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GEOPHYSICAL SURVEYS ALONG THE PLANNED TRANSPORT SYSTEM ROUTE AT THE "JUŽNI REVIR" OPEN PIT

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Abstract

Due to mining expansion at the "Južni Revir" open-pit mine in Majdanpek, relocating the existing ore transport system is required. This paper presents comprehensive geophysical investigations along a 2,267 m projected route, including a 540 m tunnel section. A multi-method approach combined Electrical Resistivity Tomography, Vertical Electrical Sounding, Seismic Refraction, and Multichannel Analysis of Surface Waves. Investigations reached depths of 35 m for surface sections and 75 m above the tunnel. The integrated approach successfully mapped structural hazards and lithological characteristics, providing critical geotechnical inputs for safe infrastructural design.

***Keywords**: geophysical investigations, ore transport system, seismic refraction, geoelectrical scanning*

1. INTRODUCTION

The expansion of large-scale mining operations frequently demands the reconfiguration and relocation of key industrial infrastructure. At the "Južni Revir" open-pit mine, the continuous development of mining activities has necessitated the relocation of the existing ore transport system located on the western and southwestern margins of the pit. Designing a new transport infrastructure within an active mining environment requires highly precise and continuous geological and geotechnical data to mitigate risks related to ground stability, fault zones, and unpredictable rock mass behavior. This paper presents the results of comprehensive, multi-method geophysical investigations carried out along the projected route of the new transport system.

In engineering geology, traditional geotechnical drilling and sampling are increasingly supplemented by surface geophysical methods to provide continuous subsurface profiles [1]. While drilling offers precise point-specific data, non-invasive geophysical surveys bridge the gaps between boreholes, mapping continuous lithological boundaries and structural discontinuities. For complex engineering projects, a single geophysical method is often insufficient due to physical ambiguities. Therefore, an integrated approach combining geoelectrical and seismic methods is widely accepted as the standard for characterization of the rock mass [2].

2. METHODOLOGY

To achieve a reliable and comprehensive characterization of the subsurface along the projected transport route, an integrated geophysical approach was deployed. The field investigations were executed utilizing the following specific geophysical methodologies:

- Electrical Resistivity Tomography (ERT)**:** Applied as a geoelectrical scanning variant along the entire length of the projected alignment to provide continuous 2D cross-sections of subsurface resistivity distribution.
- Vertical Electrical Sounding (VES)**:** Implemented as a 1D geoelectrical sounding variant at targeted locations (profile endpoints) to provide deep, discrete vertical resistivity profiles and calibrate the 2D data.
- Seismic Refraction: Conducted to map the depth of the bedrock interface and determine compressional wave (P-wave) velocities within the distinct lithological layers.
- Multichannel Analysis of Surface Waves (MASW): Utilized to evaluate the shear wave (S-wave) velocity profiles (V_s), which serve as a direct proxy for the dynamic elastic moduli and stiffness criteria of the ground.

By combining these four complementary configurations, the ambiguity inherent to individual geophysical datasets was minimized, ensuring a high-resolution interpretation of both the shallow and deeper sections of the transport alignment. The selection of methods was strategic, aiming to resolve both the geometry of structural discontinuities and the mechanical properties of the rock mass. Electrical methods, such as ERT and VES, are highly sensitive to moisture variations, clay content and fault zones. Conversely, seismic methods like MASW directly measure elastic wave velocities, which correlate closely with the mechanical strength, fracturing degree and rippability of the rock mass.

ERT was carried out along four profiles positioned directly along the alignment of the projected transport system. The field measurements were conducted using an advanced ABEM Terrameter LS resistivity meter. The reliability and high precision of this instrumentation in automated multi-electrode configurations for engineering and mining layouts have been well-documented in modern near-surface investigations [3]. The complete field setup included a 12 V external battery source, four multi-electrode cables featuring 21 takeout each, and a total of 81 stainless-steel electrodes. Data acquisition was executed in a fully automated measurement mode tailored for direct-current (DC) geoelectrical surveys. This automation effectively minimized human operator error during field recording while ensuring optimal horizontal and vertical resolution across the subsurface profiles.

VES was conducted utilizing the standard Schlumberger electrode configuration (A-MN-B), where A and B represent the current electrodes, and M and N denote the potential electrodes. The maximum current electrode half-spacing ($AB/2_{max}$) reached 80 m, to guarantee the target depth penetration. Field data acquisition, specifically the registration of the potential difference (ΔV) and the direct current intensity (I) used to calculate the apparent electrical resistivity (ρ_p) via Ohm's Law, was performed using a reliable analogue RES 300 J instrument setup.

Seismic data acquisition for both, seismic refraction and Multichannel Analysis of Surface Waves (MASW) investigations, was executed using a high-precision, 24-bit Summit X One seismic telemetry system. For the registration of the generated seismic waves, a deployment of low-frequency geophones with a natural frequency of 4,5 Hz) was utilized, ensuring an optimal signal-to-noise ratio and high-quality recording of both body and surface wave components.

