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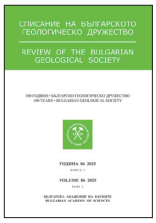

Geophysical monitoring of Chelopech tailings storage facility conditions using electrical resistivity tomography

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Abstract. This study presents the results of a geophysical investigation carried out to assess the condition of the beach tailings and to define the minimum requirements for the foundation prior to the installation of a geosynthetic clay liner during the reclamation phase of the Chelopech tailings storage facility. Electrical Resistivity Tomography (ERT) was applied to characterize the spatial variability of the tailings material and to evaluate its relative strength and degree of water saturation. The obtained resistivity models provide valuable insights into the distribution of zones with contrasting geotechnical properties and potential areas of reduced stability. The interpretation of the geophysical data was supported and verified by complementary in situ geotechnical measurements, confirming the reliability of the ERT results.

Keywords: geophysics, electrical resistivity tomography, tailings dam.

Introduction

The concept of sustainable development in the global economy aims to enhance the well-being of nations while preventing environmental pollution (Savov, Vatskicheva, 2023). The mining, mineral processing, power, and chemical industries are among the leading contributors to significant environmental damage and contamination (Yankova, 2021). Efficient and safe disposal of waste generated during mining activities is a critical concern in the mining industry. The tailings produced from ore and coal processing consist of fine particulate matter, water, and chemicals used in the processing procedures. Proper management of these tailing's is essential to minimize environmental impact and ensure the safety of surrounding ecosystems and communities (Tsvetkov, Kisyov, 2010; Aleksandrova, Koprev, 2020; Dimitrov, Grigorova, 2023; Kisyov, 2024).

The object of the conducted electrotomographic study is a section of the Chelopech mine tailings dam, representing a constructed approach extending 200 m into the tailings deposition area. Due to the need to monitor the behavior of the tailings impoundment over different periods, related to their water saturation and changes in their physical and mechanical parameters, various field studies have been carried out. The geophysical measurements conducted as part of this study were performed along a single geophysical profile, extending 190 meters along the constructed access route into the tailings pond. The method's effectiveness is due to its ability to clearly distinguish the electrical properties of the environment, which depend on factors such as genesis, grain size composition, porosity, water sat-

uration, and the chemical composition of the liquid phase within the architectural elements, highlighting the suitability of electrical resistivity tomography (ERT) for mapping the subsurface structure of the tailings facility (Kisyov et al., 2024a).

Description of the technology

The access path measures approximately 200 meters in length and 4 meters in width. Its construction involves the use of GEO PP HP 150 geotextile (150 g/m²), which is placed over a biaxial geogrid with 40×40 mm mesh. Together, the geotextile and geogrid create a stable pathway over the tailings, enhancing safety for personnel conducting the research.

The starting point of the investigated profile is located on natural ground at the western edge of the Chelopech tailings storage facility. The ERT survey was carried out along a constructed access path extending approximately 190 m into the tailings deposition area.

The survey employed two multi-core cables with an electrode spacing of 3 m, providing a total of 64 electrodes per array. Measurements were conducted using the four-electrode Schlumberger configuration. Data acquisition was performed with a ZZ Universal 96 resistivity system (ZZ Resistivity Imaging Pty Ltd., Australia), which operates with an output voltage of up to 400 V and a maximum current of 7.5 A. The system integrates a transmitter, receiver, and microprocessor unit into a single body, enabling signal stacking and analogue filtering during successive measurements.

ERT was selected as the primary investigation method due to its proven efficiency in delineating subsurface structures and characterizing variations in the physical condition of tailings materials based on resistivity contrasts (Dimovski et al., 2014; Dimovski et al., 2017; Kisyov et al., 2024b). Field data were processed and inverted using the RES2DINV software package (Loke, 2001) to obtain two-dimensional models of the apparent resistivity distribution.

The resulting resistivity cross-sections provided detailed information on the depth to the groundwater table, the degree of moisture saturation, and the delineation of the natural foundation beneath the deposited tailings. The average depth of investigation reached approximately 30 m below the surface, depending on the electrode configuration and data inversion parameters.

