

# ERT geophysical survey for Landslide Risk Management in Coastal Areas: Case Studies of Brovinje and Havišće (Croatia)

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**Abstract** – This work presents the application of Electrical Resistivity Tomography (ERT) as a key geophysical technique for the characterization of the shallow subsurface in two pilot sites, Brovinje and Havišće, located in coastal areas of Croatia. These investigations were conducted within the framework of the Project RESONANCE – Interreg Italy-Croatia, aiming to improve landslide risk prevention and management. The ERT surveys provided crucial insights into the geological and structural settings of the areas. At the Brovinje site, ERT imaging allowed for the characterization of the structural style and the identification of lithological units, discerning between high-resistivity limestone and lower-resistivity marl. At the Havišće site, the surveys revealed the presence of incoherent dumped material, approximately 3-5 meters thick, and highlighted significant fracture zones. The results demonstrate the effectiveness of ERT in providing valuable subsurface geological information essential for comprehensive landslide risk assessment and mitigation strategies in coastal environments.

**Keywords:** Electrical Resistivity Tomography (ERT); Landslide Risk Management; Croatian coastal areas; Interreg Resonance Project.

## I. INTRODUCTION

Coastal and transitional areas represent highly dynamic, quickly-changing environments [1]; these zones worldwide are increasingly vulnerable to geo-hazards, particularly landslides, which are exacerbated by factors such as climate change, sea-level rise, and anthropogenic activities. Effective landslide risk management necessitates a thorough understanding of subsurface geological conditions, including stratigraphy, structural

features, and hydrogeological properties. Geophysical methods, by offering non-invasive and cost-effective means of subsurface characterization, have emerged as indispensable tools in this context [2]. Among various geophysical techniques, Electrical Resistivity Tomography (ERT) is widely recognized for its ability to image the subsurface distribution of electrical resistivity, which is intrinsically linked to geological materials, water content, and fracture networks [3]. This makes ERT particularly suitable for investigating complex geological settings characteristic of landslide-prone areas.

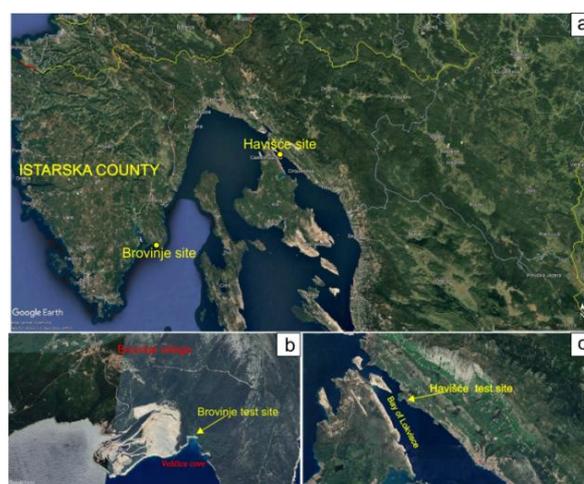


Fig. 1. Location map of the Brovinje and Havišće study sites in Croatia.

The present work describes the results of a geophysical survey, consisting on the execution of geoelectrical profiles in the test site of Brovinje and Havišće (figure 1a). Brovinje site is located in Istarska County, Raša

Municipality, southeast of Brovinje village, bottom of Vošćice cove (figure 1b); Havišće site (figure 1c) is about 7 Km NW the Crikvenica City in the Primorje-Gorski Kotar County, in close proximity to the Bay of Lokvisce.

Such prospecting is necessary to provide subsurface geological information in support of the Interreg RESONANCE “ImpRoving landslidE riSk preventiOn aNd mAnagement iN Coastal arEas” Project [4]. In general, the project (<https://www.italy-croatia.eu/web/resonance>) has as a goal to mitigate the risks of landslides and erosion in the Adriatic Region, which pose threats to both human safety and infrastructure, impacting the regional economy and tourism. In general, leveraging advancements in geophysics, remote sensing, virtual reality, mixed reality, and augmented reality, the project seeks to enhance understanding and civil protection procedures by improving understanding about the factors controlling coastal landslides and erosion processes. RESONANCE aims to predict future processes and improve communication and cooperation among stakeholders.

Specifically, the geophysical investigations described in this work concern the activity performed in the period 18-21 November 2024. N.6 geoelectric profiles were carried with the aim to characterize, with metric resolution, in terms of thickness and resistivity, the surface portion (0 - 30 meters deep) of the subsoil.