3. RESULTS AND DISCUSSION

Geoelectrical scanning and vertical electrical sounding (VES) measurements successfully indicated the subsurface distribution of apparent electrical resistivity values, both laterally and with depth. Based on these datasets, comprehensive 2D geological models were generated along the vertical planes of the profiles designated as ERT-1, ERT-2A, ERT-2B, and ERT-3. By analysing the distribution of the apparent electrical resistivity fields and correlating the results with available exploratory drilling data, distinct lithological units composed of limestone, gneiss, and andesite were successfully delineated. Furthermore, the evaluation of the resistivity field gradients enabled the assessment of the compactness and degree of fracturing within these rock masses. Additionally, the profiles registered the presence of intensely degraded zones characterized by prominent resistivity anomalies, which were interpreted as faults and structural shear zones along the surveyed alignments (Figure 1).

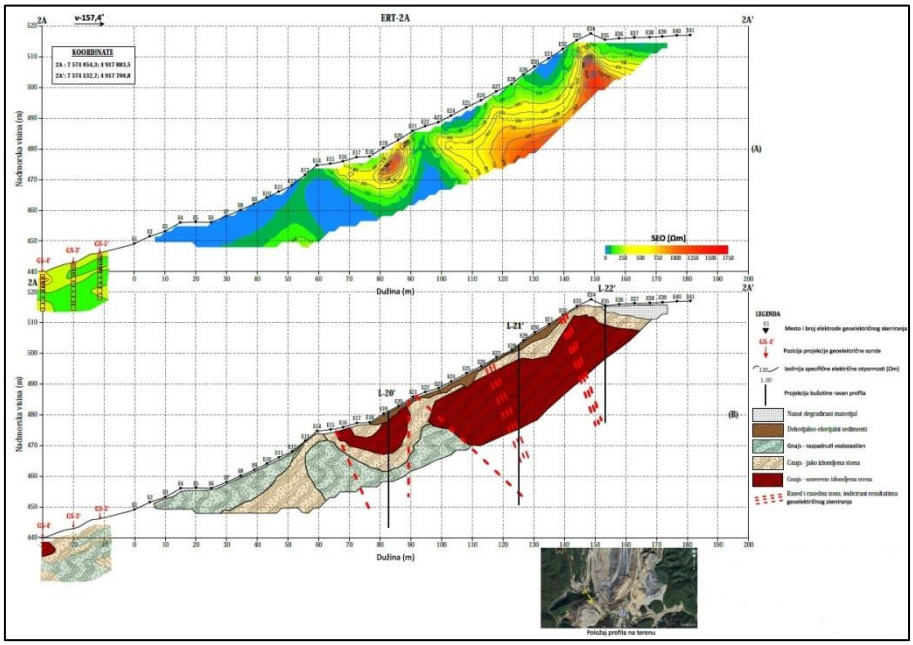


Figure 1. *ERT-2A profile - results of the geoelectrical scanning*

The seismic investigations were executed in two distinct configurations: seismic refraction surveys, which defined the longitudinal (P-wave) propagation velocity (v_p), and Multichannel Analysis of Surface Waves, which determined the transverse shear-wave propagation velocity (v_s). The obtained results, along with the calculated dynamic soil parameters for the executed profiles (REF-1 through REF-6, as exemplified in Figure 2), are systematically presented in Table 1.

Based on the derived seismic wave velocities and integrated geotechnical criteria, a classification of the local ground type was performed. The analysis confirmed that the investigated area corresponds to ground category Type B (according to Eurocode 8 standards for rock and stiff soil conditions). Furthermore, seismic hazard parameters for the planned infrastructure were determined. The structural design ground acceleration values under earthquake action were calculated at a_h= 135 cm/s^2 for the horizontal direction and a_v= 86 cm/s^2 for the vertical component.

