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Seismic Impact Assessment of Blasting on Surrounding Population Using Geophysical Methods

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ABSTRACT: The seismic impact of blasting on surrounding structures and population presents a significant engineering and ecological challenge. This study utilizes geophysical methods to assess vibrations generated by blasting, analyzing factors influencing wave propagation, including geological characteristics of the terrain and distance of structures from the explosion source. Instrumental measurements show that vibrations do not always decrease proportionally with distance, but rather depend on the properties of the soil and mass of explosives. Timely informing the population about the timing and intensity of blasting is crucial to minimize negative effects and enhance safety. The research results emphasize the need for precise vibration and noise measurements, optimal placement of measuring devices, and expert coordination to minimize risks of damage to structures and negative impacts on people. These findings can serve as guidelines for assessing seismic effects of blasting in similar environments.

KEYWORDS: seismic impact, blasting, vibrations, instrumental measurements, geophysical methods, informing the population

1. INTRODUCTION

Blasting, an essential technique in mining and civil engineering, inevitably causes seismic effects that impact rocks, soil, and the structures supported by them [1]. Excavations in rocks of varying strengths, as well as excavation in challenging locations, require the application of suitable blasting techniques [2]. The cautious application of blasting allows for the reduction of potential harmful effects on surrounding structures or buildings [3]. Determining the type and amount of explosives, as well as the blasting method, is crucial for excavation progress and the extent of seismic impact [4].

The energy released from the explosive charge during blasting is used for breaking and crushing the rocks, while a portion of that energy is converted into kinetic energy of seismic waves [5, 6]. As elastic waves travel, they cause oscillations in the ground, resulting in artificial tremors [7].

Control over the explosive charge and borehole geometry significantly affects the propagation of seismic waves, with proper selection of blasting parameters reducing the negative environmental impact [8].

Additionally, the interaction of seismic waves with different soil types can cause vibration amplification, which is especially critical in urban areas with complex geological conditions [9].

The energy of the stress waves, generated by the detonation of explosives during blasting, causes rock fracturing through mechanisms such as crushing, radial cracks and fractures in the presence of free surfaces. Within the crushing and fracturing zones, the volume of rock undergoes permanent deformation [10].

Behind the fragmentation zone, where no permanent deformation occurs due to stress waves, the waves propagate through the medium as elastic waves, causing oscillations in the particles through which they pass [11]. The following photograph (Figure 1) illustrates ground vibrations caused by blasting.

