Study of the continuity of embankment diaphragms with electrical methods

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ABSTRACT: Checking the continuity of the embankment diaphragms is a fundamental step in their construction. Here we illustrate the case study of a stretch of a river embankment, along which a long plastic diaphragm was inserted, of which we tried to verify the continuity by means of an electrical geophysical approach. The approach involves the initial study of the electrical resistivity of the embankment body transversely to the diaphragms. Subsequently, through the creation of piezometric holes, water is injected from only one side of the diaphragm and the variation in electrical resistivity over time is monitored along transversal sections of the embankment body. A possible non-continuity of the diaphragm would translate into a reduction in the resistivity values also on the opposite side of the diaphragm compared to the one where the fluid is introduced. The observation of resistivity variations over time also provides information on the on-site permeability of the soil.

1 INTRODUCTION

Extreme weather events in recent years frequently result in riverbank breaches.

We focus on a river stretch along which plastic diaphragms were built, for approximately 2 km, aligned with the embankment, up to a depth of 18 m, embedded in the clayey substrate.
These diaphragms were made in two series: the primary panel is made up of 7 m long elements, spaced 6.5 m apart. This distance is then filled by the secondary panel, with an overlap of at least 25 cm between adjacent elements, and forms a joint.

In order to verify the integrity of a joint of the plastic diaphragm, it was proposed to use electrical geophysical prospecting. Since no surface geophysical method can have, at the depths of interest in this study, such a resolution as to directly observe the continuity of the diaphragm elements and their overlaps, it was decided not to monitor the phenomenon (the integrity of the joints) but its effect (i.e. whether the diaphragm truly constituted a barrier to the passage of water or not).

A test field was therefore built in a section of the embankment by inserting two piezometric tubes upstream of the line of the diaphragms (Figure 1). Salt water was introduced into these pipes and, through a series of resistivity measurements then interpreted according to the principles of electrical tomography, it was observed whether the water was also distributed downstream of the diaphragms.

2 FIELD SURVEY

2.1 *First field survey (July 2024)*

In the first investigation campaign, an array of 48 electrodes was deployed across the embankment, connected to an Electra acquisition system (MoHo srl). Alternating current at 8 Hz and with an amplitude of 50 mA was injected into all possible electrode pairs and the apparent resistivity between all possible pairs of measuring electrodes was measured. The apparent resistivity measured data were then grouped according to the geometry known as Wenner, Schlumberger and dipole-dipole (Telford et al., 2010) and inverted by means of several least-squares iterations, until getting a low RMS mismatch between apparent resistivities (model vs. measured), thus validating the 'real' resistivity image that was obtained (Figure 2). Here we will restrict the discussion to the Wenner acquisition geometry, which provided clear results.

According to the survey, the embankment is composed of material with low resistivity (less than 100 Ωm) in the first approximately 7 m, followed by a silty body approximately 2 m thick with higher resistivity (400 Ωm) and again the low resistivity up to about 15 m depth. This interpretation appears in line with the data available from the survey (top table in Figure 2).

The head of the plastic diaphragm is located approximately 1.5 m from the current ground level level. The diaphragm (green rectangle in Figure 2) is not particularly recognizable compared to the surrounding ground, as the resistivities are similar.

This makes exploration methods aimed at identifying the continuity of the diaphragm itself ineffective, as it is itself barely distinguishable from the body in which it is immersed, electrically speaking.

Immediately 'upstream' (river side) of the diaphragm is the piezometer, with windows between 4 and 8 m deep, to introduce water (yellow rectangle in Figure 2).

We therefore proceeded to introduce a saline solution into the hole and monitored the trend of the resistivity over time. In the presence of a continuous diaphragm pushed up to the waterproof substrate, a reduction in resistivity is expected only in the section upstream of the diaphragm (on the left in Figure 2).

The resistivity was monitored after the introduction of 200 liters, 400 liters and 600 liters of water. However, a clear reduction in resistivity values was also observed on the downstream side of the piezometer, over time (Figure 3b), which is interpreted as a probable migration of the fluid even beyond the diaphragm.

In order to better understand whether this phenomenon is real, a second investigation campaign was planned.

