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Geophysical Monitoring for Stability Assessment of Integrated Mine Waste Storage Facility

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Abstract: Assessing the stability of integrated mine waste storage facilities is crucial for ensuring the safety and sustainability of mining operations. These facilities often consist of various components such as tailings dams, waste rock dumps, and water management structures. Implementing reliable monitoring systems is crucial for early detection of potential stability issues.To ensure a comprehensive and robust evaluation of mine waste storage facility regular reviews and updates to the stability assessment should be conducted throughout the lifecycle of the facility to account for changes in operating conditions and external factors. Monitoring technques such as geophysical methods can provide valuable information on factors such as slope movements, deformation behavior and physical properties of the materials in the facility. This knowledge is essential for conducting risk assessments, helps in identifying potential hazards and evaluating the associated risks. This involves considering factors such as long-term climatic changes, aging infrastructure, and evolving site conditions over the facility's lifespan.

Keywords: Mine waste, Geophysics, Electrical tomography, Monitoring

Introduction

Implementing monitoring systems in integrated mine waste storage facilities is crucial for early detection of potential issues, assessing performance, and ensuring the safety and integrity of the structures. One of the most important steps in monitoring of such facilities is to determine monitoring parameters. This may include factors such as pore water pressure, settlement, slope stability, seepage, and deformation. Identify critical parameters that need to be monitored based on the specific characteristics and risks associated with the mine waste storage facility. According to Dimitrov and Grigorova (Dimitrov & Grigorova, 2023) tailings from the processing of ore and coal are composed of fine material, water, and reagents from the process and their efficient and safe disposal is one of the most important things in the mining industry. As Dimitrov and Koprev (2023) stated the great challenge these facilities face is to control the water from tailings consolidation and the runoff inflow, because in the process of consolidation there is a great amount of water released which needs to be safely transported out of the facility. The invastigations are performed in IMWF located in Krumovgrad, part of Ada Tepe open pit gold mine. The operational sequence is following: mining operation generates excavated mine rocks which are trucked from the open-pit to the IMWF, dumped and spread to construct containment cells for the tailings. Tailings are thickened in the tailings thickening plant to the maximum practical amount (between 56-68% solids), and then conveyed by pump and pipeline to the containment cells (Diaz, 2014). Regaring to Eldridge (Eldridge et al., 2011) the lowest sections of the facility are undergo soil and soft material removal to create a solid foundation. An underdrain system is set up along the bottom of the valleys and existing drainage paths. This system gather and direct rainwater that seeps into the facility, as well as water discharged from the tailings during consolidation, to a collection point at the base of the facility. From there, the water is pumped to a reservoir for industrial use. Mine rocks, which are not used in cells construction process are placed as internal berms to allow mine equipment access and also regularly monitoring measurments along the berms. The high number of operations chalenges the operational sequance as it is stated in (Eldridge et al., 2011) and that is the reason why Dimitrov (Dimitrov et al., 2023) looked at the possibilities to construct a facility that will ensure better operational sequence and decreese the need for contingency storage cells. By implementing a comprehensive monitoring program, integrated mine waste storage facilities can effectively identify and mitigate potential stability issues, enhance operational safety, and ensure the long-term integrity of the structures. For this purpose in IMWF is implemented geophysical survey based on electrical resistivity tomography. ERT is a geophysical imaging technique that utilizes electrical resistivity measurements to create 2D images of subsurface resistivity variations. By integrating these geophysical methods, mining companies and environmental agencies can obtain a comprehensive understanding of the subsurface conditions at mining waste sites. This information is critical for effective waste management, risk assessment, and remediation planning to mitigate potential environmental impacts.

Method

Mining activities produce substantial quantities of waste material, typically stored in large storage facilities. These facilities raise significant environmental impact and require regularly monitoring to mitigate the potential for disastrous incidents and regulate the production of polluted mine drainage. This research discuss the strong potencial of electrical resistivity tomography (ERT) for the monitoring of drainage paths within mining wastes in the storage facilities. According to Ali (Ali et al., 2023) non-invasive geophysical techniques, particularly electrical resistivity tomography (ERT), have emerged as invaluable tools for hydrogeological studies and the mapping of mine waste tailings. This geophysical technique works by measuring the electrical resistivity of subsurface materials. When applied to a waste deposit, ERT can detect areas with higher electrical conductivity, which may indicate the presence of leachate or other fluids. There are several directions ERT can be utilized in the monitoring program in the IMWF:

