APPLIED GEOPHYSICAL, ENGINEERING GEOLOGICAL AND GEOTECHNICAL EXPLORATION CONDUCTED ON THE CONSTRUCTION AREA OF THE CONSTRUCTION CAMP IN BOR

Expert Paper
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Abstract: *For the purposes of designing and building the construction camp within the plant of the Jama Mine Factory, in order to better understand the geology, it was necessary to carry out geophysical, engineering geological and geotechnical exploration. The goal of the exploration was to reduce the geological and geotechnical unknowns, to analyze in detail the geotechnical environment and the facts that form the geotechnical conditions for the design and construction of facilities within the construction camp.*

In order to define the engineering geological and geotechnical conditions, exploration works were carried out, which included engineering geological mapping of the terrain, development of exploratory boreholes (core mapping, SPT (standard penetration test), borehole tests) and geophysical exploration (geoelectric and seismic). On the basis of seismic tests and propagation speeds of longitudinal and transverse waves, dynamic parameters that are important in the design, foundation and construction of buildings were calculated. Based on the propagation speed of transverse waves, mean values for a depth of up to 30 m were calculated (Vs,30 - according to Eurocode EC-8) and the type of soil was established Seismic micro-regionization was performed for the exploration area.

The paper provides a more detailed review of the geophysical tests performed and their importance for the explored location.

Key words: SEISMIC TESTS, REFRACTION TESTS, MULTI-CHANNEL ANALYSIS OF SURFACE WAVES, GEOTECHNICAL ENVIRONMENT

INTRODUCTION

In order to better understand the geology, it was necessary to carry out new geotechnical investigations in the area of the construction camp, the construction of which is necessary from the aspect of expanding pit operation within the "Borska Reka" copper deposit (Figure 1). Exploration works were carried out with the intention of contributing from the geotechnical aspect in the form of quality underlying instruments with the necessary drawings and a display of fitting the subject facilities into the existing state in the mine, defining by calculations the stability conditions of the entire complex in its environment, applying valid standards and prescribed technical measures for that type of facilities and providing a detailed base for possible rehabilitation works in the field.

For successful geotechnical design, it is necessary to collect adequate data for the creation of a geotechnical terrain model and analysis, as follows [3]:

- Establish the structure of the terrain (composition, structure and geological development);
- Determine the condition of rock masses (discontinuities, faults, fractured zones, alteration, roughness, filling of cracks, distance between cracks, sets of cracks, state of groundwater, etc.);
- Establish the physical-mechanical properties (characteristics) of the represented rock masses in all characteristic members;
- Establish hydrogeological properties of rock masses (water permeability, hydrogeological functions of certain parts of the terrain, look into the hydrogeological conditions of construction works on the construction of foundations for new buildings;
- Properly dimension foundations;
- Make the final selection of foundation methods and conditions;
- By geostatic calculations, determine the calculated bearing capacity of the foundation soil and the deformability of the ground in the intake of facilities;
- Establish the conditions and technology of excavation;
- Define modern geodynamic processes and phenomena;
- Perform microseismic division of the terrain based on the results of geophysical tests.

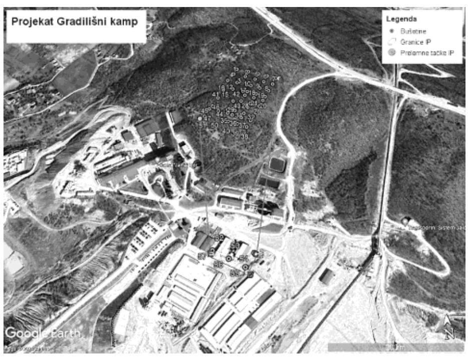

Figure 1, Exploration area with the position of the designed boreholes (taken from Google Earth)

APPLIED RESEARCH METHODS

The applied research and testing methods were carried out in accordance with the applicable legislation on the type, scope and density of exploration works and laboratory tests and were implemented through the following stages:

Field exploration works: engineering geological mapping of the terrain, instrumental locating of exploratory *boreholes* and execution of exploratory wells, engineering geological mapping of the core of exploratory wells with sampling for laboratory-geomechanical tests, performing SPT test in boreholes), geoelectrical field survey (geoelectric tomography), geophysical refraction tests.

Laboratory works: laboratory geomechanical tests on rock mass and soil samples.

