

PAPER • OPEN ACCESS

The influence of para-seismic vibrations induced by blasting works on construction structures: a case study of the ABC opencast gypsum mine

To cite this article: M Kraszewski 2019 *IOP Conf. Ser.: Earth Environ. Sci.* **261** 012021

View the [article online](#) for updates and enhancements.

The influence of para-seismic vibrations induced by blasting works on construction structures: a case study of the ABC opencast gypsum mine

M Kraszewski

Silesian University of Technology, Faculty of Mining and Geology, 2 Akademicka Street, 44-100 Gliwice, Poland

E-mail: marcin.kraszewski@polsl.pl

Abstract. The article analyses how para-seismic vibrations induced by blasting works in mines affect construction structures. It presents factors affecting the intensity of ground vibrations and their impact evaluation methods, as well as determines the importance of preventive actions aiming at minimizing harmful impact and the need to document this phenomenon. Based on the measurements of vibrations induced by blasting works carried out in the ABC opencast mine, the impact of such vibrations on nearby buildings was evaluated. The aim of this research was to determine the effectiveness of predicting harmful impact of mining operations on buildings by comparing predictions with measurement results obtained from KSPD (Mine Vibration Monitoring Station), and to determine the reasons for possible prognoses inaccuracy.

1. Introduction

A basic rock mining method in open-pit mines allowing for a high effectiveness of loading, transport, and treatment processes is based on mining rock material with the use of blasting. The usage of explosives in mining operations involves a serious risk for their users and for the property located in the blasting impact zone. This article discusses the danger of para-seismic vibrations resulting from blasting works. Preventive actions and predictions of harmful impact of blasting operations in open-pit mines will be analysed based on the case of an open-pit gypsum mine, which, due to its data protection policy, will be referred to as the “ABC mine”. Harmful impact predictions produced for the activity of the plant will further be compared with readout measurements of vibrations induced by blasting works during a half-year period of functioning of the plant in order to check the effectiveness of such predictions, allowing to verify the validity of made assumptions.

2. Impact of blasting works on the environment

The usage of explosives for civil purposes is strictly related to an explosive reaction, usually involving the following phenomena: the creation of large amounts of post-blast gases, high speed of reactions, high pressure, high temperature, light and acoustic effects. Blasting works may be accompanied by certain negative effects and threats including rock fragments dispersion, para-seismic vibrations, air shock waves, and the emission of toxic gases and post-blast fumes. Apart from the above mentioned threats, there are also other dangerous elements which can be encountered in the processes of transporting, storing, loading, and unloading blasting agents. Harmful impact exceeding the area of a mine plant may pose a risk to other persons and their property.



To ensure optimum conditions for conducting blasting operations, entrepreneurs should use safe, high quality explosives and initiating agents. It is also crucial to introduce a proper system of conducting these operations, suited for technical and organizational possibilities of the plant. All actions should be complemented by preventive measures aiming at limiting a negative impact of conducted blasting works on the areas surrounding the mine.

3. Para-seismic vibrations

Detonated explosives generate several types of waves, which differ, among others, in velocity, as they pass through media of different elasticity properties and on their way, are subject to numerous reflections and deflections on the surfaces when the massif is divided. Thus, an initially simple wave movement at the source changes with the distance, giving rise to different types of primary waves, at the same time losing some of its energy. The name “para-seismic vibrations” in itself differentiates them from naturally encountered seismic waves created during earthquakes, and denotes that a human factor is involved.

Different types of seismic waves have different parameters, such as frequency, length, or velocity; thus, as a result of splitting waves, in a given distance from the source of vibrations, vibrations of one type of waves – and not, as may be supposed, total energy of elastic waves – are decisive for the tremor intensity. The intensity of vibrations is expressed in velocity, acceleration, or displacement. Recording waves as a function of time results in seismograms.

The current state of art enforces the measurements of vibrations in directions along the axis of the Cartesian coordinate system, which leads to describing vibrations in accordance with X, Y, and Z axes. Depending on the purpose of the measurement, different axis directions are selected.

