoring of mining tailings has become a matter of primary importance, also because a standardized method has not yet been defined to monitor the stability of these structures during their life cycles.

Globally, we are moving towards the creation of standards and norms to make the management and monitoring of tailings dams as homogeneous as possible (https://globaltailingsreview.org/). The monitored parameters are normally acquired as point measurements, for example using piezometers, flowmeters, strain gauges, inclinometers. These technologies provide accurate values, but only relative to the point where the measurement is performed and cannot be used to monitor large areas of the structure due to technical and economic problems.

In recent decades, new monitoring technologies have emerged, which have sought to use volumetric or 2D measurements to fill the inherent gaps in point measurements. For example, geophysical measurements that have the advantage of being non-invasive and allowing the exploration of large areas of the subsoil through volumetric prospecting.

The electrical resistivity property depends on the composition of the soil, the porosity, the water content and the resistivity of the circulating fluids; thanks to these characteristics, geoelectric measurements can underline inhomogeneities in the dam body originating from water accumulation, presence of acid drainage, or formation of cavities. For this reason, the Electrical Resistivity Tomography (ERT) method is widely used in the mining industry, especially for exploration, groundwater studies, tailings monitoring (Karimi Nasab et al. 2011; Dimech et al. 2019; Martín-Crespo et al. 2019) and acid drainage (Hudson et al. 2018).

The geoelectrical measurements are effective when there is a difference in the electrical resistivity properties of the materials, for example when the soil is dry or wet, or when there is a cavity inside a structure. If two materials have the same properties, such as a same percentage of water saturation or some kind of pollutants, the model interpretation can be challenging, and direct measurements might be needed.

Over the last few decades, ERT has increasingly been used to monitor earthen embankments including river levees and tailings dams. We recently proposed the application of G.Re.T.A. (Geo-Resistivimeter for Time-lapse Analysis) system for permanent geoelectric monitoring to assess the inhomogeneity and integrity of mining tailings dams, both in terms of cavity formation and water accumulation.

The effectiveness of the system has been demonstrated in the last 6 years in pilot sites to monitor the internal conditions of river embankments (saturation conditions, presence of seepage, etc.) in the context of projects of national interest (Tresoldi et al. 2018; Hojat et al. 2019a; Tresoldi et al. 2019; Hojat et al. 2020; Tresoldi et al., 2020). The technology was also applied to laboratory experiments for the analysis of surface landslides (Hojat et al., 2019b; Ivanov et al., 2020) with the aim of recognizing non-homogeneous water accumulation zones and fractures.

METHODOLOGY

The G.Re.T.A. system

G.Re.T.A. is an autonomous and programmable system designed by LSI Lastem with the scientific support of the Politecnico di Milano. The system consists of a remotely controlled resistivity meter that can be connected to two cables, each equipped with maximum 24 electrodes (plate, grid or rods). The ERT profile supported by the G.Re.T.A. system can be thus composed of maximum 48 electrodes. The electrodes can be employed either on the ground surface (in case of rod electrodes) or buried in shallow trenches (plate and grid electrodes).

Unlike the common and multi-purpose portable geo-resistivimeters, the G.Re.T.A. system is a standardised solution that can be customized for each project remaining within two main characteristics of the system at the time of writing this paper: a maximum number of 48 electrodes for each central unit (the resistivimeter); and a maximum electrode distance of 3 m.

The most common unit electrode spacings are equal to 1m, 2m or 3m that, using the maximum possible 48 electrodes, allow horizontal length coverage equal to 47 m, 94 m and 141 m and the maximum depth of about 7.5 m, 15 m and 22.5 m, respectively.

On the other hand, the system is an off-the-shelf solution, easy to install in a maximum one working day with two technicians and does not require a complex configuration. The system can be later configured remotely if required.

After the installation, the device is permanently connected to a cloud software for sending real-time data, which are automatically inverted on the platform. In order to monitor subsoil variations, time-lapse data analysis algorithms are present to make comparisons between data in real time. The system allows the setting of resistivity variation thresholds and related alarms sent when the predefined thresholds are exceeded, indicating anomalous variations.

A couple of G.Re.T.A. systems are operational along river embankments and irrigation canals and another system was installed in August 2020 in the tailings dam of a mine in Chile, the name of which cannot be disclosed, respecting the privacy policy of the owner.

The study site

The objective of the geoelectric monitoring in the studied Chilean tailings dam was to evaluate the influence of the variations of the water level in two wastewater ponds on the variations of the groundwater level downstream of the dam. The ERT data were compared with the piezometric data of three piezometers installed in the area, in order to extrapolate the precise data throughout the survey area.