Cabinet works: collection and study of available documentation on previous research in the wider investigation area (synthesis and analysis of all available geological, geotechnical and hydrogeological documentation), preparation of the Study on geotechnical conditions for the construction of the construction camp in Bor.

GEOPHYSICAL TESTS

The project [4] is intended to carry out geophysical tests using geoelectrical and seismic methods. There are several geophysical techniques that are applied for exploration of geological structures. All methods are based on the mapping of specific physical contrasts between the object of research and the surrounding environment and the interpretation of changes in physical parameters. Each of the methods has advantages and disadvantages in relation to depth of examination and vertical resolution. The best solution is to select at least two methods, and this type of application is called complex geophysical testing.

GEOELECTRICAL TESTS

The aim of the geoelectric tests was to determine the boundaries between lithological environments of different specific electrical resistivity, locate potential fault zones assumed and confirmed by earlier research, correlation with seismic tests and geotechnical exploratory drilling, in order to obtain continuous profiles in parts of the terrain between exploratory boreholes [1]

Geoelectrical tests along selected profiles, performed with geoelectrical tomography - (ERTElectrical Resistivity Tomography). These tests allow maximum resolution in the horizontal and vertical direction. Geoelectrical tests were performed along four profiles by measuring the specific electrical resistivity (SEO) of the soil in order to define the lithological members in the vertical profile plane (2D) [1], [7], [8].

Measurements were performed with the ABEM Terrameter LS instrument with accompanying equipment. The data is measured in an automatic mode designed for direct current geoelectrical measurements. Thus, the impact of human error is minimized. The distance between the electrodes was 5 m. After the completion of recording on each profile, quality control of the recorded data was carried out in the field. On all three recorded profiles, the quality of the downloaded data was excellent.

Numerical processing of geoelectrical tomography data includes calculation of apparent electrical resistance based on measured values of potential, current and geometry of the electrode device. The calculated SEO values are used to create a vertical geoelectrical profile. The numerical modeling procedure produces a model of the examined half-space that reflects the lateral and vertical changes of SEO, which were caused by the influence of geological environments and geological processes to which the environment was exposed during geological time. The vertical section of the SEO distribution is obtained by a 2D inverse data modelling procedure. This procedure provides the possibility of quantitative interpretation of the measured data.

Based on the analysis of the results of geoelectrical tests, it can be concluded that the detected anomalies of specific electrical resistances on two parallel profiles (1,2) are quite well monitored, which ensures a more reliable interpretation of the data [1]. Three environments with different values of specific electrical resistivity were singled out, which can be connected and interpreted as different lithological units. A thin layer of deluvium was detected on the surface of the terrain (it is missing in some parts because it was removed by previous construction works). This layer on the geoelectric profiles has a response of very low SEO values below 50 Ωm. Then a zone with somewhat higher SEO values (up to 150 Ωm) was detected, which was interpreted as a layer of silty conglomerates in which water can be retained, which reduces the values of specific electrical resistance. Below this layer, a zone of the highest SEO values (up to 340 Ωm) was detected, which was interpreted as a layer of compact conglomerates in which moisture retention is weaker, which affects the increase of SEO values. The detected potential faults are followed quite well with the known faults previously drawn on the engineering geological map.

The results of geoelectric tests are shown in Figures 2 and 3.

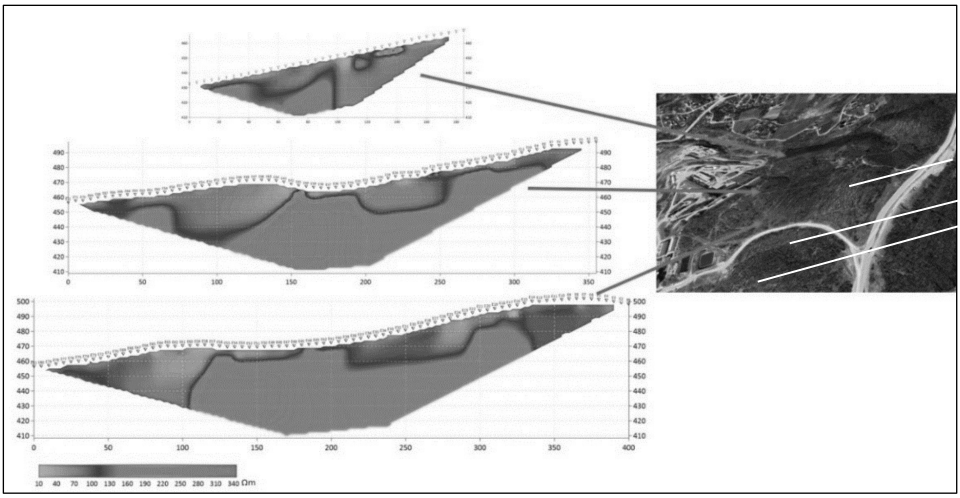

Figure 2, SEO values for profiles 1-1', 2-2', 4-4'