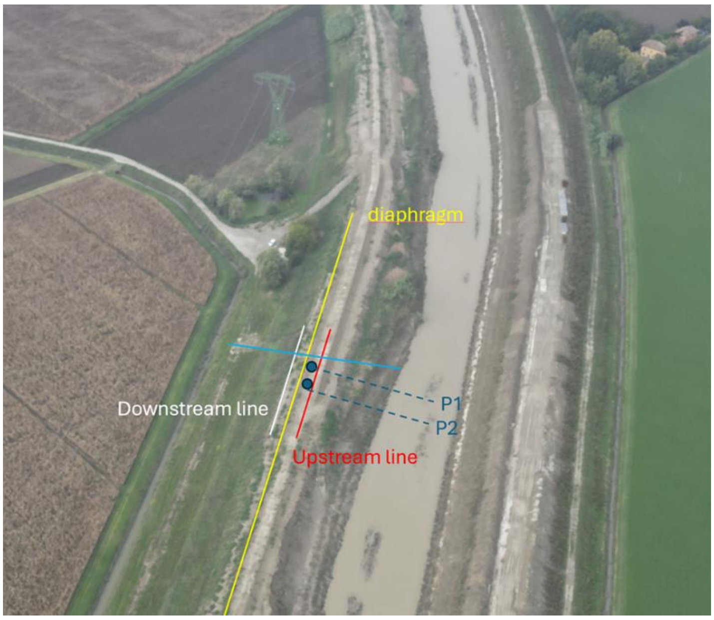

Figure 1. Plastic diaphragm line (yellow). Geo-electrical lines (transversal in blue, longitudinal upstream of the diaphragm in red, longitudinal downstream of the diaphragm in white). Indication of the holes for water injection (P1 and P2), upstream of the diaphragm. The joint investigated is in correspondence with piezometer P1.

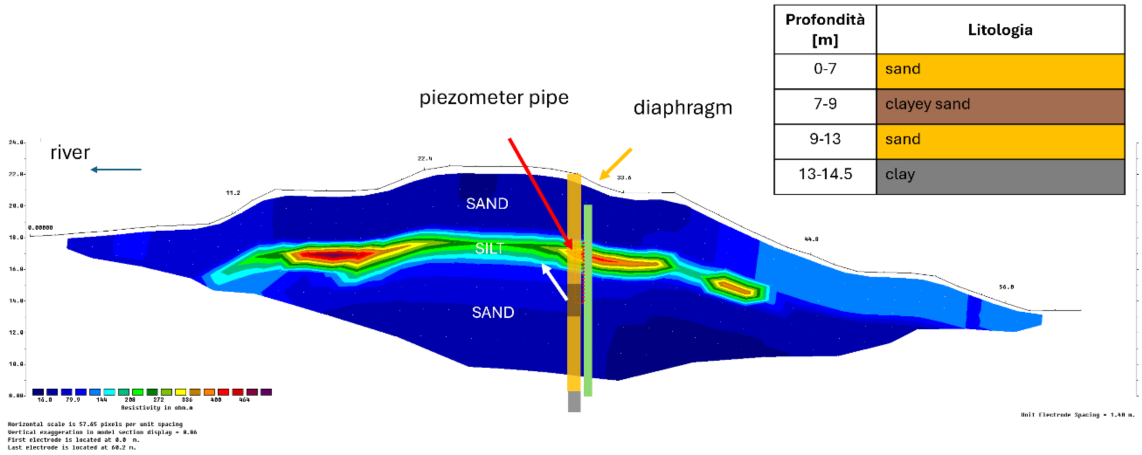

Figure 2. Stratigraphic column and electrical resistivity cross section of the embankment in the investigated section.