The way wave particles vibrate affects damages caused on buildings. For instance, more extensive damages should be expected if the building structure is under the influence of a transverse wave with horizontal and vertical vibrations than in case of only a longitudinal wave affecting the structure.

The intensity of seismic vibrations depends on the following factors:

- distance from the source of waves (location of blasting works),
- holes diameters and charge construction,
- charge volume in the hole and the series of holes,
- physical and mechanical properties of the rock environment at blasting sites, on the way of waves, and at the measuring point,
- firing (millisecond, immediate) method,
- type of used explosives,
- intershot delay and firing scheme,
- geometrical parameters of blasting (distance between holes, webs, drillings).

A rock type and structure, as well as mining conditions and the used explosives serve as a basis for determining the blasting geometrical parameters. Another element strictly related to these parameters is explosives mass and construction in the hole. The mentioned factors are usually fixed in the given geological and mining conditions. The situation is quite different in the case of, what is extremely important for the discussed problem, the charge volume and distances from the protected objects, as these are subject to regular changes.

The experiences of blasting with long holes conducted *in situ* show that it is not the total charge volume in a series of holes that has a primary impact on the intensity of vibrations, but the charge of a single millisecond delay.

As a result of this analysis, explosives in the B zone should not damage building structures, whereas A zones charges can be harmful. This is a basis for deciding upon the need to carry out seismic-metric studies (figure 1).

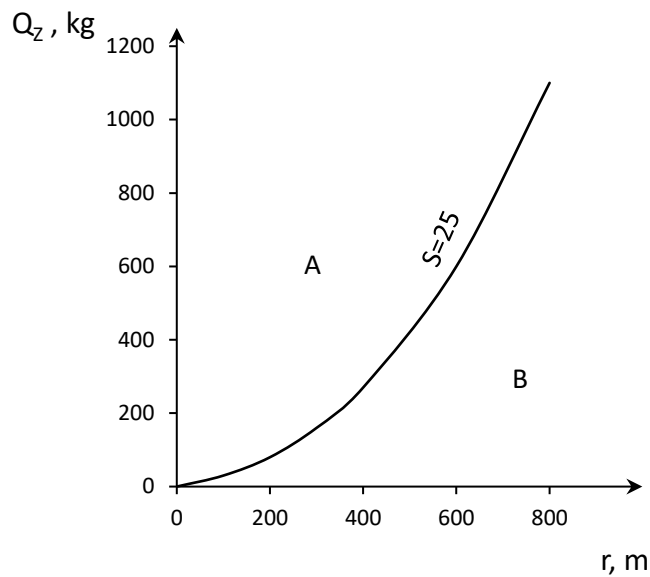


Figure 1. Dependence of Q_z explosive charge volume from the distance of the firing location (r); A – the area of likely damages in residential buildings, B – the area not subject to damages, S – harmfulness threshold, r - radius of range [1].