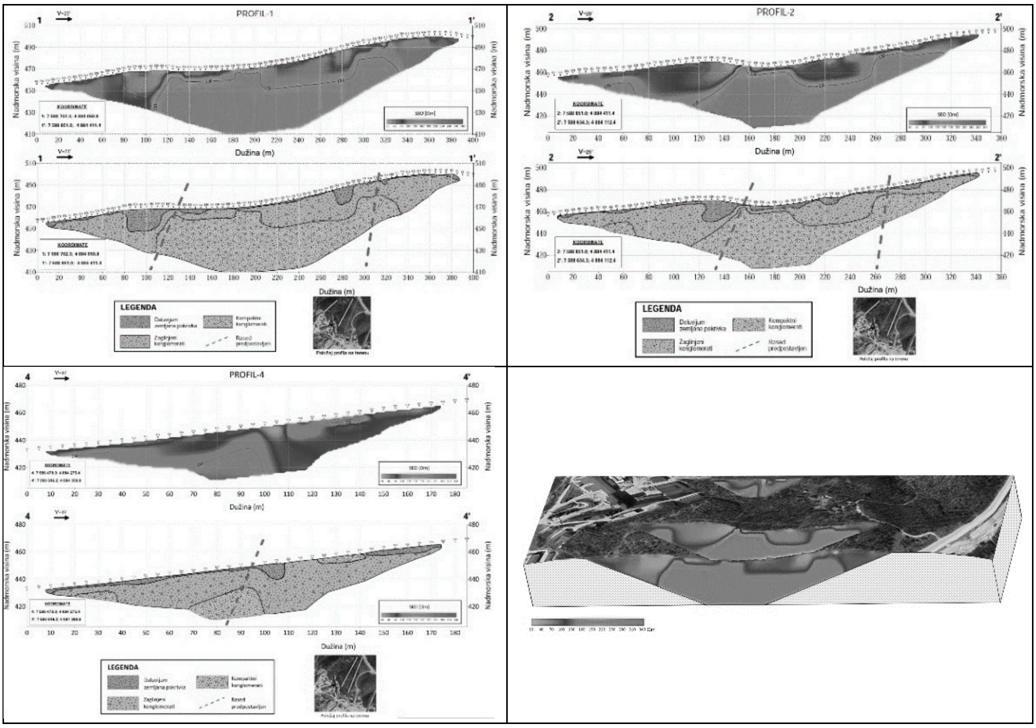

Figure 3, Interpreted profiles

SEISMIC TESTS

Seismic tests were performed using the method of refraction tests and multi-channel analysis of surface waves (MASW - Multy Channel Analysis Surface Wave) on 2 profiles 150 m long.

The task of the seismic tests was to define the elastic properties of the environment up to the depth of the interaction between the terrain and the facility. On the basis of seismic tests, the velocity of longitudinal (Vp) waves was determined using refraction tests and the speed of transverse (Vs) waves using multichannel analysis of surface waves (MASW), on the basis of which the assessment of the physical and mechanical characteristics of lithological environments and their classification was performed. The results of the seismic tests were used to define the terrain model, seismic parameters for the purposes of building design and the assessment of seismic hazard and risk [1], [5], [6]. When performing seismic tests, the basis is the design of the parameters of the source and reception of the seismic signal. They should provide good horizontal and vertical resolution. The equipment used for the seismic tests is a 24-bit SUMMIT X One (Germany 2023), with single vertical geophones with a natural frequency of 4.5 Hz. The recording of seismic data was performed on two seismic profiles with a device of 150 m, where 48 channels were used for recording with a distance between receivers of 3 m. The chosen geometry of the seismic device, the parameters of the source and reception of the seismic signal ensure good horizontal and vertical resolution. Five point sources were taken on each profile (Figure 4).