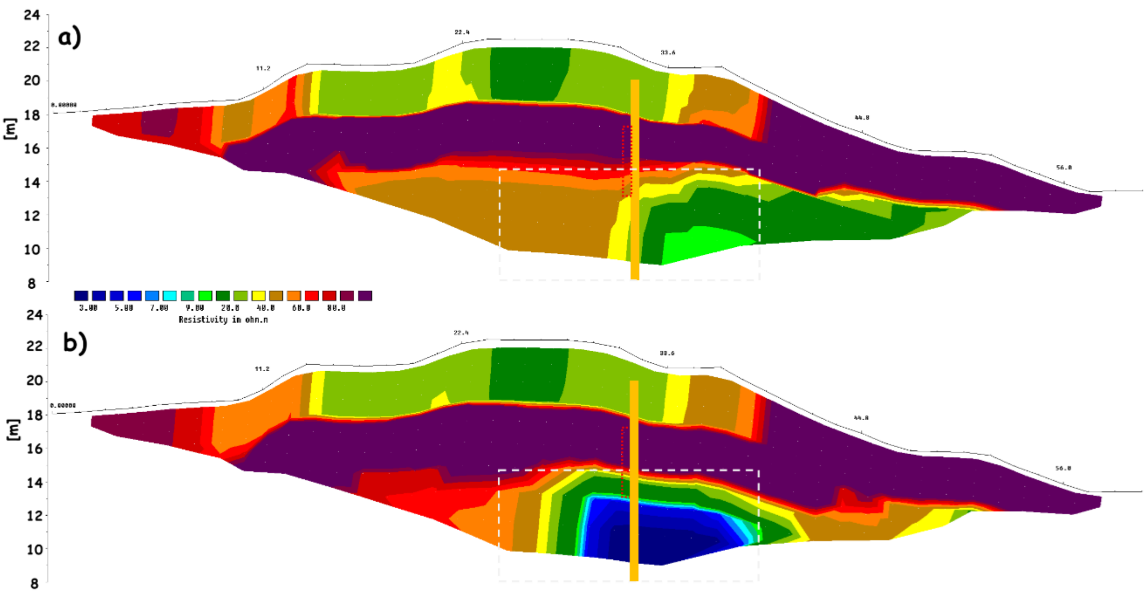

Figure 3. Cross section of the embankment, in electrical resistivity, with focus on resistivity values lower than 100 Ωm. a) before the introduction of salt water into the piezometric hole, b) after the introduction of 400 liters of salt water.

2.2 *Second field survey (November 2024)*

On this occasion, fluid was injected first from piezometer P2 and then from piezometer P1. In Figure 4 we can observe the evolution from the pre-injection stage to the stages at the end of the injection in P2 and P1, respectively, for the section upstream of the diaphragm.

In the first stage the diaphragm shows the already described (Figure 2) succession of sand (low resistive) – silt (high resistive) – sand (low resistive).

In the second stage, an expansion of the low resistivity zone is observed around the P2 entry point and in the third stage, a further expansion of the low resistivity zone is observed (Figure 4).

All this was expected, since the injected fluid has the effect of lowering the resistivity of the soil and in a few minutes the soil absorbed over 500 liters of water for each piezometer.

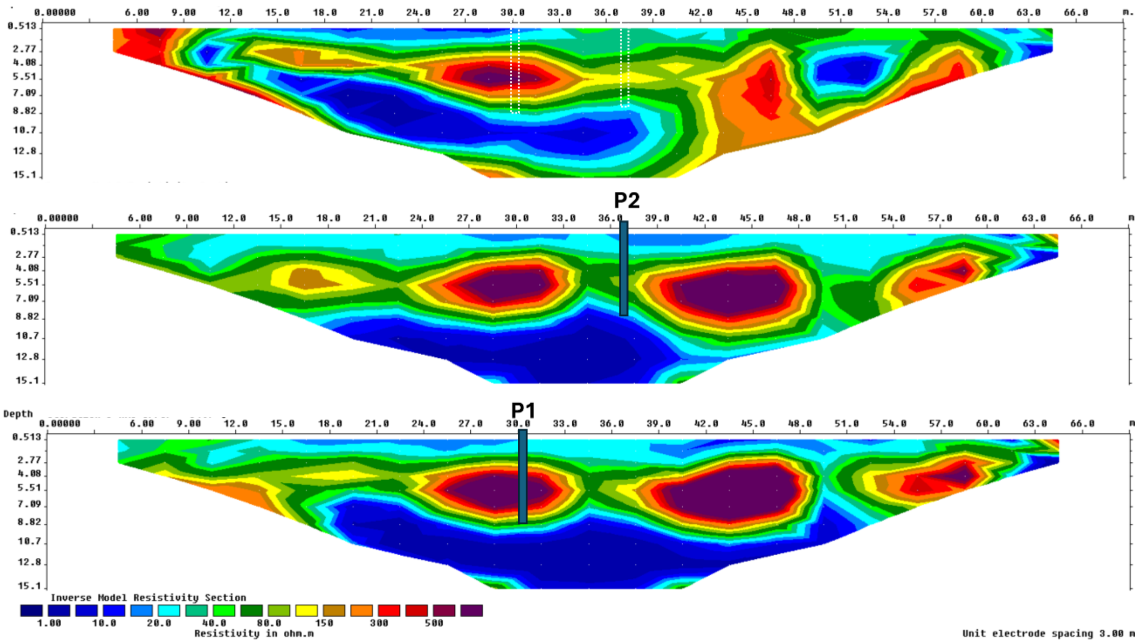

Figure 4. Resistivity tomography of the upstream longitudinal section with respect to the diaphragm. Top: pre-fluid injection situation. Center: during the injection of fluid in piezometer P2. Bottom: during the injection of fluid in the piezometer P1. The fluid injection took place between 4 and 8 m depth.