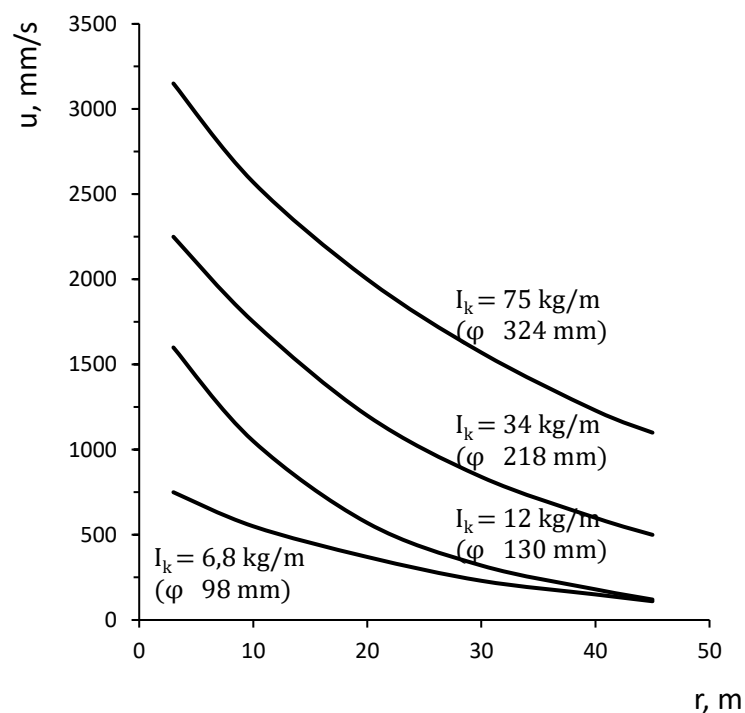


Figure 2. Impact of opening diameters on the intensity of vibrations; r - radius of range, φ - opening diameter, u - velocity[1].

The intensity of para-seismic vibrations to a large extent depends on how blasting works are performed. That is why blasting methods present not only the limitation of orogen vibration rate. It specifically applies to blasting in long openings. What should also be noted, the details of planning

works are crucial. A basic problem here is the dependence of vibrations intensity from the opening diameters and the size of a web. There is a direct dependence between the listed parameters.

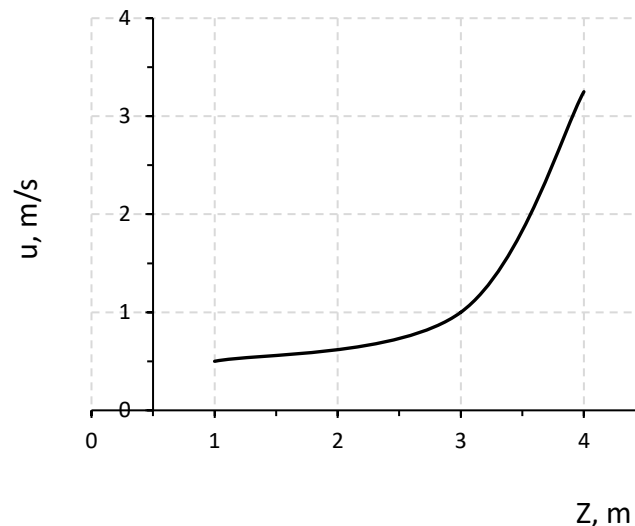


Figure 3. Impact of the web size on the intensity of vibrations; Z – size of web, u -velocity [1].

Divided (layered) charges are extensively used, in which case a proper sequence of firing explosives and interblast delays can lead to very good effects in both minimizing vibrations and in disintegrating material output.

More positive effects were achieved by millisecond detonations, thanks to the possibilities provided by the NONEL system in the selection of interblast delays. It allows to prepare diverse blasting schemes which can be easily adapted to local conditions. The intensity of vibrations is also affected by the total charge of a series of openings – a number of charges fired in a given blast. The intensity of vibrations increases with the number of charges.

4. Methods of evaluating how para-seismic vibrations affect building structures

It is a legal obligations of every mine based on mining law to protect the mine surroundings, including buildings that can be negatively affected by vibrations induced with blasting works. The choice of a proper preventive method used by the mine to minimize negative impact of blasting works should depend on the frequency of conducting blasting operations, the means of doing so, and the threat level and specifications of buildings in the mine surroundings (including the floor amplification ratio).

Preventive actions conducted by mines can be divided into two groups of operations: determining the conditions of performing blasting works in a way that is safe for the surroundings, and those related to documenting the impact level of the works.

In practice, the first group is based on specifying limitations regarding the weight of used explosive charges, the usage of state-of-art firing systems, and the quality of used explosives. The problem of impact of blasting works on the surrounding area in open-pit mining has clearly decreased in the last decade thanks to implementing the technology of non-electric and electronic firing or mechanical charging to blasting openings of emulsion explosives or ANFO. However, the problem of blasting works affecting the surroundings has not been solved and forced mines to undertake actions related to documenting and keeping the archives of events related to the usage of explosives in operations. More frequently, concessions include requirements regarding control tests and monitoring, and in their

opinions for concession bodies, local authorities emphasize the need to minimize the impact of mining operations on the mine surroundings.