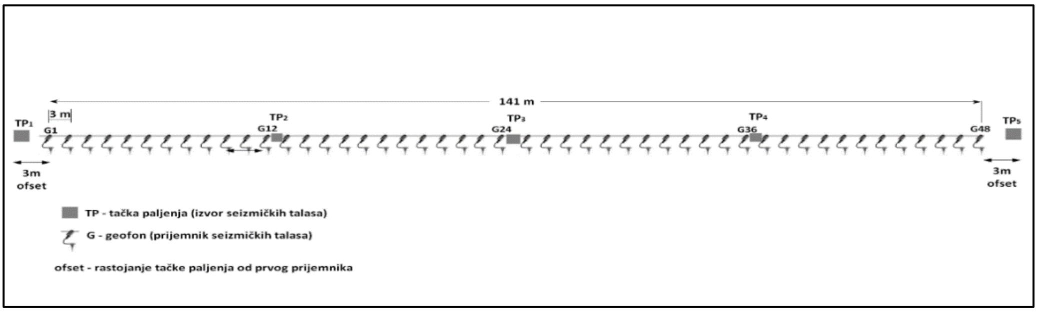

Figure 4, Device for refraction tests

For all reception and source points on the profiles, a geodetic survey was performed using a handheld GPS device Gezgin-1 GNSS1J+1. The accuracy of the instrument is 1.5 cm in position (x,y) and 2.5 cm in the height parameter. The mentioned accuracy is achieved using RTC (real time correction) correction. In total, 96 seismic wave reception points and 10 seismic wave source point positions were geodetically recorded. On the basis of the hodochron on both profiles, the two-layered areas of seismic wave propagation can be clearly distinguished, where the first layer is edging out. The first medium is made up of deluvium, occasionally silty, while the second medium is made up of "Bor" conglomerates of compact compaction. The results of refraction tests are shown in Figures 5 and 6.

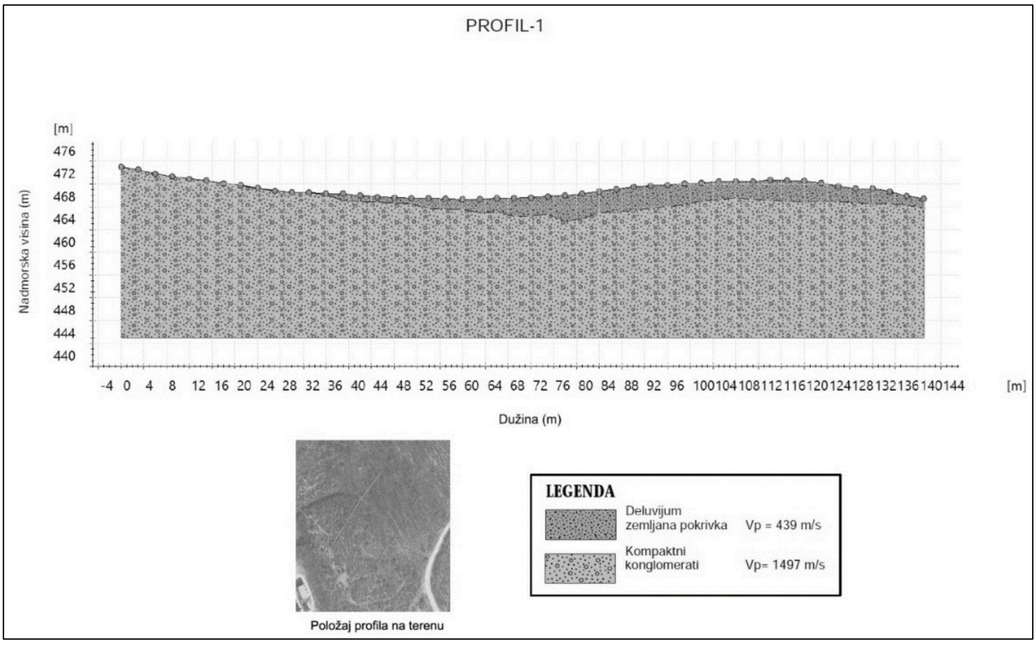

Figure 5, Results of refraction tests Profile 1-1'