In Figure 5 we can observe the evolution from the pre-fluid injection stage to the stages at the end of the injection in P2 and P1 for the section downstream of the diaphragm. In conditions of an intact diaphragm, continuous and deep enough to reach the not-permeable substrate, no variations in resistivity downstream of the diaphragm would be expected.

However, the electrical tomographies suggest also in this occasion, as in July 2024, a reduction in the resistivity values around the piezometers. The situation is particularly clear in the case of injection from piezometer 1, i.e. in correspondence with the investigated joint.

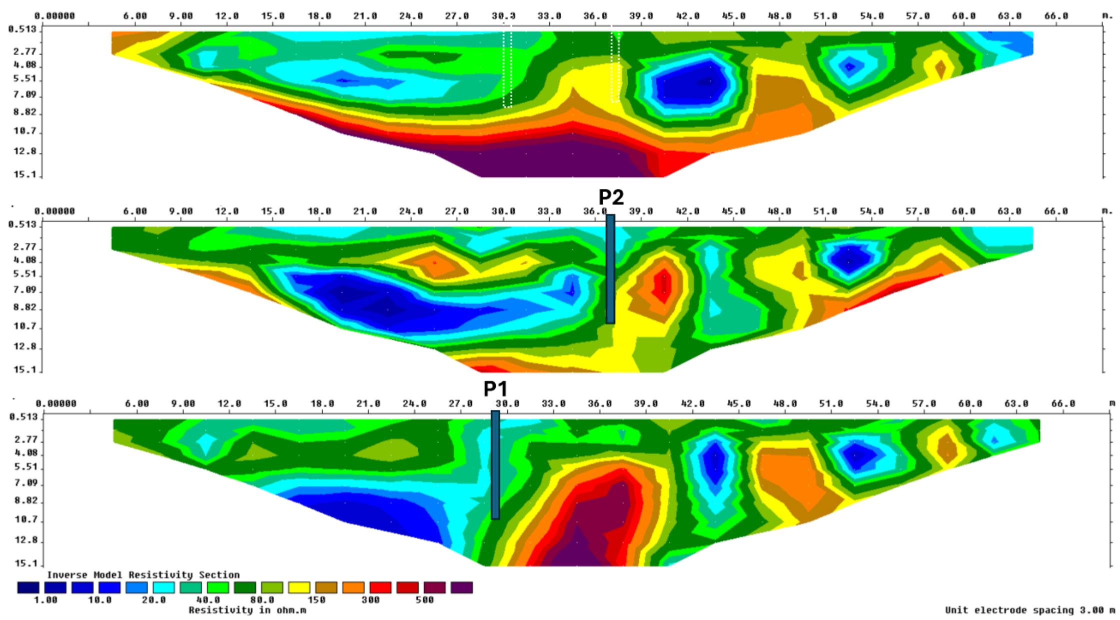

Figure 5. Resistivity tomography of the downstream longitudinal section with respect to the diaphragm. Top: pre-fluid injection situation. Center: during the injection of fluid in piezometer P2. Bottom: during the injection of fluid in the piezometer P1. The fluid injection took place between 4 and 8 m depth.

3 DISCUSSION AND CONCLUSIONS

Checking the continuity of the embankment diaphragms is a fundamental step in their construction and there are few non-invasive geophysical techniques that can help in this sense.

In this study we presented the case of verifying the continuity of one of the joints of a plastic diaphragm on a river embankment, recently affected by episodes of failure following extreme events.

Since the plastic diaphragm ha electrical resistivity characteristics that make them not distinguishable from the encasing ground, we proposed to study their continuity by verifying whether they let water diffuse from 'upstream' (river side) to 'downstream'.

We therefore studied the variations in electrical resistivity first along a transversal section of the embankment and the diaphragm panels (injecting water upstream), in correspondence with the joint examined, and then along two longitudinal sections, one arranged upstream and one downstream of the diaphragm.

The proposed method proved to be useful in observing the effectiveness of diaphragm joints.

References

Telford, W.M., Geldart, L.P. & Sheriff, R.E., 2010. *Applied Geophysics*, Cambridge University Press, 792 pp.