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G.RE.T.A. INSTALLATIONS FOR REAL-TIME MONITORING OF IRRIGATION DAMS AND CANALS*

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Abstract

Climate change, with periods of drought and concentrated periods of intense rainfall, has drawn attention on the importance of retaining and properly managing water for agriculture. More than 50% of water in Italy is addressed to irrigation and 47.9% of the total extracted water does not reach the final user (ISTAT report on water 2015-2018). The construction of new irrigation reservoirs is expected in Italy (PIANO NAZIONALE NEL SETTORE IDRICO – "SEZIONE INVASI" art. 1, 155, 145/2018) and one critical issue is ensuring the integrity of these infrastructures, not only for saving water but also for reducing the hydrogeological risks. G.Re.T.A. (Geoelectrical Resistivimeter for Time lapse Analysis) is an Italian autonomous geo-resistivimeter developed by LSI Lastem with scientific support of Politecnico di Milano. It uses Electrical Resistivity Tomography (ERT) measurements for long-term installations. Since soil resistivity is a function of granulometry, porosity and water saturation, G.Re.T.A. can monitor structures in real-time to identify potential seepages, fractures, and similar heterogeneities that can lead to leakages (loss of water) or collapse (risk for human lives and economic activities). The system works remotely and sends data to a cloud platform, where results can be analyzed. Thresholds of alarm can be set and the instrument can be programmed accordingly. Consorzio di Bonifica di Piacenza has recently included a permanent geoelectrical monitoring system in the technical specifications of a tender for the construction of an irrigation basin that will be built in Fabbiano di Borgonovo. The monitoring system will scan the daily situation of the structure, providing an innovative method to assess the vulnerability of the dam to avoid loss of water and to increase the effectiveness of the distribution network. G.Re.T.A. has been already installed along two levees to

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monitor possible concentrated seepages and detect animal burrows: an irrigation canal in San Giacomo delle Segnate, and Parma river in Colorno.

Keywords: basin, climate change, electrical resistivity tomography, geoelectrical monitoring, irrigation, levee

1. Introduction

Climate change has an important impact on the availability of water resources for irrigation in agriculture. Periods of drought alternated to concentrated periods of intense rainfall are stressing the irrigation water supply systems and all the agriculture sector. The main problems related to irrigation network in Italy are the ancient origins and the unknown inner conditions of the retaining structures. This prevents 47.9% of the total extracted water for irrigation, which is more than 50% of the total extracted water in the Country, from reaching the final user (ISTAT report on water 2015-2018). Monitoring of irrigation canals and levees is performed by Consorzi di Bonifica through periodic visual inspections made by personnel or volunteers. This human-dependent procedure can only assess the external part of structures, without understand the undergoing subsoil processes such as seepages, rodents burrows, and leakages.

The irregular hydrologic flow due to climate change is causing the construction of new irrigation reservoirs, expected in Italy after the definition of a National Plan (PIANO NAZIONALE NEL SETTORE IDRICO – "SEZIONE INVASI" art. 1, 155, 145/2018). Ensuring the integrity of these infrastructures is of vital importance, not only for water saving but also for reducing the hydrogeological risks.

In last decade geophysical methods and most of all geoelectrical methods have been used to assess the vulnerability of earthen structures. Electrical Resistivity Tomography (ERT) method proved to be a reliable and successful method to underline seepages and cavities in levees and dams (Asch et al., 2008; Comina et al., 2020; Hojat et al., 2019a, 2020; Inazaki, 2007; Perri et al., 2014; Zumr et al., 2020).

In this study we describe G.Re.T.A. (Geoelectrical Resistivimeter for Time-lapse Analysis), a system to monitor in real-time the inner condition of embankments and dams. Preliminary studies and pilot installations are described, as well as the recent proposal of G.Re.T.A. installation for a tender for the construction of an irrigation basin by Consorzio di Bonifica di Piacenza.

2. Material and methods

Electric resistivity is a soil physical characteristic depending on granulometry, porosity, water content and resistivity of the circulating fluids. Changes in water saturation and formation of voids can significantly affect resistivity variations.

G.Re.T.A. is a geo-resistivity meter designed by LSI Lastem with the scientific support of Politecnico di Milano. It is an autonomous device formed by a central measuring and communicating unit connected to two cables with a total number of 48 electrodes (plate, mesh or rod type). Cables and electrodes can be buried inside a shallow trench (usually 30-50 cm deep) or deployed on the soil surface. The station is permanently connected to a cloud-based database and software, where measured data are sent and where the device can be programmed remotely. The instrument permits the real-time monitoring of a large subsoil section in terms of soil resistivity variations along time. The user can check the data on the cloud and set thresholds of instability based on resistivity variations. Thanks to samples from any study site, it is also possible to relate inverted resistivity values to soil water content, calibrating a function based on direct values of water content measured in laboratory.