- Non-invasive monitoring **-** ERT is a non-invasive technique that can be deployed without disturbing the surface or subsurface infrastructure of the waste storage facility. This allows for continuous monitoring without the need for extensive excavation or drilling activities.
- Seepage detection - ERT can help identify zones of increased moisture content or water saturation within waste storage facilities. By monitoring changes in electrical resistivity over time, ERT can detect potential seepage paths or areas of groundwater ingress, which may indicate potential stability issues;
- Characterization of subsurface structures – ERT can provide valuable information about the subsurface structures and geological features beneath the waste storage facility. This includes identifying potential subsurface weaknesses, faults, fractures, or preferential flow paths that may affect stability.
- Assessment of seepage control measures – ERT can be used to evaluate the effectiveness of seepage control measures such as berms or cutoff walls. By monitoring changes in resistivity profiles along these structures, ERT can help identify potential areas of seepage or leakage.
- Early warning system - ERT can serve as part of an early warning system for potential stability issues. By continuously monitoring changes in subsurface resistivity, ERT can provide early detection of anomalous conditions that may indicate impending failures or instability within the waste storage facility.
- Integration with other monitoring techniques - ERT can be combine with other monitoring techniques such as piezometers and inclinometers. By providing additional subsurface information, ERT can enhance the overall understanding of the site conditions and improve the accuracy of stability assessments.

In current research apparent resistivity data were collected with a Wenner array on the ground surface. The electrodes are arranged along a line with a constant spacing between them. ERT data processing and modelling were done using the RES2DINV. This computer program determines the 2D resistivity model automatically for the observed data (Griffiths & Barker, 1993). The 2D model used by the inversion program, consists of a number of rectangular blocks, arange around to the distribution of the data points in the pseudosection. The distribution and size of the blocks is automatically generated by the program using the distribution of the data points (Edwards 1977).

Results and Discussion

The aim of recent research is to determine spatially distribution of water content and to assess the level of drainage between two conducted surveys in different periods - 2020 and 2023. For monitoring purposes four lines are measured and matched for comparison (Figure 1 to Figure 4).

The length of each line is present in the Table № 1.

Table 1. Total length of each line of integrated mine waste facility

Line	ERT section along Berm 320	ERT section along Berm 330	ERT section along Berm 340	ERT section along Berm 350
Length, m	150	170	210	210

Based on interpretation of ERT lines it can be observed that from the analysis of ERT data within the IMWF, it can be inferred that the electrical resistivity distribution is well differentiated in depth across all profiles. The comparison between ERT section along Berm 320 measured in 2020 and again in 2023 (Figure 1) shows that the drainage is still in progress, but also there is significant improvement according to water drainage.