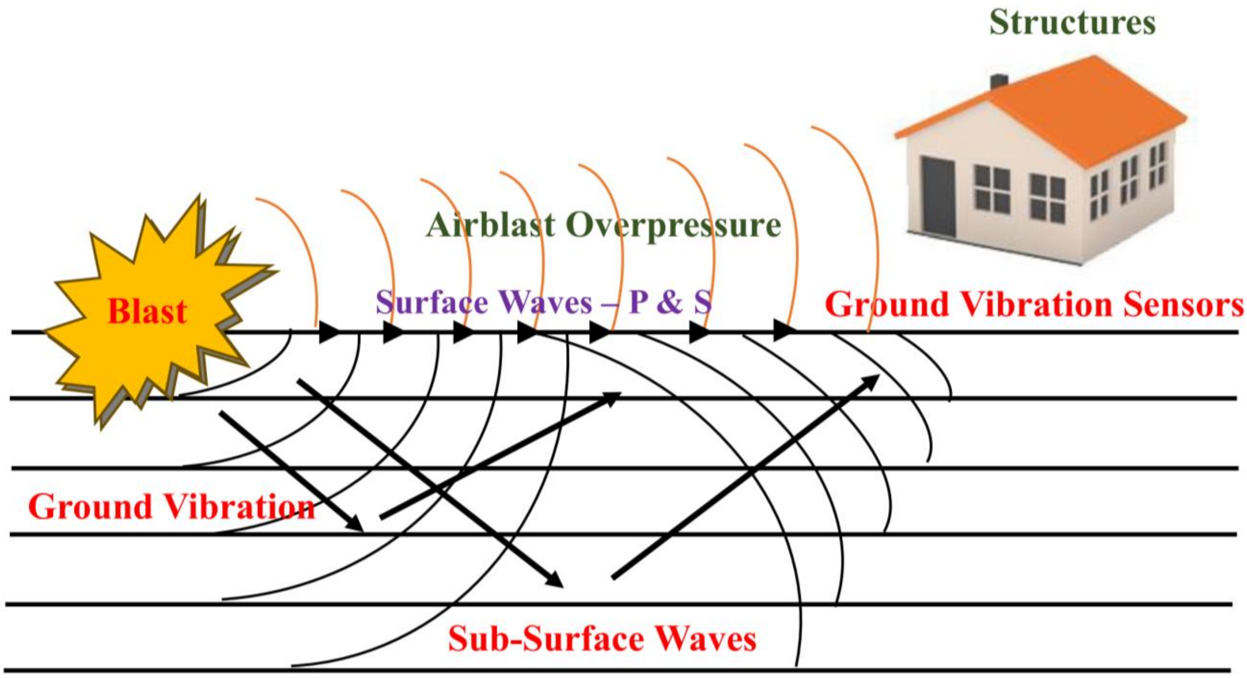

Figure 1. Ground vibrations during blasting[12]

Blasting inevitably causes negative effects such as seismic waves, air blasts, dust, and the creation of toxic explosive gases. Although it is impossible to completely eliminate these effects, reducing them to acceptable levels must remain the continuous responsibility of experts [13].

2. METHODOLOGY

This study examines the possibility of applying geophysical methods to assess the seismic impacts of blasting on the surrounding population. The methodological framework of this research includes a series of steps aimed at analyzing and evaluating the seismic effects of blasting.

2.1 Measurement of Ground Oscillation Velocities

Blasting, as a technique used in mineral extraction, underground chamber construction, tunnel engineering, mining, and civil engineering in general, is inseparable from seismic impacts on rock, soil, and structures based on them [14]. Seismic waves are generally divided into volumetric and surface waves. Volumetric waves travel through the interior of the Earth, while surface waves spread through the shallow layer along the free surface of the Earth [15].

Volumetric waves include longitudinal and transverse waves. Longitudinal waves, known as primary (P) waves, travel faster and have approximately 73% higher speed than transverse waves, known as secondary (S) waves. Surface waves, according to researchers who first described them, are divided into Love waves and Rayleigh waves [16]. A Love wave is a transverse wave with horizontal oscillations perpendicular to the direction of propagation, while a Rayleigh wave is a combination of longitudinal and transverse waves with oscillations in a plane perpendicular to the surface, parallel to the direction of propagation. Surface waves have a slower speed than volumetric waves, with Love waves propagating faster than Rayleigh waves [17].

The measurement of ground oscillation velocities is carried out using mobile seismographs equipped with three-component geophones (Figure 2). Each geophone records oscillation velocities in three components [18]:

- Horizontal component in the direction of the detonation – records longitudinal oscillations (marked 1 on Figure 2);
- Horizontal component perpendicular to the detonation direction – records transverse oscillations (marked 2 on Figure 2);
- Vertical component – records oscillations in the vertical plane (marked 3 on Figure 2)