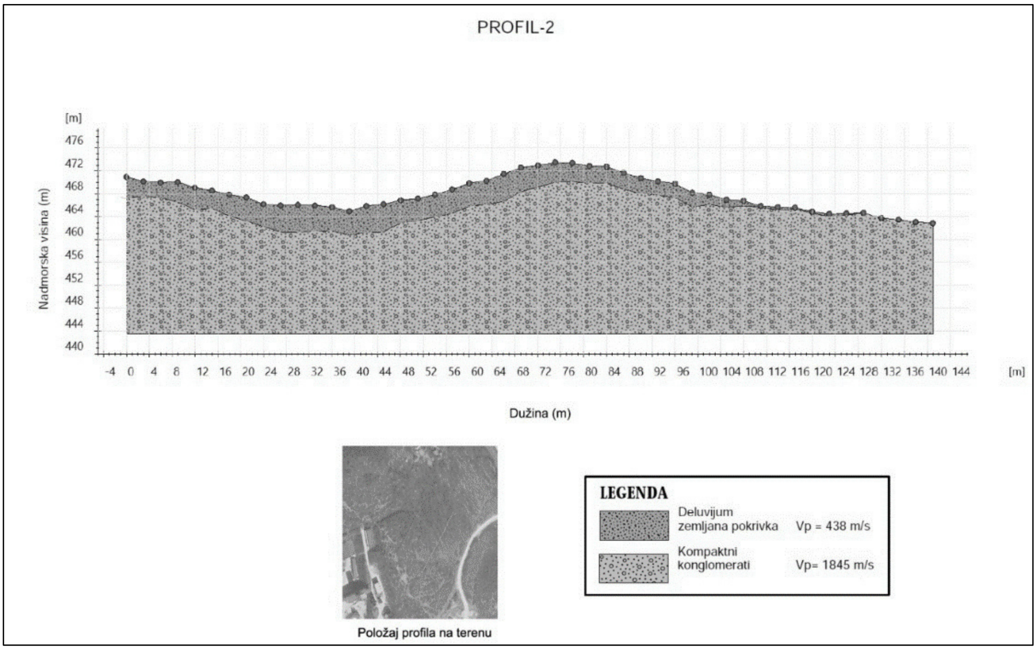

Figure 6, Results of refraction tests Profile 2-2'

MULTICHANNEL ANALYSIS OF SURFACE WAVES - MASW

The technique of multichannel analysis of surface waves - MASW is based on the seismic analysis of transverse Vs waves from Rayleigh waves, which are the strongest seismic waves and make up 90% of surface waves. By measuring the transversal (shear) wave, the stiffness of the soil is estimated, usually up to a depth of 30 m. Based on the average velocity of transverse waves up to 30 m deep, the soil type of the microlocation for which the tests were performed is determined.

Recording of seismic data using the method of multi-channel analysis of surface waves was performed on two profiles with 14 (fourteen) positions, where each profile had 7 (seven) positions. There were 24 active channels in the active device, so the total length of the active device was 70.5 m (Figure 7).

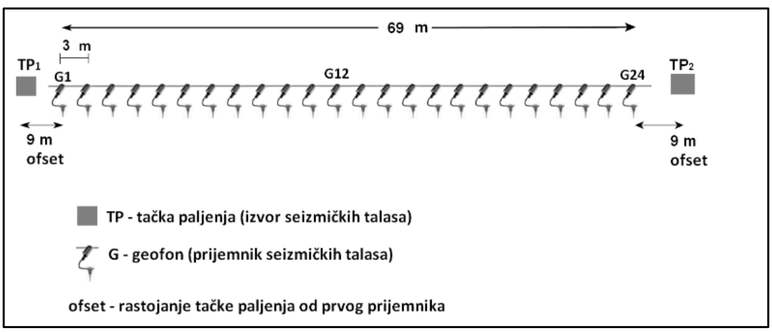

Figure 7, Device for MASW tests

For recording with multi-channel analysis of surface waves, there were 24 channels in the active device. After recording the first position, the recording continues with the RollOn technique, so that 6 receivers are connected to the active device, and 6 receivers are disconnected from the end of the profile (Fig.8). With this recording technique, data was obtained from seven positions, which were recorded as 1D, and with the software, after inverse modelling of the data, a 2D view was obtained, i.e. profile in the vertical plane.