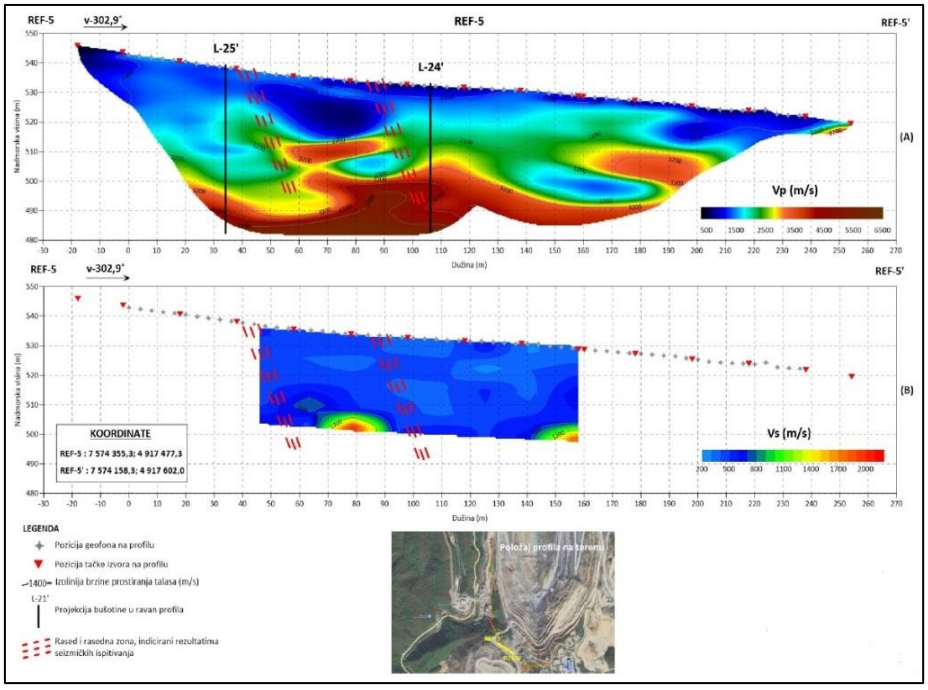


Figure 2. *Profile REF-5 - Seismic investigation results: (A) refraction and (B) MASW*

Table 1. *Values of dynamic parameters of the rock mass along the profiles*

Profile	Lithology	v_p (m/s)	v_s (m/s)	γ (kN/m^3)	υ	E_{dyn} (*MPa*)
REF-1	1- Fill	802	378	21.78	0.36	844.7
	2- Weathered gneiss	1241	575	26.80	0.36	2416.0
	3- Gneiss	2646	1467	28.30	0.28	15568.3
REF-2	1- Fill	871	503	18.95	0.25	1198.4
	2- Weathered gneiss	1336	701	26.70	0.31	3437.7
	3- Gneiss	2564	1056	26.33	0.40	8208.7
REF-3	1-Clay	698	335	19.21	0.35	582.2
	2- Weathered andesite	1488	565	25.99	0.42	2349.2
	3-Andesite	2427	1301	26.21	0.30	11520.1
REF-4	1- Fill	559	314	27.32	0.27	683.4
	2 - Weathered gneiss	1493	657	28.11	0.38	3347.5
	3- Gneiss	2550	947	28.43	0.42	7233.3
REF-5	1- Fill	969	490	26.75	0.33	1706.1
	2- Weathered gneiss	1456	618	27.60	0.39	2930.7
	3- Gneiss	2478	968	28.00	0.41	7398.5
REF-6	1- Fill	861	491	26.94	0.26	1635.4
	2- Weathered gneiss	1301	697	27.91	0.30	3520.6
	3- Gneiss	2514	1016	28.00	0.40	8106.7

The quantitative analysis of the dynamic elastic properties presented in Table 1 reveals a distinct three-layer velocity and stiffness architecture across all investigated profiles. The surficial layer, consisting of heterogeneous fill material and superficial clay, exhibits low seismic velocities (v_p < 1000 m/s), V_s < 500 m/s) and correspondingly low dynamic modules (E_{dyn} ranging from 582.2 MPa to 1706.1 MPa). A significant transition is marked by the underlying weathered gneiss and andesite layers, where a steady increase in density and seismic velocity confirms a higher degree of compaction. The bedrock, represented by unweathered gneiss and andesite, demonstrates excellent mechanical competence, with v_p velocities exceeding 2400 m/s and reaching up to 2646 m/s along the REF-1 profile. Consequently, the dynamic elastic modulus E_{dyn}) escalates sharply in the bedrock zone, hitting peak values of 15,568.3 MPa for gneiss and 11,520.1 MPa for andesite. This rapid vertical gradient in dynamic stiffness underlines the high structural bearing capacity of the deeper lithological units. Similar correlations between integrated seismic velocities and the engineering classification of intact vs. degraded crystalline rocks have been thoroughly established in near-surface geotechnical design guidelines [4].

4. CONCLUSION

This paper successfully presented the results of comprehensive geophysical investigations carried out along the projected route of the new transport system at the "Južni Revir" open-pit mine. The integrated application of geoelectrical (ERT and VES) and seismic methods (refraction and MASW) enabled overcoming the physical ambiguities inherent to individual methods and provided an insight into the engineering-geological structure and structural characteristics of the rock mass. Based on the lateral and vertical distribution of apparent electrical resistivity and seismic velocities, a distinct three-layer ground model was successfully defined along the entire alignment. By correlating the geophysical data with exploratory drilling, three key lithological units were precisely mapped: the superficial fill and clay, degraded rock masses, and competent bedrock consisting of gneiss and andesite. The analysis of resistivity field gradients and seismic-geological boundaries enabled the detection of intensely degraded zones, which were interpreted as active faults and structural shear zones. Seismic investigations demonstrated a clear increasing trend of longitudinal (v_p) and transversal (v_s) wave velocities with depth, directly indicating an increase in rock mass compactness.

All these findings provided continuous and reliable geotechnical inputs necessary for the engineering design of both the surface alignments and the tunnel section. Finally, the conducted study confirms that an integrated geophysical approach represents a highly effective tool that significantly contributes to the safe design of critical mining infrastructure within active open-pit environments.

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