The impact on the surroundings can be documented in two ways: by control tests or by monitoring. Periodic control tests are based on verifying the effectiveness of a previously prepared vibrations intensity prediction. Such vibrations intensity prediction can be determined for any point in the mining pit surroundings using the propagation equation, including the accepted limitations and weights of explosives, as well as the distance from the blasting works location. Such a prediction results in estimated values of vibrations intensity for a specific blasting. The comparison of measurement values obtained during periodic control tests with the predicted ones allows to estimate the effectiveness of predictions and, as a result, to verify whether accepted assumptions are still valid. The next action within control tests is to measure vibrations in the construction structures themselves and assess their impact in accordance with norms and applicable procedures.

A great disadvantage of documenting impact by performing regular control measurements – the one which actually undermines the purpose and effectiveness of such measurements – is their periodic character. Time periods between subsequent measurements can be as long as several years, which undermines the purpose of performing them and serves as an argument for parties applying for damages.

The deficiency of control test can be remedied by monitoring of vibrations. The concept of monitoring is understood as a constant measurement of vibrations performed by instruments archiving the measurement results and self-switching. The instruments operate in a continuous mode, archiving each event along with its date and time. Such operations are related to the need to install permanent measurement instruments on specific buildings which are characteristic for the conducted studies, as, for technical and economic reasons, it is usually not possible to perform measurements on all construction structures in the mine surroundings. Unmanned stations are mounted on buildings, and the whole monitoring system can be operated by internal employees of the mine. Such monitoring of vibrations has been implemented in the case of the ABC gypsum open-pit mine.

A negative impact of para-seismic vibrations on buildings is assessed by comparing measured vibrations with proper scales including organized effects of para-seismic wave activity. Such scales are usually divided into levels with a descriptive character and a numeric value of amplitude, acceleration or velocity assigned to each of them. Slightly different scales are used to assess the negative impact of post-blasting vibrations than to evaluate vibrations from earthquakes, as vibrations from these two sources differ, especially in their nature, the type of waves inducing those vibrations, the time of vibrations increasing, their duration, and other parameters.

The scales of dynamic influences SWD I and SWD II allow us to present an approximate characteristic of negative impact of vibrations in accordance with the PN-B-02170:1985 standard. They are presented in the form of nomograms allowing for a quick orientation in how great the impact of registered vibrations is by applying the measurement results on the nomogram.

Scale SWD I – applies to buildings of a compact shape, small external dimensions in a horizontal view (not exceeding 15 m), one- and two-story buildings, structures not exceeding any of the dimensions in a horizontal view[2].

Scale SWD II – applies to buildings not higher than five stories, lower than their smallest width doubled in a horizontal view, and to low buildings (up to two stories) which do not meet the requirements specified for scale SWD I [2].

The above SWD scales have been presented in the form of logarithm-based diagrams, where the vibrations velocity values (vertical axis) correspond to the frequency of vibrations (horizontal axis). Horizontal vibration components are considered while assessing the impact. Both scales consist of five zones separated with thresholds determining the harmfulness level of vibrations measured for a given building. Each threshold is drawn in the form of a continuous and a dashed line. Such a variant selection has been introduced to consider the evaluation of a ground type, building type, and vibrations type.