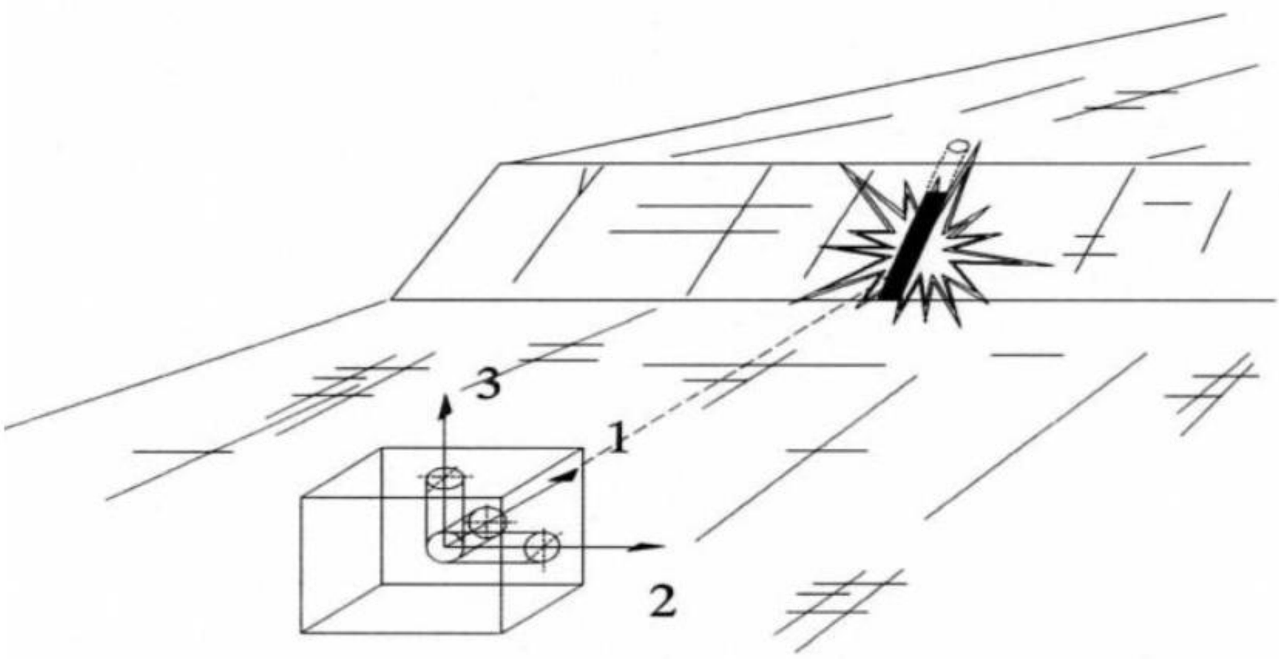

Figure 2. Geophone orientation relative to the detonation point

The goal of monitoring the seismic effects of blasting is the instrumental recording of the negative impacts of artificially induced tremors, with a special focus on the directions of the most pronounced seismic activity. As an illustrative example, PK Koritnik II is used, whose mine is surrounded by structures on all sides, allowing for a better analysis of the seismic effects on surrounding buildings (Figure 3) [19].

