CORRECTING THE INFLUENCE OF 3D GEOMETRY TO PROCESS 2D ERT MONITORING DATA OF RIVER EMBANKMENTS AT THE LABORATORY SCALE

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Introduction. The frequent extreme floods occurred in last ten years in Europe have arisen an interest in decreasing hydrogeological risks and assessing the stability of the defense structures. In last years, geophysical methods have been used to assess the stability of embankments. Geoelectrical methods have specifically shown to be very suitable in monitoring the variations of water saturation and detecting inhomogeneous seepage zones in earthen slopes, dams and dikes (Dahlin et al., 2008; Kuras et al., 2009; Jomard et al., 2010; Supper et al., 2012; Perri et al., 2014; Loperte et al., 2016). In 2015, a geo-electrical monitoring system was installed on the earthen levee of an irrigation canal in San Giacomo delle Segnate, Mantua, northern Italy (Arosio et al., 2017) to monitor the inner condition of the structure in real time. The device is a prototype of resistivity meter installed permanently with two buried cables equipped with 48 stainless-steel plate electrodes, together with a meteorological station. The system is still working, operating remotely and sending the measured resistivity data through an internet connection to provide real-time information about the variations in water saturation and seepage in the levee body based on a defined calibration procedure (Tresoldi et al., 2018).

To study resistivity changes within the structure due to changes in the water level in the channel as well as rainfall events, and to better analyze the monitoring data recorded so far, a small-scale flume was constructed in Applied Geology and Geophysics Laboratory of
Politecnico di Milano. A couple of tests were performed on a small-scale levee – representing the real site – experiencing different levels of water in the channel and various rainfalls. The survey layout, the materials and the geometry of the structure being known, we implemented a forward modelling approach to assess the 3D effects and the influence of buried electrodes to correct the measured data. Quantifying the effects related to 3D geometry and the survey configuration on 2D datasets is very important to correct the measured apparent resistivity values and to properly identify the variations of the embankment conditions (Sjödahl, 2002).

**Small-scale laboratory tests.** The actual test site was scaled down for a scale of 1:12 (Fig. 1a) on a laboratory flume with transparent plexiglass walls and base size 80×200 cm. Two taps were put to allow water entrance and discharge and 6 sprinklers were placed on the top frame of the flume to simulate rainfalls. The embankment was built with homogenous sand with initial volumetric water content of 13%. Future tests are also planned to be performed with the soil collected from the real site. Two miniaturized cables equipped with 48 2 cm-long stainless-steel electrodes were designed, assembled and tested for laboratory purpose and connected to an IRIS Syscal Pro resistivity meter. Time-lapse ERT measurements were carried out with the Wenner array configuration (a = 3 cm), with a horizontal resolution of 3 cm and a vertical one of 1.5 cm, and the electrodes were buried at a depth of 2 cm along the levee in order to avoid preferential paths for rainfall infiltration. In addition, a TDR was embedded in the structure to measure volumetric water content values during the tests and two GoPro cameras were set to take pictures every 10 s.

Three sets of experiments were performed to investigate the ideas of this research. In one test, the seasonal filling and drawdown procedure typical for irrigation canals was reproduced (Fig. 1b). Levees of irrigation canals are subject to seasonal cycles of saturation and drying,
that are not common in large river dikes and that are quite dangerous for the stability of the structure. To model the water level variations in the canal in the real site, water heights of 5.5 cm and 11.5 cm from the channel base were studied at the laboratory corresponding to half of the scaled maximum height in the field and the maximum scaled, respectively. The water level was then lowered with the same procedure. Resistivity variations and accordingly the water saturation changes within the levee were continuously monitored during the test using high speed acquisitions taking about 3 min. High frequency of measurement is crucial in time lapse monitoring, especially in small scale tests and with the material used in these tests, that has high permeability. In the second test, a rainfall event with different intensities was simulated at the end of the irrigation period. This test was performed also because in the field it is quite difficult to separate rainfall influence from the effect produced by changes of water level in the canal. The reason is that the managing authority lowers the water level in the canal during the rain to avoid overtopping. Rainfall event was simulated when the canal was empty, but the water saturation of the soil was estimated about 35% according to TDR measurements. Two different rain intensities of 57 mm/h and 65 mm/h were used for this test. In the third experiment, a rainfall event during winter period, when irrigation is not performed, was modelled after a short drying period. Time-lapse ERT data were measured with empty canal and volumetric water content of the soil was 24%. Two rainfall intensities of 79 mm/h and 90 mm/h were used to simulate precipitation intensities.

