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DETERMINING ACCEPTABLE EXPLOSIVE CHARGE MASS UNDER DIFFERENT GEOLOGICAL CONDITIONS

PROBLEMATYKA WYZNACZANIA DOPUSZCZALNYCH ŁADUNKÓW MW W ZRÓŻNICOWANYCH WARUNKACH GEOLOGICZNYCH

This article presents a procedure for determining the safety of explosive charges for their surrounding environment, using a limestone mine as a case study. Varied geological structures, as well as other constructions in the surrounding area of a mine, sometimes necessitate the use of two or more ground vibration propagation equations, and thus a variety of explosive charges, depending on the area of rock blasting. This is a crucial issue for the contractor, as it is important to blast the rock as few times as possible, while using the maximum amount of explosive charge for each blast.

Keywords: blasting works, propagation equation, ground vibrations, acceptable explosive charge mass

Wykonywanie robót strzałowych w górnictwie polega na odpalaniu mas materiału wybuchowego (MW) celem uzyskania dużej ilości odpowiednio rozdrobnionego urobku. W momencie zwiększonego popytu na surowce skalne zakłady górnicze zmuszone są do zwielokrotnienia wykonywania prac strzałowych aby zapewnić regularne dostawy produktu. Konsekwencją takich działań jest ponoszenie dodatkowych kosztów operacyjnych. Celem ich minimalizacji oraz uzyskania jak największej efektywności prowadzonych robót strzałowych jest wydłużanie serii, a więc stosowanie coraz to większych mas ładunków materiałów wybuchowych. Efektem takiego postępowanie jest możliwość wystąpienia w otoczeniu oddziaływania o potencjalnie szkodliwym charakterze m. in. drgania parasejsmiczne. Aby wyeliminować powyższy problem oraz zapewnić niezbędny komfort mieszkańcom, Prawo geologiczne i górnicze, Prawo ochrony środowiska i rozporządzenia wykonawcze nakładają na podmiot wykonujący roboty strzałowe obowiązek ochrony otoczenia, poprzez prowadzenie działalności profilaktycznej w zakresie kontroli, monitorowania oraz wyznaczania dopuszczalnych mas ładunków MW.

W momencie gdy nie ma możliwości ograniczenia niepożądanych wpływów dynamicznych po przez zmianę parametrów siatki strzałowej czy modyfikację struktury czasowo-częstotliwościowej drgań, jedyną możliwością staje się ograniczenie całkowitej masy ładunków materiału wybuchowego odpalanego w całej serii oraz mas przypadających na pojedynczy stopień opóźnienia. Podejście takie stanowi

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w ostateczności jeden ze sposobów minimalizowania niekorzystnego oddziaływania drgań na obiekty budowlane znajdujące się w bezpośrednim otoczeniu kopalni.

Metodyka wyznaczania dopuszczalnych mas ładunków MW dla danych warunków górniczo-geologicznych, mimo że w sposób szczegółowy opisana w literaturze fachowej oraz znajdująca szerokie zastosowanie, niekiedy musi zostać zmodyfikowana w zależności od odmiennej struktury masywu skalnego, warunków topograficznych oraz urbanizacyjnych. Zróżnicowana budowa geologiczna złoża oraz struktur geologicznych na których posadowione zostały chronione obiekty budowlane determinuje strukturę częstotliwościową i sposób propagowanych drgań. Istotą w takim przypadkach staje się określenie progu szkodliwości drgań, który pozwoli na bezpieczne prowadzenie robót bez możliwości wystąpienia uszkodzeń na obiektach chronionych zlokalizowanych w otoczeniu kopalń. Dodatkowo jak przedstawiono w artykule może dochodzić do sytuacji gdzie wykonywanie robót strzałowych w jednym miejscu wyrobiska może powodować zupełnie odmienną propagację drgań w różnych kierunkach. Rozpatrując powyższe względy oraz uwzględniając, że często ma się do czynienia z bardzo bliską zabudowę znajdującą się w otoczeniu kopalni niekiedy zachodzi konieczność wyznaczenia dwóch lub więcej równań propagacji drgań parasejsmicznych. Postępowanie takie prowadzi w konsekwencji do wyznaczenia różnych, często odmiennych, dopuszczalnych mas ładunków MW, których detonacja nie powinna powodować niekorzystnego wpływu na obiekty budowlane.