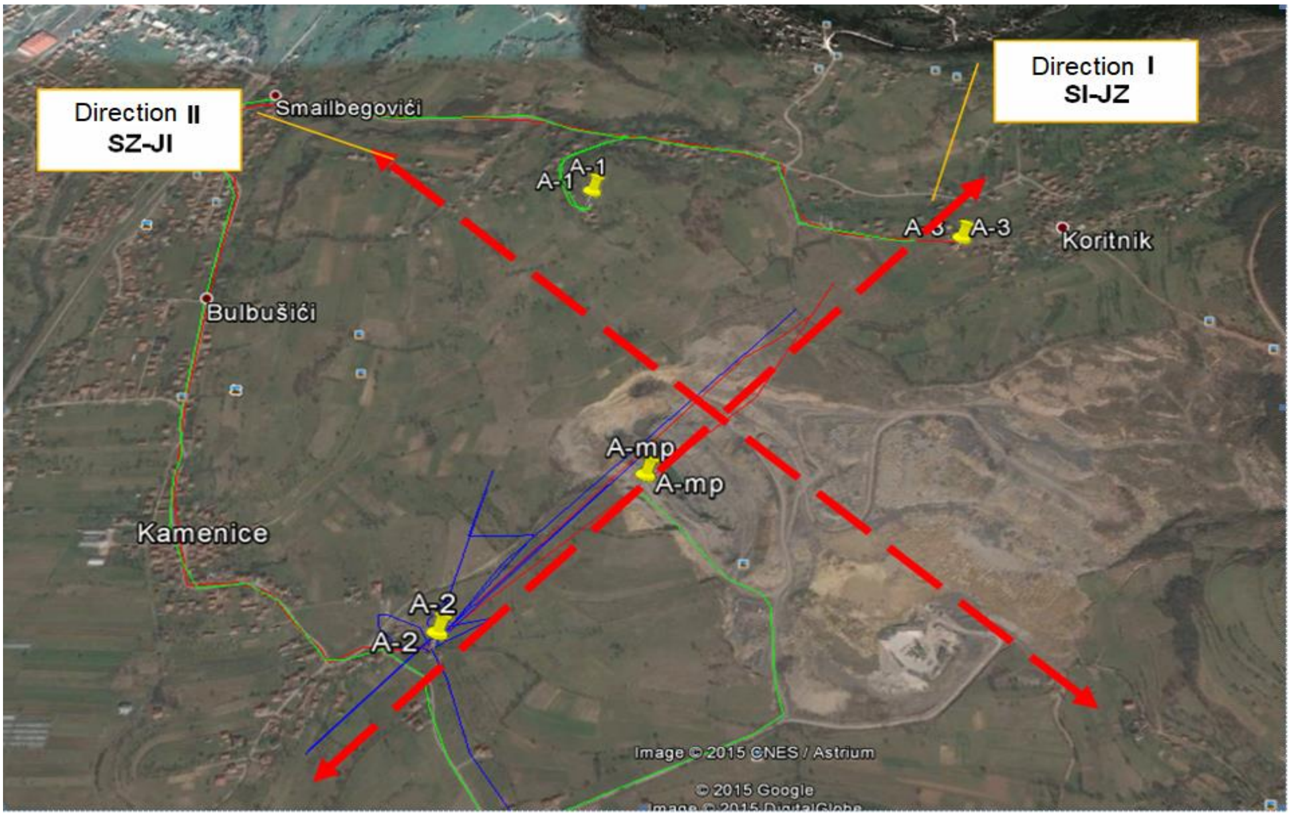

Figure 3. Seismically most critical directions (PK Koritnik II, Breza, Bosnia and Herzegovina) [19]

After the detonation, each geophone records an individual curve that is displayed on the seismogram (Figure 4), providing insight into the seismic disturbance caused by the blasting
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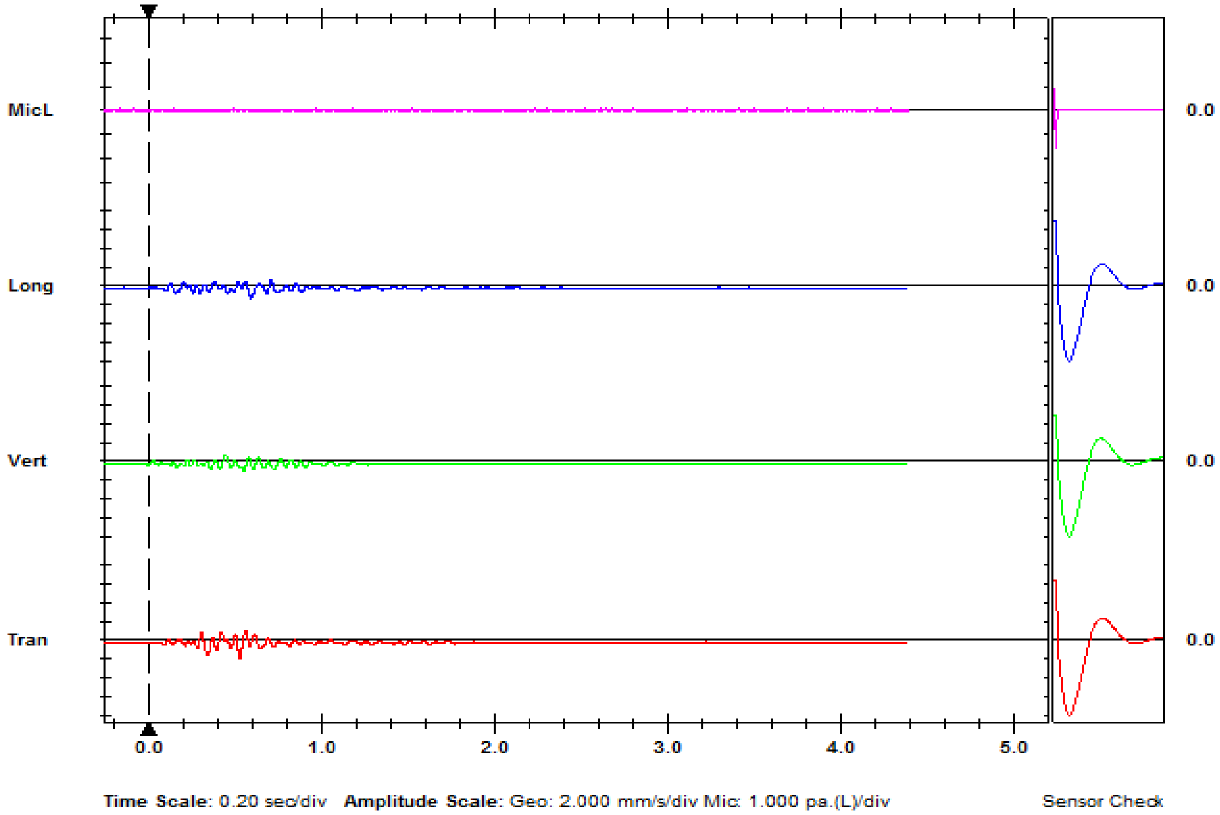