For this evaluation, two medium-term monitoring campaigns, lasting two weeks each, were set up along two semi-perpendicular profiles downstream the ponds located at the base of the dam. Profile 1 was arranged parallel to the slope downstream of the settling tanks (Fig. 1) and Profile 2 was placed almost perpendicular to the flow, with some limitations related to positioning due to non-flat topography. For these two monitoring profiles, an installation was prepared with cables placed on the surface, using stainless steel rod electrodes, implementing the Wenner configuration. We recall that the Wenner configuration is one of the most common linear configurations in which, the distance between the successive electrodes is the same. There are three types of Wenner configurations and we used the Wenner alpha array which is composed of the two external electrodes dedicated to insert the current and the two interior electrodes that are used to measure the voltage. We used the unit electrode spacing of 3 m between electrodes resulting in the profile length equal to 141 m and the maximum investigation depth of about 22.5 m. Using different quadrupoles, with different position along the profile and different distance between electrodes, it is possible to explore the whole section.

Figure 1 G.Re.T.A. system installed downstream the tailings dam in Chile, Profile 1

ANALYSIS

Data quality assessment

In order to obtain quality data from long-term geoelectric monitoring in an arid and harsh environment such as tailings dams, it is important to ensure a good coupling of the electrodes with the ground. Usually for long-term monitoring it is preferable to use plate electrodes installed horizontally in a shallow trench and covered with soil to ensure that contact is guaranteed over time thanks to the settling of the soil. In this case study, the medium-term installation did not make it easy to bury the electrodes, favouring the choice of rod electrodes, with the related problems in terms of contact resistances. To ensure a good coupling and acquire good quality data, salt water was used on the electrodes. Moreover, the contact resistances were measured daily for the entire installation period to analyse the trend over time.

As shown in Fig. 2b, the first measurements of contact resistances, carried out with the focus-one protocol (Ingeman-Nielsen et al., 2016) on 25 August 2020, the day of the installation of Profile 1, showed high values especially in the final part of the profile. This part of the profile was characterized by a drier soil and a greater grain size. The problem of high contact resistance was solved with better hammering the electrodes in that part of the profile as well as reducing the resistance by adding salt water. During monitoring, up to the last day, even thanks to the precipitation events at the site, the contact resistances were further improved, and they were found to be reduced to around 1-1.5 kΩ along the entire profile. This is quite a reasonable range to have high-quality data from this point of view.

To further control the quality of the measurements, each measurement was repeated and with the standard deviations of the measurements were calculated. The standard deviation values were less than 1.7% on the day of installation and less than 1% over the medium-term monitoring period which confirms high-quality data acquisitions (Fig. 3).

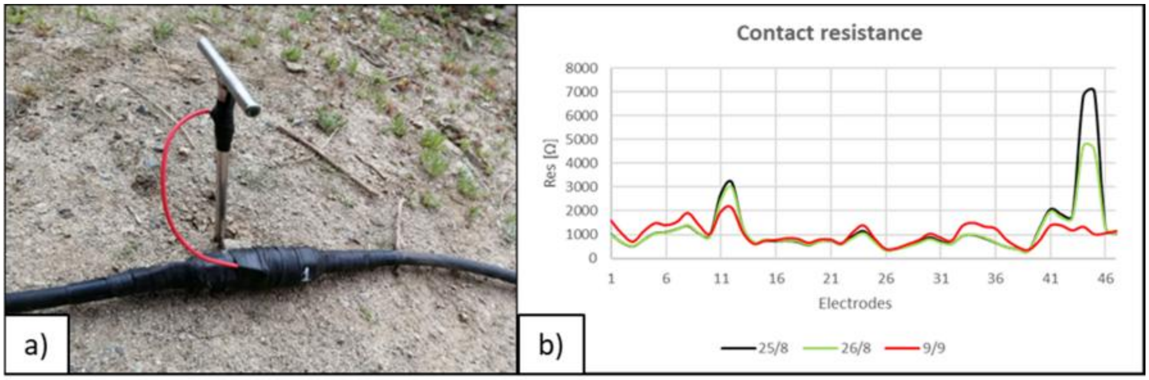

Figure 2 a) Rod electrode; b) Contact resistances along Profile 1 during installation (black curve), after the sprinkling of salt water (green curve), at the end of monitoring (red curve)