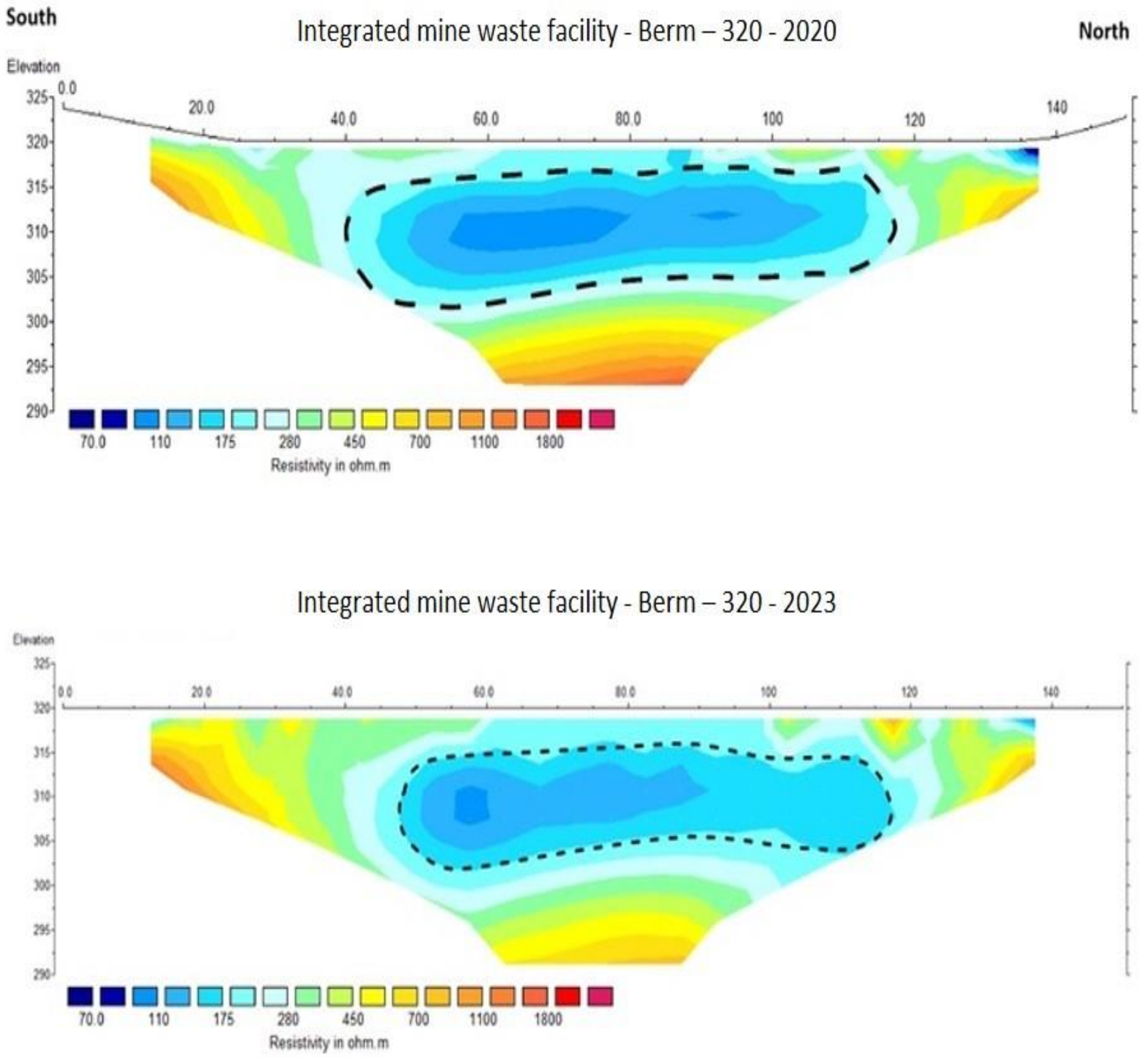

Figure 1. Comparison between ERT section along Berm 320 measured in 2020 (top) and in 2023 (bottom)

According to the measurement results it is considered that specific electrical resistance of the observed area varies from 70 Ωm to more than 2000 Ωm. Across all surveyed lines, noticeable regions of relatively low electrical resistance, ranging from 70 Ωm to approximately 200 Ωm, are evident in the central areas. These zones marked the spatial distribution of an environment with increased water saturation due to the incomplete drainage of the deposited material.

The comparison between ERT section along Berm 330 measured in 2020 and again in 2023 (Figure 2) also shows that the water drainage for three years is significant, but there are still zones with slowly increase of water content across the line. This comparison also shows that the area is currently characterized by increased values of electrical resistance in the southern direction (corresponding to the slope of the natural terrain), probably due to the successful drainage of the cell and the gradual drying of the deposited material.