Figure 4. Record of component velocities, air shock wave (PK Koritnik II, Breza, Bosnia and Herzegovina)

The resultant ground oscillation velocity is equal to the vector sum of the velocities of the individual oscillation components, which are taken from the seismogram at the moment of maximum disturbance:

$$V_R = \sqrt{V_T^2 + V_V^2 + V_L^2}$$

where:

V_R- resultant ground oscillation velocity,

V_L- velocity of the longitudinal component of oscillations,

V_T- velocity of the transverse component of oscillations,

V_V- velocity of the vertical component of oscillations.

2.2 Determining the Radius of the Affected Zone During Blasting

Safety distances are determined based on several factors, including the type and amount of explosives, geological characteristics of the area, type and density of settlements, and specific technical characteristics of the blasting [20]. Safety distances serve as boundaries within which serious consequences could occur due to vibrations, air blasts, or other effects such as damage to structures or risks to human safety. Based on years of observation and measurements of ground oscillation velocities, their dependence has been established. For the purpose of orientationally determining the boundaries within which seismic waves may have a harmful effect on structures, the following equation is used [21]:

$$R_u = 0{,}12\sqrt[3]{Q}$$

where:

R_u – radius of the affected zone during blasting (m),

Q – amount of explosive charge currently detonating (kg).

The radius of the affected zone can be orientationally determined using empirical formulas from various authors [22]. Genschel's formula is simple and is given by the expression:

$$R_U = Q^{2/3}$$

To determine the radius of the affected zone, formulas from authors S.V. Medvedev and Sadovsky [14, 21, 22] are also used. Based on measured values of ground oscillation velocities, the intensity of the tremor caused by blasting is determined, and its impact on nearby structures is assessed. The ground oscillation velocity at a desired point can be calculated if the amount of explosive charge per mine hole that is currently detonating and the distance from the point to the blast field are known. There are various methods and standards for calculating the ground oscillation velocity at a desired point [23]. According to certain authors [24], the velocity of ground oscillations is calculated using the following formula:

$$v = 714\left(\frac{D}{W^{a}}\right)^{b}$$

where:

v - ground oscillation velocity (mm/s),
D - distance between the mine field and the observation point (m),
W - maximum amount of explosive charge per blasting stage (kg),
a - exponent for the charge amount (0.512, taken as 0.5),
b - exponent for the rock factor (-1.63, taken as -1.6).

According to Sadovsky, the oscillation velocity is calculated using the following formula [14]:

$$v = k\left(\frac{\sqrt[3]{Q}}{R}\right)^{n}$$

where:

v - ground oscillation velocity (cm/s),
Q - maximum amount of explosive charge per blasting stage (kg),
R - distance between the mine field and the observation point (m),
k - coefficient for the blasting method, and
n - coefficient for attenuation of seismic waves during propagation.

Based on previous related research, it can be seen that empirical methods have been studied by many researchers [25, 26]. Most of the models developed to predict the maximum particle velocity caused by blasting are based on a linear relationship between the amount of explosive per firing stage and the distance of measurement from the blasting site [27, 28].