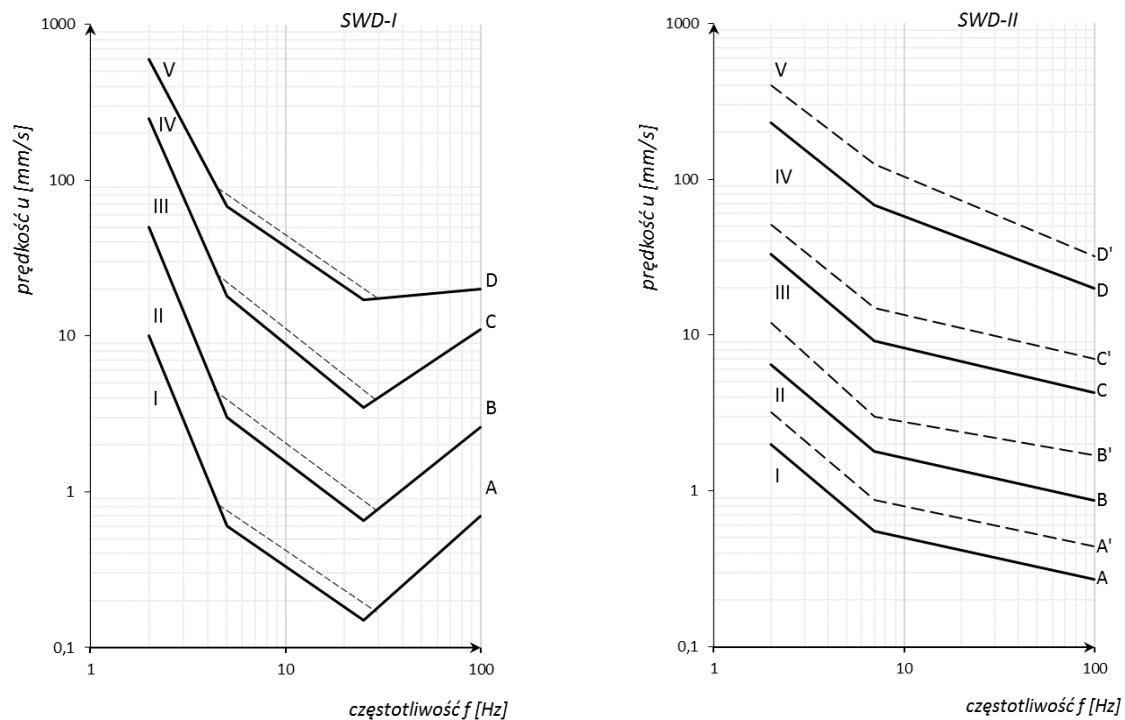


Figure 4. Scales SWD-I and SWD-II pursuant to PN-B-02170:2016-12 standard (velocity-dependent version).

Variant curves (a continuous and dashed line) have been applied on the nomograms of SWD scales allowing for evaluation with the consideration of such additional conditions as the construction and condition of the building, the character of vibrations, and the type of ground. The variant depends on the number of prevailing characteristics.

Another commonly used scale is the MSK scale. It distinguishes three categories of buildings with regard to their construction as well as five levels of their damages. This scale has been well-prepared for the evaluation of how harmful tremors in the Upper Silesian Coal Basin (Górnosławskie Zagłębie Węglowe) and in Legnica and Głogów Copper Mining Area (Legnicko-Głogowski Okręg Miedziowy) are, but it is not particularly suitable for the evaluation of tremors created in small opencast mines.

Specific scales and norms pertain to specified, definite types of buildings and specific types of para-seismic vibrations (a division with regard to the source characteristics). For example, there is a significant difference between vibrations caused by blasts and those resulting from transport. Vibrations caused by blasts, even those characterized by bigger amplitudes, are shorter and less harmful for construction structures than vibrations caused by heavy vehicles passing. In case of these latter ones, frequencies are bigger and the duration is longer. That is why it is so important to distinguish between the source of vibrations and define their negative impact thresholds.

An example of scales adapted in such a way abroad is the one determined in the Bureau of Mines (USA), which includes three parameters of vibrations: displacement, velocity, and frequency. This scale takes into considerations the resistance of a construction structure to tremors.