Given the necessity to monitor temporal variations in the condition of the tailings material particularly related to water saturation and the resulting changes in physical and mechanical properties field investigations were conducted in three consecutive stages: Stage 1 (19 June 2024), Stage 2 (23 July 2024), and Stage 3 (27 August 2024). The mechanical parameters of the tailings were established through complementary geotechnical investigations (e.g., DPL and CPT tests) performed in parallel with the geophysical measurements, ensuring a reliable correlation between the datasets.

Results and analysis

It is determined that the tailings exhibit sufficient stability at depth to support the planned activities. Additionally, both the plasticity and resilience of the material are uniformly distributed, both vertically and laterally, indicating consistent mechanical behaviour throughout the investigated area. In all three stages, it was found that the studied area lacks domains with a sharp change in tailings stability (Fig. 1).

The examined geoelectric section is characterized by three distinct electrical resistivity zones, each representing layers with varying compositions and different water saturation.

– Zone 1 (10–30 Ohm.m). The first electrical resistivity zone (Zone 1) is located at the upper part of the section, characterized by electrical resistivity values ranging from 10 to 30 Ohm.m. This zone corresponds to the deposited tailings material and its thickness varying between 2 and 25 meters.

– Zone 1a (from 3 to 10 Ohm.m). The second resistivity zone (Zone 1a) exhibits the lowest resistivity values in the studied section, ranging from 3 to 10 Ohm.m. This zone likely corresponds to areas with increased water saturation and predominantly small fractions of tailings material. A higher concentration of finer, clayey materials is observed.

– Zone 2 (from 30 to 180 Ohm.m). The third electrical resistivity zone (Zone 2) exhibits the highest resistivity values in the studied section, ranging from 30 to 180 Ohm.m. This zone likely marks the boundary (or bottom) of the sedimentary lake, composed of rock and soil materials.

Based on the analysis of the results obtained from the ERT survey, the following conclusions can be drawn:

– The geoelectrical section shows good consistency in terms of the distribution of electrical resistivity with depth.

– The electrical resistivity of the materials composing the studied section varies significantly, ranging from 3 to 200 Ohm.m. This variation is primarily due to the substantial differences between the rock-fill base, which forms the sedimentary lake,

and the tailings deposited within it, the latter being characterized by a high degree of water saturation.

Based on the three measurements conducted at the test section of the sedimentary lake over three consecutive months, the following changes in the tailing's material were observed: a reduction in both the number and size of water saturated zones was observed, with each subsequent measurement showing a shift of these zones to greater depths. This trend suggests the compaction and drying of the surface zones, particularly at depths up to 8–10 m. This fact is most clear in the ERT profile 3 from 27 August 2024, where a zone at a depth between 480 m and 487 m (approximately 7 m thick) shows a distinct increase in electrical resistivity, reaching around 20 Ohm.m.

Analysis of the processed data and resulting resistivity profiles indicates a slight increase in electrical resistivity values beyond the 70–80 m along the profile length. This observed change in resistivity may be interpreted as a reduction in water content within the tailings in that section. Such a trend is likely associated with seasonal variations, suggesting a decrease in moisture content during the summer months.

Based on the obtained electrical resistivity values, an assumption can be made regarding the location of the water level (Fig. 1, indicated by a red dotted line). A consistent deepening of the water