Zależności te są zmienne w funkcji miejsca wykonywania robót strzałowych, a tym samym kwestia ta stanowi ważne zagadnienie z punktu widzenia przedsiębiorcy, którego głównym celem jest maksymalizacja jednorazowo odpalanej w serii masy ładunków MW przy równoczesnej minimalizacji liczby odpalanych serii.

Jedyne utrudnienie, które może wynikać z wyznaczania w taki sposób ładunków oraz stosowania otrzymanych zależności może dotyczyć sposobu wykonywania robót strzałowych.

Słowa kluczowe: roboty strzałowe, równanie propagacji, drgania parasejsmiczne, dopuszczalne ładunki

1. Profile of the research site

Rock blasting in opencast rock mines is the detonation of large masses of explosives, whose aim is to obtain spoil of a consistency adapted to the needs of the mining company and processing plant. As a result of explosive charge detonation, aside from the obtainment of spoil, a large amount of energy is discharged into the rock mass, which results in a certain intensity level of vibrations registered in the surrounding area. These vibrations can affect building structures located near the excavation site. Though the vibrations themselves do not necessarily entail a harmful effect on such structures, it is still necessary to take preventative measures aimed at reducing this effect. Recognizing the degree of vibration intensity and the direction of its discharge is crucial, especially due to the protection of existing or planned building structures in the vicinity of a rock blasting area (Winzer, 2008).

Literature (Batko, 1993, 1994, 2002, 2004; Biessikirski et al., 2001, 2007; Crum & Siskind, 1993; Dojcar, 1996; Dubiński & Mutke, 2008; Egorov & Glozman, 1997; Karakus et al., 2010; Kelly & White, 1993; Korzeniowski & Onderka, 2006; Kuzu & Hudaverdi, 2005; Maciąg, 1979; Maciąg et al., 2007; Modrzejewski, 2004a, b, 2006; Müller & Böhnke, 2003; Oloffson, 1990; Onderka et al., 2003; Onderka & Sieradzki, 2004; Pyra, 2008; Soltani et al., 2011, 2012; Siskind, 1976; Winzer et al., 2006; Winzer & Pyra, 2007) on the subject of vibrations resulting from the use of explosive charges in opencast mines describes a number of factors affecting the intensity of these vibrations. These include:

- the geological structure in the rock blasting area and in the area affected by diffused elastic waves,
- longitudinal wave velocity as a profile of rock mass in a place of mining and measurement,

- type and profile of explosive material and the construction of the charge in the hole,
- geometric parameters of the blast hole grid (shape of the grid, length of the holes, the distance between the holes and rows of holes, diameter),
- explosive charge mass: in a series of holes (Q_c,) per individual delay between blasts (Q_z) and the construction of the charge in the hole (Q_1),
- the detonation order of explosive charges and delay between blasts,
- the distance from the measurement point to the source of vibrations,
- initialization system, precision of detonators,
- atmospheric conditions.

There are several other factors which additionally affect the intensity of vibrations in a protected building structure, such as:

- construction of the building,
- the technical state of the building,
- the makeup of the ground under the building,
- the type and depth of foundation,
- the profile of vibrations emanating from the ground to the building,
- the frequency of the building's own vibrations,
- the location of the building in relation to the blast.

While we have absolutely no control over some of the enumerated factors, we do have a certain amount over others. Experienced authors have nevertheless pointed out that the main factors affecting vibrations propagated through detonation of explosive charges are: distance from the blast area; geological structure of the ground in the blast wave radius zone; explosive charge per delay (Kuzu & Hudaverdi, 2005); and the length of the delay (Dick et al., 1983).

The majority of research works concerning the limitation of ground vibrations takes into account especially the mass of explosive charges and the distance of the rock blasts from other protected building structures. The remaining factors (e.g. geological structure, the initialization system being used, the length of the delay in milliseconds, etc.) are generally difficult to define, which is why their influence is analyzed according to local conditions. An important element of conducted research was the adaptation of blasting works parameters to the properties of the medium in which the vibrations are propagated, such as to minimize the impact of the vibrations on building structures located in the surrounding area.

As aforementioned, changing geological conditions are difficult to take into account on a global scale, which is why the issue of determination of propagation equations and acceptable explosive charge masses under such conditions was addressed locally, with respect to individual limestone deposits.

1.1. Geological structure of the deposit

The deposit is located in the Silesian Voivodeship. Upper Jurassic layers are represented by the lower, middle, and upper Oxfordian stage, as well as the Kimmeridgian. In the profile of the Jurassic sediments of the deposit, limestone rock is the oldest occurring rock. They are hard, thick-banked, and do not contain siliceous nodules, but are silicified in certain places. At the top of these limestone deposits is cretaceous limestone with flints, and rock limestone directly above. Meshed with them is also plate limestone, micrite limestone, and marl limestone with interlayers of marl.