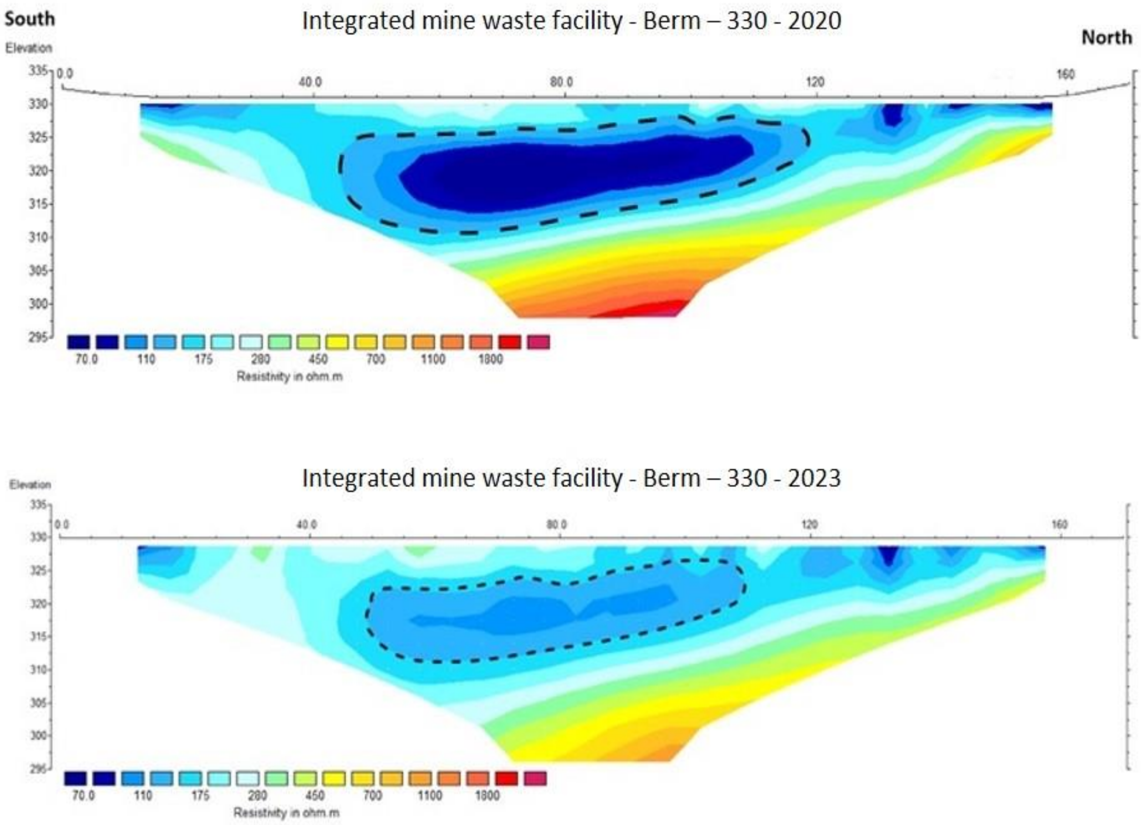

Figure 2. Comparison between ERT section along Berm 330 measured in 2020 (top) and in 2023 (bottom)

The comparison of the electrical resistivity distribution along Berm 340 measured in 2020 and in 2023 (Figure 3) shows that the area currently has slightly elevated electrical resistivity values, which is most likely due to the drainage of the cell and the consolidation of the material placed in it.

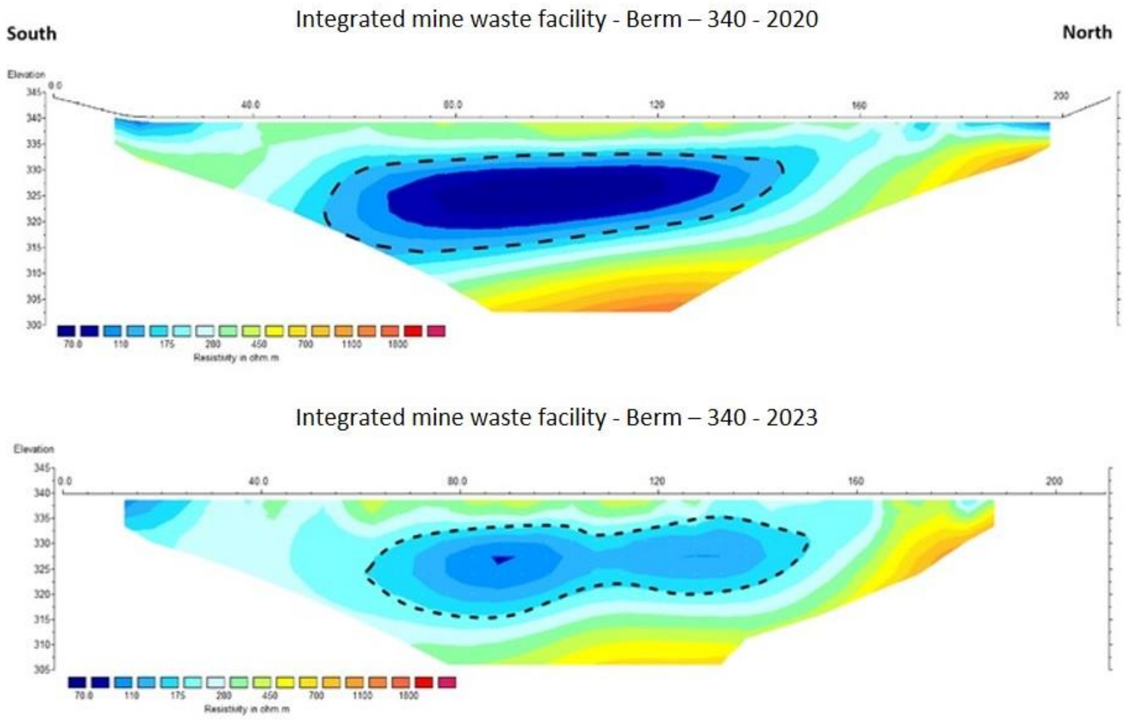

Figure 3. Comparison between ERT section along Berm 340 measured in 2020 (top) and in 2023 (bottom)

Monitoring of ERT section along Berm 350 measured in 2020 and in 2023 (Figure 4) shows that a certain spatial displacement of the watered areas is observed, related to the process of their drying and the accumulation of heavy masses in the cells above. It is very likely that the size of the low resistance zones along the measured lines is determined by the weight of the mining waste deposited during the period in the overlying cells.