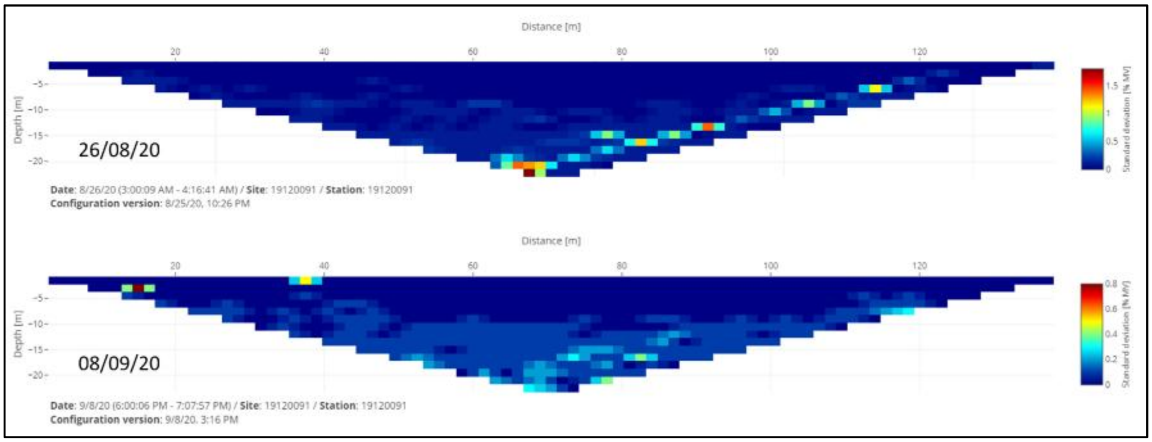

Figure 3 Standard deviation pseudosections: 26/08/20 (above) and 08/09/20 (below)

RESULTS

ERT data vs Piezometric data

The inverted section of Profile 1 (Fig. 4) shows a clear resistivity contrast that suggests a two-layer model: a first layer, up to 5-8 m of depth, with higher resistivities (from 200 to 700 Ωm) and a second layer with significantly lower resistivities (<80 Ωm). These layers were interpreted, by comparing the ERT data with the piezometric ones, with the presence of the groundwater in the lower layer. By observing the punctual data of the piezometer present along the profile, it is possible to recognize how the limit between the two layers underlined by geoelectrical measurements is in agreement with the piezometric data, with level of the aquifer on 2 September 2020 equal to -8.50 m.

The geoelectric data acquired along the monitoring periods allow to follow the variations in the groundwater level indicated by the piezometers on site, providing spatially distributed data of the influence of the level variation of the wastewater ponds on the groundwater level.

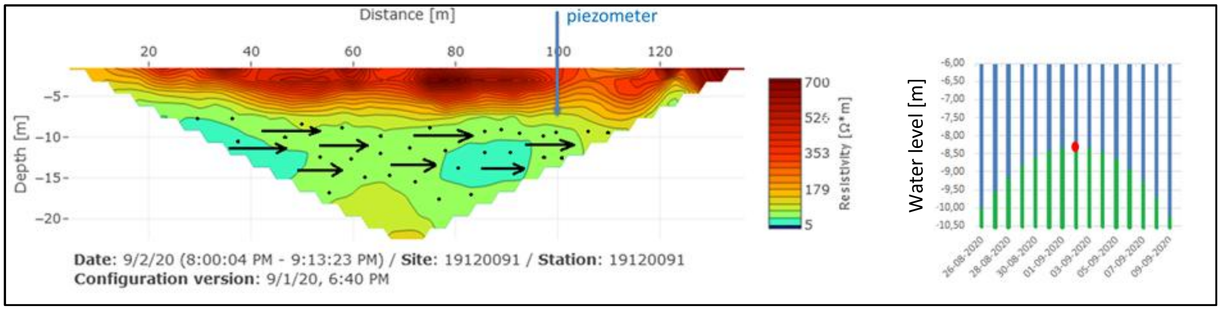

Figure 4 Left: Inverted section of Profile 1 dated 02/09/20 with positioning of Piezometer 3 (blue arrow); Right: Groundwater level during the monitoring period with indication of the level in 02/09/20 (red dot)

CONCLUSIONS

The G.Re.T.A. system, an autonomous geo-resistivimeter for time-lapse measurements, can fill the technological gap for soil water content, seepage or cavity formation monitoring in tailings dams. Continuous geoelectric measurements can indicate the processes and variations in progress in the dam structure, caused by filtrations, fractures or different soil water contents.

The two medium-term campaigns carried out in August 2020 in a tailings dam in Chile highlighted the effectiveness of the technology for monitoring the variation in the groundwater level due to a filtration phenomenon. The remote and autonomous installation in an extreme environment such as that of mining tailings dams has been successful ensuring high data quality and effective remote parameter control.

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