The most important scales for evaluating the impact of vibrations on structures used in the world also include C. Ashley's scale (USA), the Portuguese scale of harmfulness (J. M. Esteves), the harmfulness scale used in Russia (based on the MSK-64 scale), the Australian norm (CA 23-1967), or the German DIN 4150 norm.

Table 1. Zones and their limits for the SWD scale [2].

V. -	Vibrations causing walls to collapse, ceilings to drop, etc., with full danger to people's lives
D polyline-	Building stability limit, above which the whole building may get damaged
IV. -	Highly harmful vibrations, many cracks are created, local damage to walls and other individual elements of the building
C polyline -	Resistance limit of individual elements of the building
III. -	Vibrations which are harmful for the building, causing local scratches and cracks
B polyline -	Building stiffness limit
II. -	Vibrations which can be felt but are not harmful; only the wear and tear of the building proceeds faster
A polyline -	Lower limit of building experiencing vibrations and considering dynamic impact
I. -	Vibrations which are not experienced by buildings

5. Instruments measuring the size of vibrations caused by blasting works

Measurement and observations of stress processes require specialist research instruments. Theoretical calculations of vibrations intensity allow to obtain estimated values and cannot be a foundation for a detailed assessment of this phenomenon. That is why soil research and studies in protected buildings with specialist instruments are crucial. Current technologies allow to directly register spatial vibrations of a rock medium particles, and that is why the presently applied instruments include devices constructed of three mutually perpendicular components: x, y, and z.

It has been found that an optimum solution allowing for constant registration of vibrations in a longer time period with their identification and the observations of damages is Mine Vibrations Monitoring System (Kopalniany System Monitoringu Drgań, KSMD). KSMD quickly found its application in mines with an independent protection of their surroundings. The system includes measurement instruments (registering blast-caused vibrations) and computer software (using measurement results to design blasting works that are safe for the environment). This allows to observe vibrations caused not only by blasts, but all other vibrations related with everyday exploitation of a constructions structure. The monitoring of vibrations allows to achieve highly precise evaluation of how blasting works impact protected objects in comparison to randomly performed measurements.

The actions of the Mine Vibrations Monitoring System Station include:

- measuring the intensity of vibrations in protected buildings,
- designing blasting works in accordance with the previously prepared guidelines,
- archiving data (on performed blasting works and the results of their impact).

6. Evaluation of the impact of blasting works performed in the ABC mine

The ABC gypsum mine selected to represent this topic is an open-pit hillside mine which uses longwall and shortwall mining systems, parallel to a straight advance of a working front line. The deposit is exploited on two levels, two mining floors that are 6-21-meter high. The daily extraction rate is 6000 Mg/day. The deposit mining is carried out by blasting in long openings with a continuous or divided charge and a non-electric system of firing explosives. The deposit mining is performed with the usage of methods of blasting in long openings angled by 20°, with a continuous or divided charge and a non-electric system of firing explosives. Since it is possible that harmful para-seismic vibrations are induced, the selection of millisecond delays of fuses in impact charges, surface fuses (connectors), and a construction of a blasting network is applied, leading to a faster initiation of the upper charge.

In accordance with field studies, the reach of harmful seismic vibrations for the ABC deposit should be 500 m and it depends on the explosives volume per hold and in the whole series and distance from the protected building to the site of performing blasting works. Exploitation levels and the mine itself

are located in the centre of three groups of buildings which are located to the north, west, and east of the mine, and each group of buildings is represented by one building (typical for the group in general) on which an independent measurement point for the Vibrations Monitoring Mine System Station was installed. These buildings were brick, compact structures of small dimensions, in a good technical condition, without damage or alterations. All selected buildings met the requirements of the SWD I scales. The first two buildings (village A and village B) were placed on a soil of little stiffness, whereas the building in the Gipsowo village – and a stiff soil base constituting an outcrop of the gypsum deposit (a currently exploited layer).