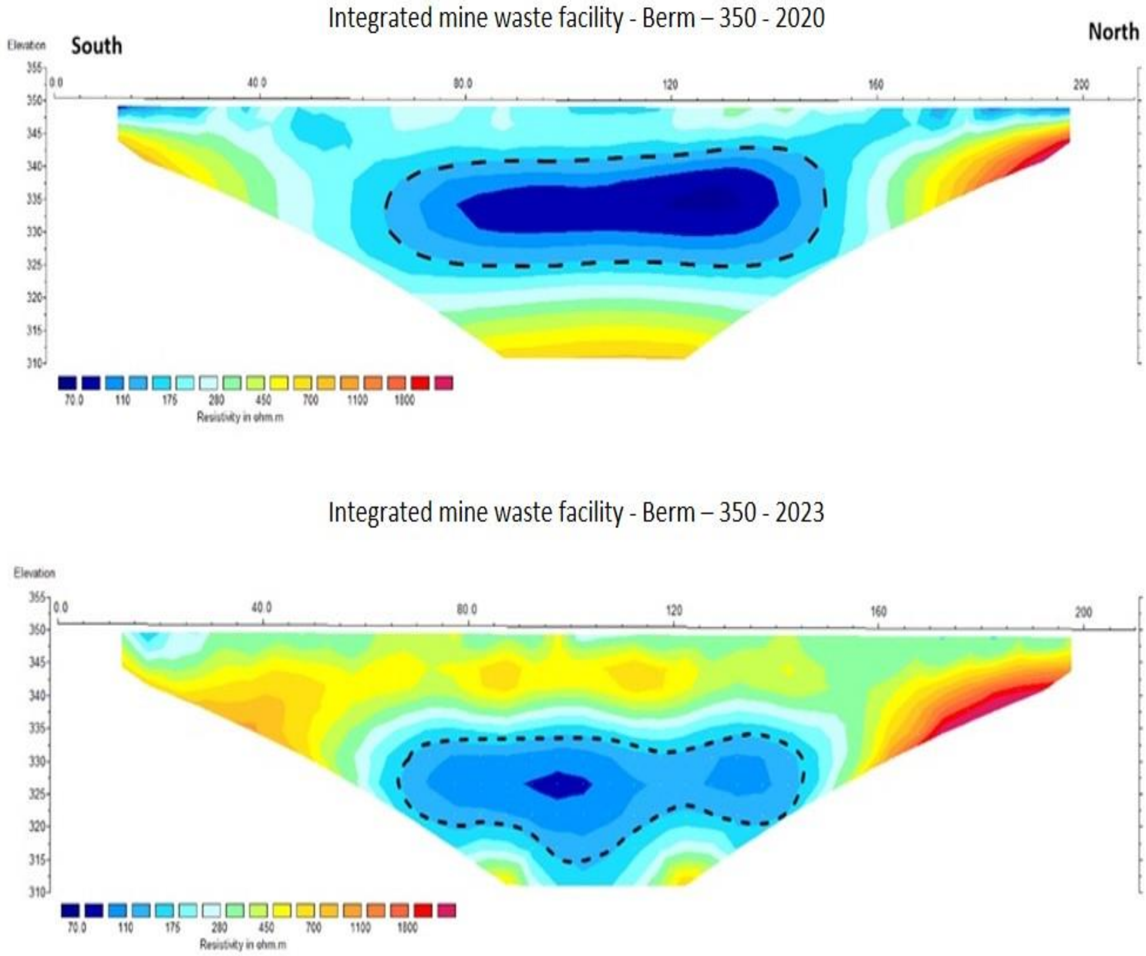

Figure 4. Comparison between ERT section along Berm 350 measured in 2020 (top) and in 2023 (bottom)

The regular monitoring of electrical resistance along the designated profiles enables tracking of the drainage progress and the level of drying within the section.

Conclusion

Overall, a comprehensive stability assessment of integrated mine waste storage facilities requires a multidisciplinary approach, incorporating geological, geotechnical, hydraulic, and risk management considerations to ensure the safety and sustainability of mining operations. The application of geophysical methods during the various stages of construction, subsidence, and dewatering of the cells in the IMWF improves the overall understanding of the operation of the facility and allows informed and timely actions to be taken if necessary. Incorporating geophysical techniques throughout different stages of mining projects can mitigate geological ambiguity by identifying and delineating conflict zones and by providing important information for decision-making in planning follow-up actions.

Scientific Ethics Declaration

The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM journal belongs to the authors.

Acknowledgements or Notes

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