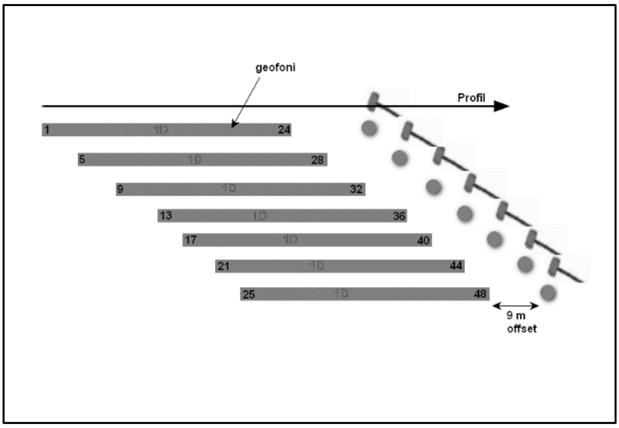

Figure 8, Recording technique of multichannel analysis of surface waves – MASW

During the processing of seismic data, the records from all receivers are analyzed for the frequency and phase shift of the waves on each signal record. This makes it possible to determine the wavelength λ, and based on the knowledge of the wavelength λ and the frequency f, the speed of the wave is calculated. The change in speed depending on its frequency f enables the dispersion curve to be determined (Figure 9). The dispersion curve is determined in the useful signal range (high S/N ratio).

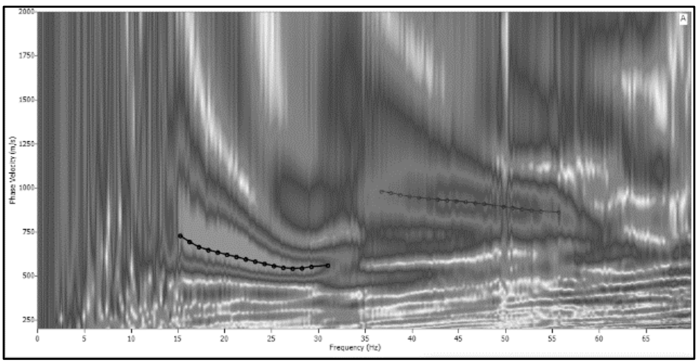

Figure 9, Dispersion curve

The procedure of the inverse modelling process is carried out in several iterations until the minimum absolute error of the difference between the measured and calculated values is reached. The average absolute error in % on the profiles is from 3.14 to 5.53%, so the obtained absolute error values are low enough for the obtained models. Specific mass (ρ in units of kg/m3) is taken as one of the essential input data for model setup. The specific mass was obtained on the basis of laboratory tests of core samples from exploratory boreholes. The results of the multi-channel analysis of surface waves - MASW are shown in Figure 10. Based on the connection of elastic constants with the dynamic characteristics of soil and rock mass, the following values were calculated: Poisson's number (σ), Jung's modulus (E), oedometric or deformation modulus (Eoed0), and shear modulus (μ). The parameters given in Table 1 are important in the design, funding and construction of capital facilities (dams, tunnels, bridges and high-rise buildings).

Table 1, Calculated dynamic parameters

Lithological environment	**Vp (m/s)**	**Vs (m/s)**	**ν**	**E (MPa)**	**Eoed (MPa)**	**μ (Pa)**	**Profile**
1-deluvium	439	211	0,35	292,01	468,65	108,15	1
2-conglomerate	1497	719	0,35	3782,81	6071,18	1401,04	
1-deluvium	438	210	0,35	290,16	465,68	107,47	2
2-conglomerate	1845	886	0,35	5750,62	9229,38	2129,86	

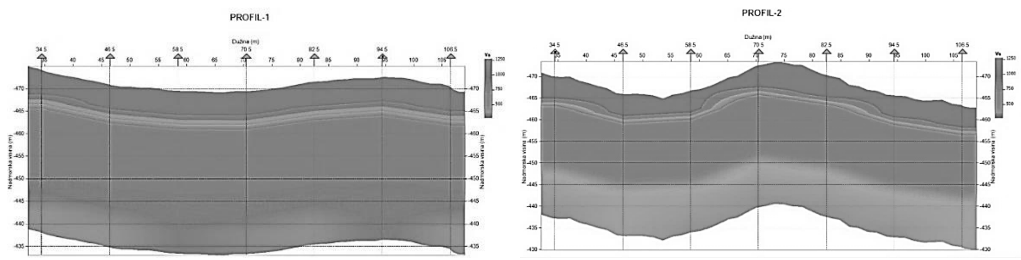

Figure 10, Results of multi-channel analysis of surface waves - Profiles 1-1', 2-2'

According to Eurocode EC-8, it is assumed that geological, engineering geological and hydrogeological conditions in the last 30 m to the surface of the ground are responsible for the result of the action of the earthquake on the surface of the ground. For the classification of the local soil, the mean value of the propagation speed of the transverse (shear) waves in the last 30 m Vs30 is used. The relation by which the calculation was performed is:

$$V_{s,30}=30\,/\sum_{1}^{n}\frac{h_i}{V_i}$$

Where:

h_i – layer thickness,

V_i – velocity of propagation of transverse waves through the layer,

$n -$ number of layers in the last 30 m to the ground surface,
$V_{s,30}$–mean speed of transverse waves up to a depth of 30 m.