In practice, the performed evaluation of vibrations is treated as a preliminary one. It included determining the peak velocity amplitudes and their corresponding instantaneous frequency (a direct method), but it did not consider the so-called dominating frequency obtained as a result of a spectrum analysis of vibrations course in time (as it is done in the indirect method). A more detailed characteristic allows to determine the frequency-based precision with which a dominating frequency of the highest importance can be specified in the form of power density. Spectral density can be found in literature as PSD (Power Spectrum Density) and serves as a basis for the indirect method analysis. Due to the limitations in accessing data necessary to evaluate the intensity of vibrations with an indirect method, only a direct method analysis was performed.

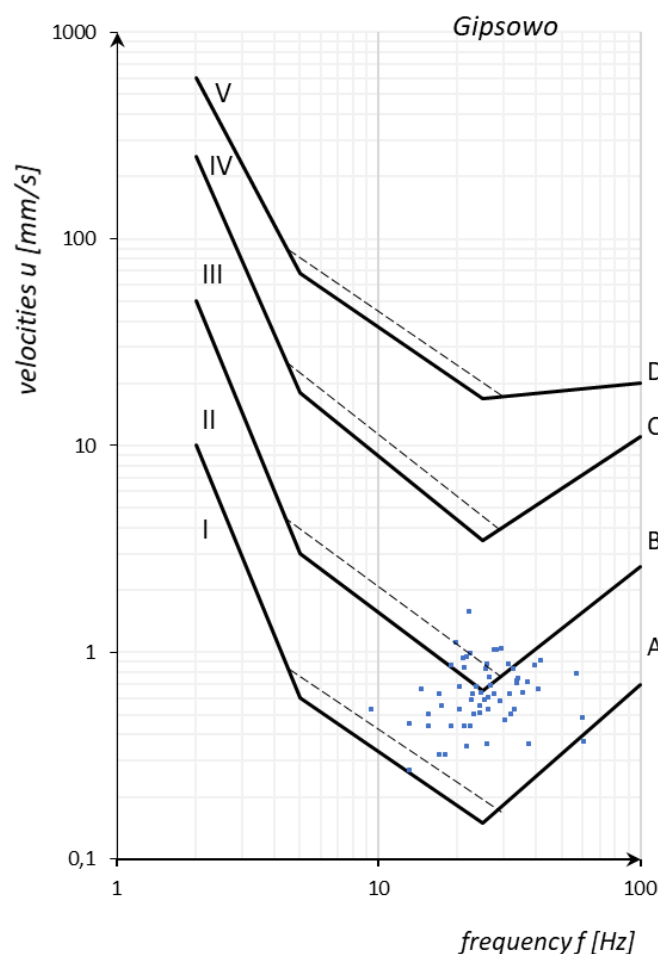


Figure 5. Results of measuring vibrations on the SWD I scale – Gipsowo.

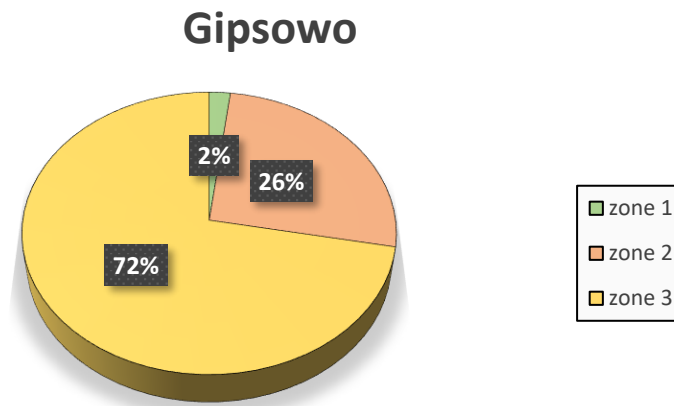


Figure 6. Percentage share of vibrations measurements read in different impact zones on the SWD scale (table 1) for the Gipsowo station.

In the period included in the analysis of measurements – from 1 January to 30 June 2015 – the level of vibrations registered in the buildings in village A and village B was experienced but it did not affect the building construction.