The first installation of G.Re.T.A. system dates back to 2015 (Arosio et al., 2017, Hojat et al., 2020; Tresoldi et al., 2018, 2019). The monitoring system, that can now be applied in different studies (landslides, tailings dams, landfills, contaminated sites, agriculture, transportation embankments, etc.), was firstly designed and conceived for sustainable and resilient agricultural water supply. The system was installed on the levee of an irrigation canal in San Giacomo delle Segnate, in the district of Consorzio di Bonifica Terre dei Gonzaga in Destra Po (Fig. 1), using the Wenner array with unit electrode spacing of 1 m, obtaining a profile length of 47 m and a maximum penetration depth of 7.5 m. The aim was monitoring of concentrated seepages and leakages in the levee body as well as analysis of the influence of buried electrodes and meteorological variables on resistivity data.

Fig. 1. G.Re.T.A. system in operation in San Giacomo delle Segnate, checked frequently through comparison with a portable instrument

The second installation designed for hydraulic monitoring was completed in 2018, in Colorno (Hojat et al., 2019a), in the district of Agenzia Interregionale del fiume Po (AIPO). The installation site was selected after preliminary geophysical measurements (one-shot and time-lapse geoelectrical measurements and fast scanning electro-magnetic campaigns). The selected site is a stretch of embankment of Parma River, subjected to partial collapse after a flood in December 2017 and partially rebuilt with more impermeable materials. An additional important factor that was considered for installation was the presence of houses nearby the levee, since exposure of the surrounding areas is a determining factor for risk protection. In this case, since the height of the embankment is 5-6 m, the selected electrode spacing was 2 m resulting in a profile length of 94 m and a maximum investigation depth of 15 m. The aim was to monitor the heterogenous levee body in order to recognize the creation of fractures and the generation of seepages that could lead to collapse.

Consorzio di Bonifica di Piacenza has recently included a permanent geoelectrical monitoring system in the technical specifications of a tender for the construction of an irrigation basin in Fabbiano di Borgonovo. The authority wants to use a geoelectrical system to permanently monitor the part of the irrigation reservoir with higher levees along a total length of 350 linear meters. The part of the dam to be monitored is 5-6 m high, with a steep curvature. LSI Lastem designed a monitoring system composed of several G.Re.T.A. stations, with different electrode spacings, in order to properly monitor different sides of the basin. The objective of the monitoring is to enhance the security level and assess the vulnerability of the structure, avoiding seepages that can result both in the loss of water and in collapse events.

3. Experimental studies

The data gathered by G.Re.T.A. installations in pilot sites from 2015 allowed us to carefully study the geoelectrical monitoring strategy for earthen structures. We have analyzed the effect of buried electrodes, resistivity response to external parameters and 3D geometry of the structure. The procedure to obtain a relation between resistivity and water content is also defined.

In order to be able to relate rainfall, air and soil temperature and canal water level to inverted resistivity data during different irrigation periods, G.Re.T.A. system in San Giacomo was installed with a weather station, a Time Domain Reflectometry (TDR) probe and a water level sensor (Tresoldi et al., 2019). Since electrodes are installed in a trench of 0.5 m of depth, the influence of buried electrodes was analyzed and a correct formula for the geometrical factor of measurements was obtained and applied to G.Re.T.A. data.

In Colorno, the river is not directly in contact with the monitored levee and thus, only a weather station was installed, and the effects of rainfall and 3D effects related to geometry were studied. Resistivity measurements are subjected to the so-called 3D effects because resistivity measurements are not only affected by variations below the ERT line, but also by the changes in the direction perpendicular to ERT lines. Therefore, the 3D geometry of levees, dams and such structures must be considered in analysing the data. This problem was well studied in laboratory and numerical studies (Hojat et al., 2019c, 2020). During last years, several small-scale levees were built in the Laboratorio di Idraulica Montana of Politecnico di Milano, Lecco campus (Hojat et al., 2020). During lab tests on small scale levees, different boundary conditions and rainfall events were analysed.

After having analysed the importance of 3D effects at the laboratory scale, 3D effects were also estimated for each pilot site (Hojat et al., 2019b, 2020).