**Data processing.** After performing the experiments and having a look at measured resistivity pseudosections of different times, we noticed that all datasets showed an anomalous increase of resistivity values with the depth. Fig. 2 shows two examples of such meaningless trends in measured pseudosections for the experiment simulating filling and drawdown periods. Fig. 2a is measured at T29 when the water level in the canal was 5.5 cm and Fig. 2b was measured at T1.37 when the water was discharged from the canal. This amplification of resistivity values was so strong that inversion of datasets was useless ending in resistivity sections without any geological meaning.

The increasing effect was first assumed to arise from the high resistivity base of the flume. 2D analytical calculations for a two-layered earth model, and forward modellings performed in Res2dmod software proved other important factors being responsible for rapid resistivity increases with the depth (Arosio *et al*., 2018). The problem is born from the limitation of 2D surveys and models in assuming that the resistivity does not change in the direction perpendicular to ERT profiles. Apparent resistivity values measured along a river embankment are not only influenced by the materials directly below the ERT line, but also by severe lateral resistivity changes at the sides of the profile (river channel with varying water levels on one side and the air on the other side). Moreover, high-resistivity base and sides of the flume also
affect the measured data in laboratory studies. Therefore, we developed a method to assess such 3D effects on 2D ERT data measured along the river levees (Arosio et al., 2018). Moreover, we developed an analytical procedure to take into consideration the effect of buried electrodes. The presence of buried electrodes, not in contact with the air-soil surface, appears to modify the measured resistivity, lowering the real value in the shallow depth. The result is a data correction strategy to correct the effect of buried electrodes, transforming the measured data as it was performed with surface electrodes, and then to correct the geometry effect of each test implementing a forward modelling with Res3dmod and then obtaining a correction curve indicating the geometrical amplification of the resistivity of the soil (Arosio et al., 2018).

Fig. 3a and Fig. 3b illustrate the final correction graphs obtained for T29 and T1.37. The graphs are calculated for the Wenner array with the unit electrode spacing used in the corresponding experiment. The correction graphs show how fundamental is to process 2D ERT data for 3D effects to remove artefacts in the analysis of the resistivity variations. It is clear that such an amplification is not correlated with geological aspects and can strongly affect the interpretation of the data. Fig 3c and Fig. 3d show the pseudosections of T29 and T1.37 corrected using their corresponding correction graphs. Fig.3.c now shows a reasonable range of resistivity values. The soil is mostly saturated even if the water level is not at a maximum height in the canal due to the high permeability of pure sand. TDR data also showed that shortly after adding water in the canal, the volumetric water content reached a maximum value of 35% and then remained constant at this value regardless the further increase of water level. Resistivity variations in Fig.3.c are attributed to compaction variations resulting from the manual construction of the levee model. Fig.3.d shows the situation after the drawdown procedure when the resistivity values are slightly higher. The sand has a fast response to water circulation and therefore,
resistivity values are reflecting this characteristic. For this reason it is really important to select an appropriate sampling frequency to perform high speed resistivity measurements.

Conclusions. Although 2D ERT profiles along earthen embankments provide a reasonable layout to study the internal conditions of these structures, 2D profiles are significantly affected by 3D effects arising from the geometry of the embankment. Buried electrodes also play an important role in measurements of apparent resistivities, especially in the shallow part of the investigated area. Analytical modelling was performed to quantify this effect and remove this influence, transforming the data as they were measured with surface electrodes. We used a correction strategy developed by the authors to correct raw data obtained along the river levees and the results show that ERT data are considerably changed after being processed for the effects of 3D geometry and buried electrodes. The correction graphs show that the measured resistivity values are highly amplified with the depth due to 3D geometry of levees. The correction strategy is reasonably removing such effects but it is still an interesting area of research to be well developed to accurately correct these effects.

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References