## II. METHODOLOGY AND FIELD ACTIVITIES

Multi-electrode electrical resistivity tomography (ERT) is a geophysical technique used to experimentally determine the distribution of electrical resistivity in the subsurface. By injecting artificially generated electric currents of known intensity into the ground and measuring the resulting potential differences, it is possible to infer the resistivity distribution. This information can then be used to reconstruct the subsurface lithology [5]. Knowledge of resistivity values, for different types of materials in the subsurface, is of extreme importance in order to obtain, from this resistivity distribution, a geologic description of the investigation area [6, 7]. The geoelectric ERT profiles were acquired by applying the resistivity method.

The geophysical survey involved the acquisition of six geoelectrical profiles (Figures 2 and 3), using a Dipole-Dipole array configuration with varying interelectrode spacings ( $\Delta x$ ), as summarized in Table 1. It is specified that profile 01 and profile 02 were acquired using a roll-along geometry with 24 electrodes overlapping.

The collected apparent resistivity data were then processed and inverted using specialized software useful for the purpose of achieving the true resistivity image of the area under investigation [8]. The inversion process aims to minimize the difference between observed and calculated apparent resistivities, yielding a geologically

meaningful resistivity model. The electrical resistivity is, in fact, a function of a number of soil properties, including the nature of the solid constituents (particle size distribution, mineralogy), arrangement of voids (porosity, pore size distribution, connectivity), degree of water saturation (water content), electrical resistivity of the fluid (solute concentration) and temperature. Therefore, the knowledge of resistivity values, for different types of materials in the subsurface, allow to obtain, from this resistivity distribution, a geologic description of the investigation area.



Fig. 2. Location map of the ERT profiles acquired in Brovinje.

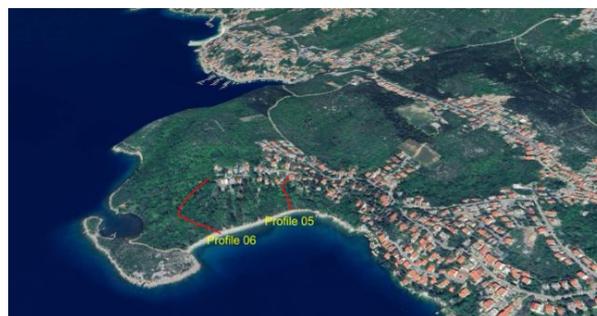


Fig. 3. Location map of the ERT profiles acquired in Havišće

Table 1. Geometric characteristics of ERT profiles

Name	$\Delta x$ (m)	Electrodes	Lenght (m)
Profile 01(Brovinje)	2	48	94
Profile 02(Brovinje)	2	48	94
Profile 03 (Brovinje)	5	48	230
Profile 04 (Brovinje)	5	48	230
Profile 05 (Havišće)	2	48	94
Profile 06 (Havišće)	5	48	230

## III. RESULTS AND DISCUSSION

The Brovinje site is situated within a geological context

characterized by the alternation of carbonate (limestone) and clastic (marl) formations. This lithological variability, coupled with structural discontinuities, often contributes to differential weathering and instability. The presence of bedding planes and fracture systems within these formations can act as potential failure surfaces. The Havišće site, similarly, is located in a coastal setting where the interaction between geological units and coastal erosion processes creates conditions conducive to landslides. The area is marked by a dynamic geological environment, often featuring unconsolidated Quaternary deposits overlying more competent bedrock.

The ERT surveys conducted at the Brovinje and Havišće sites yielded valuable information regarding their subsurface characteristics, contributing significantly to the understanding of landslide predisposition in these coastal areas.

- Brovinje Site

At the Brovinje site, the ERT profiles provided clear images of the subsurface, allowing for the interpretation of the area's structural style and the delineation of different lithological units (figure 4).

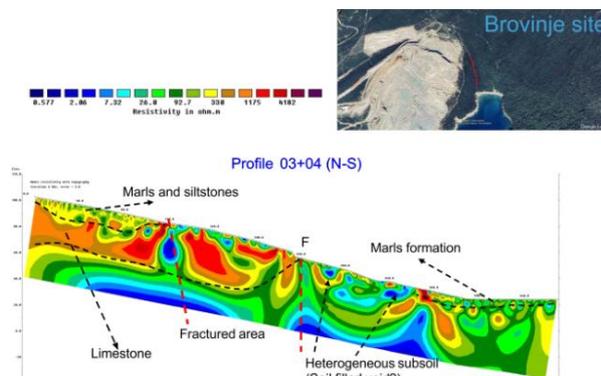


Fig. 4. The observed resistivity is influenced by structural style, with high resistivities (>1000 Ohm-m) associated with limestone and lower resistivity in the marl, due to greater fracturing and potential water circulation.