Another possibility provided by the geoelectrical monitoring is the quantification of water content variation. Since resistivity and water content are inversely proportional and many empirical relations exist in bibliography, it is possible to convert inverted resistivity values into water content or saturation data. In San Giacomo delle Segnate, an empirical and site dependent relation was obtained thanks to coring information on the levee crest. Ten samples were extracted at different depths and their water content values were analysed in laboratory. Knowing the resistivity at each point, it was possible to calibrate a function that links the two variables.

4. Results and discussion

What emerged from pilot sites is that the meteorological variable that influences most the data is rainfall, because when water infiltrates the soil, resistivity suddenly decreases down to 1-1.5 m of depth. Air and soil temperature variations influence soil resistivity with high frequency only in the shallow part, slow seasonal variations can interest also deeper parts (Tresoldi et al., 2018).

Studies on 3D effects demonstrate that soil heterogeneities and geometry of levees and dams can greatly influence the data, but the influence does not change in time as long as the boundary conditions (e.g., water level) are not changed. Therefore, 3D effects are ignored for daily comparisons while corrected for long term analysis. 3D effects were quantified site by site and removed thanks to a correction procedure (Hojat et al., 2020).

The technology proved to be reliable and has been increasingly considered as an effective method for subsoil monitoring. The tender for the irrigational basin in Fabbiano di Borgonovo, closed in late July, proves that geoelectrical monitoring is now indexed among methods to enhance safety of retaining structures. The tender specified an area to be monitored that is straddling a curve of the reservoir, with a total length of 350 m. When designing the monitoring system, it was necessary to consider both the maximum length of linear parts (because curvatures in the ERT profile are not recommended) and the maximum depth to be reached, always guaranteeing a sufficient data resolution.

To cover the desired length, four G.Re.T.A. systems, with 48 electrodes each, have been proposed (Fig. 2), with different electrode spacings according to the segments of levees to be analysed:

- ERT1 with 3 m spacing resulting in a total profile length of 141 m and a maximum penetration depth of 22.5 m;
- ERT2, positioned in the sharp curvature, with 1 m spacing and thus, a profile length of 47 m. The constrain of the limited available linear space causes a limited penetration depth, only down to 7.5 m;
- ERT3 and ERT 4, partially superimposed to cover all the desired length, with a distance of 2.5 m between electrodes and an investigation depth of 18.5 m.

The systems will be permanently connected to a cloud software where the users can access the data, process and compare them and set alarm thresholds to be notified if anomalous changes happen.

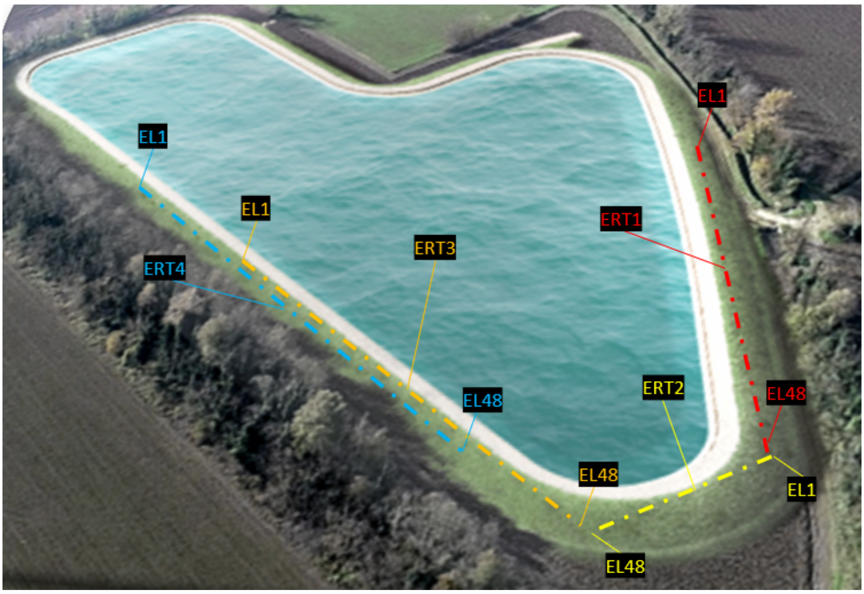

Fig. 2. Design of the suggested monitoring systems for the irrigation basin in Fabbiano di Borgonovo

6. Conclusions

After several studies on pilot sites, G.Re.T.A. system proved to be a reliable monitoring tool for irrigation and river structures, able to detect subsurface changes in soil structures, such as development of voids or leakages.

The system has been improved and the parameters affecting the measured data have been studied along several years. The correction procedure is well developed accordingly.

G.Re.T.A. is now ready to be implemented as an innovative monitoring system to ensure an optimised operation of key water infrastructures (dams, levees, reservoirs) to cope with the present and future problem of water shortage related to climate change.

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