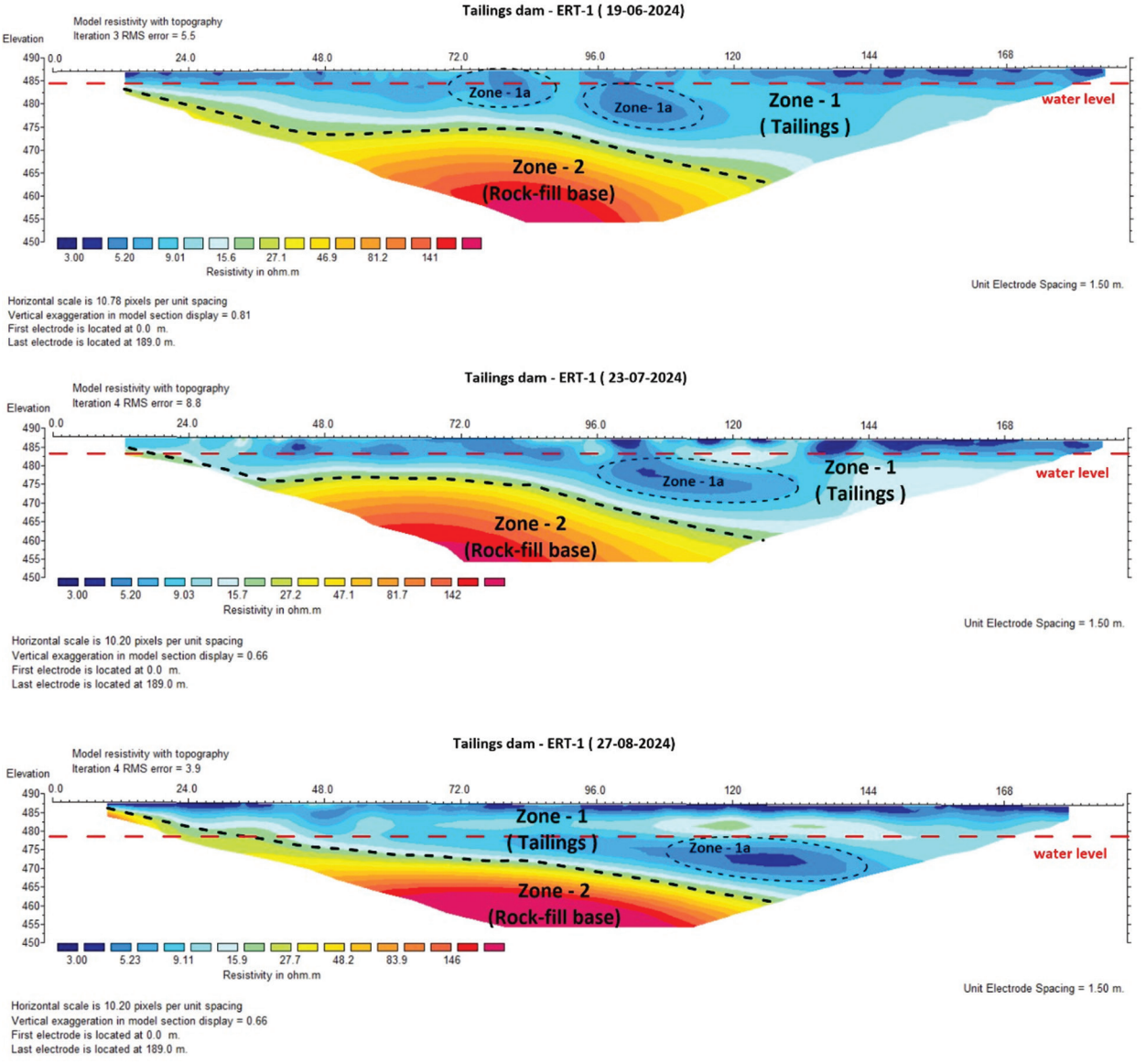

Fig. 1. Electrical resistivity tomography (ERT) profiles from the three stages of the study.

level is observed across all three measurements. In the first profile, it is identified at a depth of 5 m, in the second at 8 m, and in the third at 12 m.

Conclusion

The geophysical survey conducted in the sedimentary lake has provided valuable insights into the subsurface conditions and behaviour of the tailing's material. Through the analysis of electrical resistivity profiles, three distinct geoelectric zones were identified, each corresponding to variations in material composition and water saturation. The study revealed that the tailings exhibit significant changes in water content over time, with a consistent deepening of the water level observed across multiple measurements. This deepening, coupled with an increase in resistivity in certain zones, suggests compaction and drying of surface materials, particularly at depths up to 8–10 m.

The findings from this study confirm that the geophysical approach, particularly electrical resistivity tomography, is a useful tool for monitoring the stability and water saturation of tailings in the pond. It also highlights the potential of this method for detecting anomalous zones, determining the depth of the natural terrain, and assessing the depth of groundwater in areas with significant water saturation. The geophysical survey conducted at the tailings pond demonstrates the method's applicability and effectiveness under the given site conditions. The results provide valuable information for delineating the depth of the natural terrain, detecting anomalous zones within the tailings material, and potentially identifying the groundwater level in areas where it lies at greater depths. Overall, the approach offers a non-invasive and informative means of characterizing the subsurface, supporting both safety assessments and further engineering-geological and hydrogeological studies.

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