2.3 Standards for Determining the Allowed Ground Oscillation Velocities

In domestic practice, there are no standards for the proper analysis of data obtained from measurements of artificially induced tremors (blasting) [15]. Therefore, when processing and interpreting the results, foreign standards and norms are used, which best meet the conditions (geological, hydrogeological, tectonic, construction methods, etc.) of the area where the blasting is carried out. Around the world, there are a number of adopted standards – specialized scales used to assess the intensity of tremors from artificially induced earthquakes. According to Stanković (2011), the most commonly used standards are:

- USBM RI8507 and OSMRE,
- ISO 4866:1990,
- British Standard 7385,
- Swedish Standard, and
- DIN 4150.

All standards determine the allowed values based on ground oscillation velocity (mm/s) and frequency (Hz). The following table shows the categorization of structures according to the DIN 4150/3 standard [21]. The standard defines three categories of structures, or three allowable levels of oscillations, depending on the frequency, where no damage is expected [29]. The DIN 4150/3 standard has correlated oscillation velocity and frequency, which gives it several advantages over other standards, making it the most commonly used in Europe today.

Table No. 1 - Categorization of Structures According to DIN 4150/3 Standard

Level (*L*)	Description of Structure	Allowed Oscillations Vi (mm/s) at:			
		Foundations			Floors
		Frequency (Hz)			All Frequencies
		< 10	*10–50*	*50-100*	
1	Industrial buildings and similar reinforced concrete structures	20	20 – 40	40 – 50	40
2	Residential buildings and structures with similar construction	5	5 – 15	15 – 20	15
3	Structures not included in the above descriptions, damaged structures, or structures under protection (historical monuments)	3	3 – 8	8 - 10	8

2.4 Effects of Vibrations on Humans

The sounds that cause the greatest discomfort include the rattling of window panes, doors, and unstable objects, as well as impacts from the exterior of the building or the roof. These sounds cause even greater discomfort if they occur suddenly and unexpectedly [14].

Prior information or awareness of an upcoming sound impact can reduce subjective discomfort, as it allows for psychological adaptation to the expectation of the intensity and duration of the impact [30]. Under certain conditions, a person can detect vibrations as small as one micron, while amplitudes of 0.05 microns can be felt at the tip of the finger [31].

Basic data on the sensitivity of the human body to vibrations were studied by Reicher and Meister (1931), who concluded that vertical vibrations are more strongly felt when a person is standing, while horizontal vibrations are more pronounced when lying down. The intensity of vibrations depends on the amplitude and frequency of oscillations [32].

Amplitudes of 100 microns at a frequency of 5 Hz cause disturbances, while the same vibrations at 20 Hz can cause pain. Vibrations with an amplitude of 10 microns at 5 Hz are barely noticeable, while at 50 Hz, they become unbearable. The sensitivity threshold, determined based on oscillation speed, corresponds to oscillations of 0.3 mm/s, while vibrations of 2.5 mm/s become disturbing [15].

3. DISCUSSION

The analysis of seismic effects from blasting is crucial for assessing potential damage to surrounding structures. Instrumental monitoring of vibrations using three-component geophones and seismographs allows for precise risk evaluation [33]. By employing these methods, it is possible to quantify ground oscillations and their potential impact on structures, with PK Koritnik II being selected as an example due to its specific location among structures. However, the methodology can be universally applied to similar sites.

The geological characteristics of the terrain significantly affect the propagation of seismic waves. Vibrations can be more pronounced in deeper layers due to the higher wave propagation speed through solid rocks, which can cause stronger oscillations at the outcrops of these layers, even if the structures are physically farther from the blasting source [34]. This was confirmed by measurements carried out at PK Koritnik II, where vibrations were more intense at structures located above harder layers. Figure 5 illustrates the geological profile of PK Koritnik II, showing the floors and measurement points used for vibration result analysis