The level of registered vibrations in the same period in the building located in Gipsowo was higher than in two remaining buildings equipped with a measuring station. The nomogram of the SWD – I classification showed that the measurements in vibrations reports from KSMD had exceeded the B curve, which means that these vibrations negatively affect the building and can lead to occasional local cracks and scratches. Predictions prepared for the discussed blasting works did not include harmful vibrations that could permanently affect the building, which shows that the prediction for the third building did not prove true.

7. Conclusions

The result of the conducted study led to a site inspection, which proved many irregularities in the third building (“Gipsowo”) and other neighbouring developments. Multiple cracks around windows in the shape of St. Andrew’s cross, characteristic for mining damages, were found. Similar cracks were also observed in the area of ceilings or on pavements.

Deficiencies in the prediction of negative effects on construction structures located to the north from the front line of works can be attributed to many possible examples of negligence. The difference in the level of registered vibrations can result from karst phenomena in the way of para-seismic waves propagation from the blasting works site to the location of the building equipped with station no. 3. Karst phenomena and underground caverns can both intensify and damp tremors. Liquids can serve as a media after which vibrations intensify or decrease, whereas caverns and holes filled with gases show damping properties. Both mining levels are characterized by an increased water inflow with the current development of the mining front line towards Gipsowo, which may result in filling the mentioned holes with underground water, leading to stronger records read by seismometers in this direction. Karst phenomena were recorded in documentation of the plant only on the way of waves propagation towards station no. 3.

Another reason can be an uneven distribution of geological layers in relation to measurement stations. The gypsum deposit outcrop is directed directly towards the building in Gipsowo. The gypsum layer has different geomechanical properties than the overcap layer which partially transports vibrations towards the remaining measurement stations. Going through only one layer, vibrations can be damped a lot less than when the medium changes. What is more, station no. 3. in Gipsowo has a similar land coordinate to the coordinate of the first exploitation level. The other stations are located higher or lower than the

height coordinate of the exploitation levels. Tremors best propagate along the surface, which means that they are damped faster in the vertical direction than in the horizontal one.

Reasons for the observed phenomena can be also found in poorly designed blasting works. Holes with too large diameters or incorrectly calculated maximum charge zones can lead to vibrations which are dangerous for buildings. In case of errors in designing works, charges used in a single blasting can be disproportionately large in comparison to the distance of a protected building from the blasting site.

The monitoring of vibrations, which means a constant register of vibrations, in a longer period of time along with the identification of vibrations and the observation of damages turned out to be a very prospective research method. It allows to observe not only blast-originating vibrations, but also all other vibrations related to the everyday usage of a construction structure. With monitoring of vibrations, it is possible to achieve a much higher precision of the evaluation of blasting works impact on protected buildings than with randomly conducted measurements. Predictions of negative impact play a significant role in preventive actions carried out by open-pit mines, but they become truly valuable when correct parameters are considered for blasting works, which are monitored continuously and not only from time to time, as it had been before KSPD was implemented to mines.

8. References

- [1] Korzeniowski J I and Onderka Z 2006 *Blasting works in opencast mining* (Wrocław: Wydawnictwa i Szkolenia Górnicze Burnat & Korzeniowski)
- [2] PN-B-02170:2016-12 *Assessment of the harmful impact of vibrations transferred by the ground on buildings*
- [3] Dawding C 1993 *Blast Vibration Monitoring for Rock Engineering* Comprehensive Rock Engineering (London: Pergamon Press)
- [4] Kawulok M 1983 *Mining Subsidence Engineering* (Berlin, Heidelberg, New York: Springer Verlag)
- [5] Onderka Z 1999 *Bezpieczeństwo Pracy i Ochrona Środowiska w Górnictwie* **7-8** 5
- [6] Winzer J, Sieradzki J and Sołtys A 2008 *Bezpieczeństwo Pracy i Ochrona Środowiska w Górnictwie* **4** 26