The resistivity values observed were generally consistent with the expected geological formations, in particular:

- High Resistivity Zones: these zones, typically exhibiting resistivities in the order of hundreds to thousands of Ohm-m, were consistently associated with the presence of competent limestone formations. The higher resistivity reflects the denser, less porous nature of these rocks, especially when unfractured.

- Lower Resistivity Zones: conversely, areas displaying lower resistivities (tens to a few hundred Ohm-m) were correlated with marl layers. Marl, being a softer, more

argillaceous rock, tends to have higher porosity and water content, leading to lower electrical resistivity.

The ERT images therefore revealed significant variations in resistivity that indicated zones of fracturing and heterogeneity within the subsoil.

- Havišće Site

The ERT investigations at the Havišće site focused on identifying areas of unconsolidated material and subsurface structural discontinuities (figure 5).

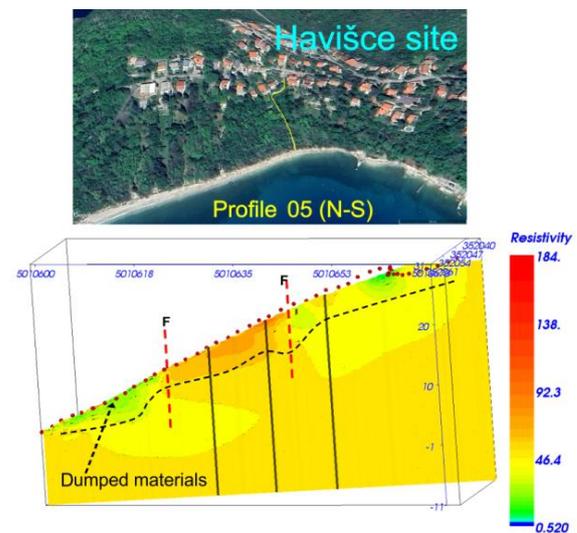


Fig. 5. The ERT profile reveals incoherent dumped material (less resistive), with a thickness of less than 3 meters, alternating with more competent material, which suggests the presence of possible discontinuity elements (label F).

The resistivity models obtained from this site provided critical information, in particular:

- Incoherent Dumped Material: The surveys successfully detected zones with significantly lower resistivity values, indicative of incoherent dumped material. These layers were found to have a thickness ranging from approximately 3 to 5 meters.

- Fracture Zones: Beyond the surficial deposits, the ERT profiles also highlighted zones of localized low resistivity within what would otherwise be more resistive bedrock.

#### IV. CONCLUSIONS

The geophysical investigation utilizing Electrical Resistivity Tomography (ERT) at the Brovinje and Havišće sites has provided invaluable subsurface geological information with metric resolution, supporting

the Interreg RESONANCE Project. The distinct resistivity contrasts observed at both sites underline the effectiveness of ERT in mapping subsurface heterogeneities critical for landslide assessment. The integration of these geophysical findings with existing geological data and geomorphological observations significantly enhances the overall understanding of the sites' stability. The characterization of the subsoil in terms of thickness and resistivity could significantly contribute to improving landslide risk prevention and management strategies in these coastal areas.

Specifically, the ERT imaging surveys revealed:

- At the Brovinje site, a clear understanding of the structural style was obtained, highlighting high resistivities associated with limestone and lower resistivities indicative of marl. This differentiation, coupled with the detection of features likely due to greater fracturing and heterogeneous subsoil, is crucial for assessing potential failure mechanisms and for informing future geotechnical investigations.
- At the Havišće site, the presence of incoherent dumped material, with a thickness ranging from 3 to 5 meters, was successfully identified. Such material, often characterized by high porosity and variable compaction, is considered highly susceptible to instability, especially when saturated. The ERT images clearly delineated the spatial extent and depth of these problematic layers. Furthermore, the surveys outlined significant fracture zones within the underlying bedrock. These anomalies were interpreted as fracture zones, where the increased water saturation within the fractures or the presence of highly weathered material leads to reduced electrical resistivity. Both findings are critical indicators of increased landslide susceptibility and highlight areas requiring targeted mitigation strategies.

In conclusion, ERT has proven to be an indispensable tool for providing detailed subsurface insights in complex coastal environments. The data acquired from these surveys form a fundamental basis for subsequent engineering geological analyses and the design of effective mitigation measures, thereby strengthening the overall framework for landslide risk reduction.

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