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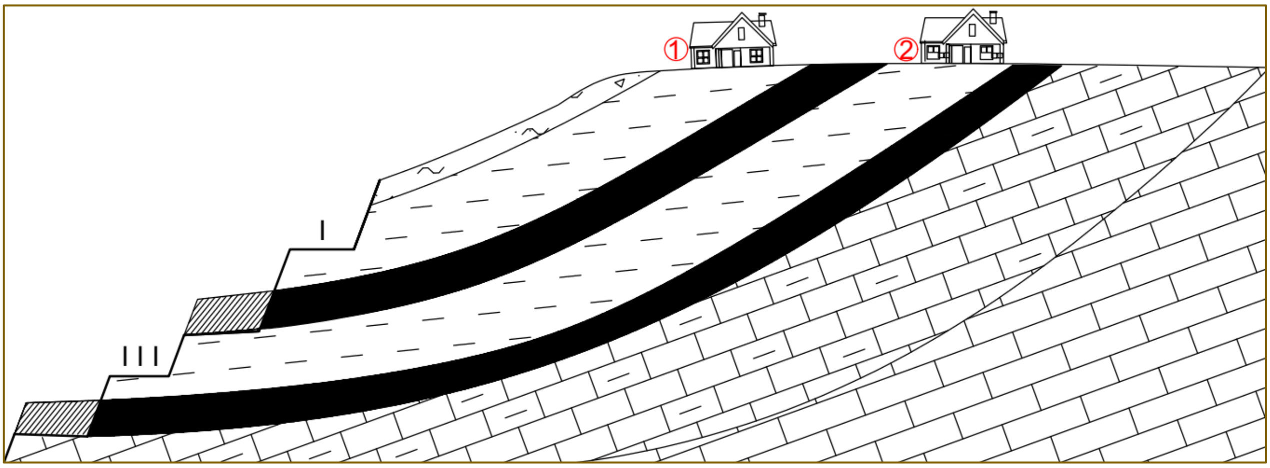

Figure 5. Illustration of the geological profile of PK Koritnik II showing floors and measurement points for vibration result analysis

Blasting took place on floor III on February 10 and 28, 2017. During this period, the measured values of ground oscillation speeds at different positions were as follows: on position 1 on February 10, 2017, they were 0.974 mm/s, while on position 2 they were 1.391 mm/s. On February 28, 2017, position 1 recorded 1.479 mm/s, and position 2 reached 1.792 mm/s. These results indicate variability in the impact of blasting depending on location and soil characteristics.

Timely informing the public is crucial for mitigating the negative effects of blasting. Providing information about the time and intensity of blasting helps the local community take necessary preventive measures [8]. The population should be informed about expected vibrations and potential consequences, which reduces uncertainty and stress. Kahriman (2002) emphasizes that inadequate information can lead to increased perception of risk and negative psychological effects [35]. Additionally, involving the community in the information process can improve the understanding of seismic impacts and reduce potential conflicts between mining companies and the local population [36].

Apart from vibrations, it is essential to consider the sound effects of blasting, which may have long-term consequences on the quality of life of residents. Studies show that noise caused by blasting can lead to stress and sleep disturbances, making it necessary to properly place measurement devices to monitor vibrations and noise in urban areas [37].

Instrumental vibration monitoring methods enable precise assessment of seismic impact and reduction of the risk of structural damage. Studies have shown that reducing the mass of explosive material per blasting phase can significantly decrease vibration intensity [8]. Additionally, using digital seismographs and automatic monitoring systems allows for early identification of risk zones and implementation of appropriate protective measures [36].

4. CONCLUSION

The assessment of seismic impact from blasting on surrounding population requires a combination of instrumental measurements and analytical methods to ensure accurate monitoring of vibrations and their potential effects on structures and people. The research conducted at PK Koritnik II revealed that vibration intensity does not always decrease linearly with distance from the epicenter of blasting, but instead depends on the geological characteristics of the terrain and distribution of seismic waves. The measurements confirmed that deeper layers with higher propagation speeds can lead to amplified vibrations at more distant locations, which is crucial when determining critical impact zones.

In addition to precise vibration measurements at key locations, timely informing the population about the timing and intensity of blasting is essential. Clear and transparent communication reduces uncertainty, allows for the implementation of preventive measures and contributes to the protection of health and property. Implementing systematic notifications through local media, direct messages, or public announcements can significantly reduce negative consequences for the population.

Data analysis shows that proper placement of measurement devices and coordination of experts in the fields of geophysics, geology, and engineering seismology enables a realistic assessment of the impact of blasting and optimization of technical measures to reduce vibrations. Furthermore, the application of seismic methods in combination with empirical models allows for a better understanding of wave propagation and more efficient planning of blasting in populated areas.

Finally, the results of this research can serve as guidelines for similar assessments in other mining and construction projects, with the aim of minimizing risks and ensuring the safety of the population.

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