Based on the results of the speed of transverse waves, the average speed up to a depth of 30 m was calculated (Eurocode 8 - $V_{s,30} \approx 785$ m/s) and the soil type (B) was determined.

SEISMIC MICRO ZONING

In addition to the regional seismic characteristics of the terrain, in order to determine the overall seismic hazard at a specific location, it is necessary to determine the influence of the local seismological properties of the terrain of the location during the impact of an earthquake. Local changes in the elastic properties of the soil significantly affect the modification of the amplitude-frequency composition, which are registered in the conditions of the local geotechnical environment in relation to the base rock of the site. Based on the data obtained from the seismic tests, a geotechnical soil model was given and the maximum seismic accelerations were calculated. Amplification in the surface layers was calculated [2].

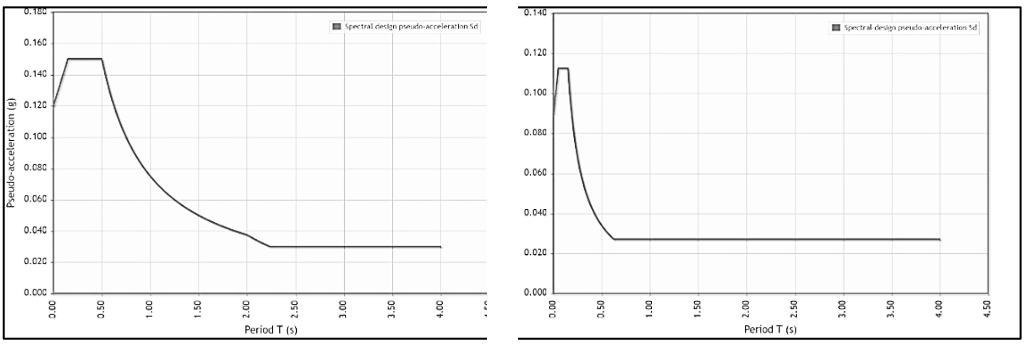

Figure 11, Left horizontal, right vertical response spectrum

The exploration area where the tests were carried out is located in eastern Serbia in the area where spectrum type 3 is used (SRPS EN 1998). Earthquake phenomena are most frequently displayed through the elastic spectrum and response to ground acceleration, and two spectra are displayed:

- Horizontal elastic spectrum (Figure 11),
- Vertical elastic spectrum (Figure 11).

Based on these data, the project parameters of seismicity were given [2].

CONCLUSION

Based on the analysis of the results of geophysical tests, environments with different values of specific electrical resistivity were singled out, which can be connected and interpreted as different lithological units [3]. Soil categorization was performed, zoning of the examined terrain was carried out in accordance with the valid categorization, as well as according to the parameter of the predominant period of soil oscillation and maximum horizontal seismic accelerations on the surface of the terrain for the project risk levels, i.e. return periods. For soil type B, which was determined on both seismic profiles, the maximum horizontal acceleration on the ground surface according to SRPS EN 1998-1/NA:2018 for a return period of T_{NCR}=475 years, i.e. with a probability of exceeding the PNCR of 10% for the operational life of the facility since t_e = 50 years, it can be expected to be a_h = 0.242 g = 237.40 cm/s^2. The results obtained based on the calculation of the amplification factor according to Kobayashi's relation are similar for the same return period and amount to a_h = 0.20 g = 197.57 cm/s^2. But considering that they are somewhat smaller for designing, the results obtained according to SRPS EN 1998-1/NA:2018 should be applied. Maximum vertical accelerations on the terrain surface according to SRPS EN 1998-1/NA:2018 for a return period of T_{NCR}=475 years, can be expected to be $\mathbf{a}_v$ = 0.154 g = 151.07 cm/s^2 at periods from T = 0.03 s to 0.32 s.

The applied geophysical tests contributed to a more precise definition of the geotechnical model of the terrain, the definition of seismic parameters for the purposes of building design and the assessment of seismic hazards and risks in the area intended for the construction of the construction camp in Bor.

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