Occurring in the whole area above the lower plate limestone is marl of the lower marl unit. Above the marl is sheet micrite and marl limestone. All of the above units belong to the latest Oxfordian stage. The boundary between the Oxfordian and Kimmeridgian stages is within the youngest lithological unit in the Cretaceous limestone of the Kuchar.

The most important raw material is the „lower plate limestone." It is significantly thick and does not contain flints. Occurring between the lower and middle plate limestone deposits, i.e. the „lower marl unit," it has an undervalued basic parameter content – approximately 43% CaO.

The whole surface of the deposit is covered with quaternary deposits, whose thickness ranges from 0.3 m to 10.0 m. These are sands, clays, loams constituting moraine deposits of the middle Polish ice age, and soil.

Among the tectonic phenomena found in the deposit bed, aside from corrugations and changes in the angles of collapsing layers, was a geological fault. It is located on the northern part of the deposit, and its course runs from NW – SE. The maximum thickness of the overburden above the balance deposit amounts to 10.0 m. The average thickness of the overburden above the balance deposit amounts to 3.7 m, and for the whole deposit 4.1 m.

1.2. Description of field measurements and rock blasting

A basic method of mining is the detonation of explosive charges placed in long holes with diameters of 95 mm and 105 mm. Until the target height of 3rd-floor level exploitation has been reached, rock blasting was conducted in accordance with the restrictions outlined in 2003 for 1st and 2nd-floor levels of exploitation.

During the period of research, work was done using bulk Emulgit emulsion explosive ANFO Hanal cartridges with a diameter of 65 mm. The charges were detonated using a non-electric system with a delay of 42 ms. Measurements were performed on profiles (measurement lines) leading to the closest building structures located north and south of the excavation site. The blast holes were positioned in one row. Series of 10 charges each were detonated with a delay of 42 ms. Explosive charge mass in each hole and per delay was 40.5 kg and 43.0 kg, and total explosive charge mass was 405 and 430 in each series.

The placement of measurement stands was determined by the immediate environment of the excavation area (two places), namely from the south side of the buildings structures in location A, and from the north side of the building structures in location B. Therefore, the measurement positions were located in 2 directions: south direction (profile 1 – position 20, 22 and 23, profile 2 – position 21, 24 and 25 – location A); north direction (profile 3 – from position 31 to 34 – location B).

2. Method of determining acceptable explosive charges

The relationship between vibration intensity u, mass of the detonated explosive charge Q, and distance of the rock blasts from the measuring point is represented by the general formula (Onderka et al., 2003):

$$u = K \cdot Q^{\alpha} \cdot r^{-\beta} \tag{1}$$

where:

u — vibration velocity,
K, α, β — coefficient and exponent, determined empirically for each mine.

The determination of unknown parameters K, α, β requires research under given geological and mining conditions, in particular with a consideration for changes in the distance of measuring points from rock blast, as well as the significant variation in charge size and delay time for each series. This is not always possible under the conditions of production, which is why – given the current level of knowledge, and using the results of years of research on seismic effects – a simplified equation based on the relationship in (1) is commonly used:

$$u = K \cdot \rho^{\beta} \tag{2}$$

where: ρ represents the relative charge and can be calculated using formula (3):

$$\rho = \frac{Q^n}{r} \tag{3}$$

In which exponent n is defined as (4):

$$n = \frac{\alpha}{\beta} \tag{4}$$

The problem is assigning the appropriate value to n. Use of the dimensional analysis to theoretically describe the impact from the detonation of explosive charges on the rock environment gives an initial estimation of the value of the exponent as $n = 1/3$. The basis of these considerations was a concentrated charge placed in an unlimited homogeneous environment, the assumptions of which justified the inclusion of wave volume. This exponent is applicable when using small charges with small meuring distances, where the variability of the environment does not play a significant role.

Blasting works which are conducted in surface mines differs fundamentally from the presented model, in terms of both the shape of the charge and the type of waves emitted. Elongated charges in the holes form a rock environment witdistinct structural variety, usually with two planes of exposure, and with surface waves transferring the overwhelming part of detonation energy.

Research of the seismic effect from rock blasting has revealed that under conditions of surface mines, the value of the exponent can be assigned as $n = 1/2$ or $n = 2/3$. It has also been found, that with millisecond detonation the vibration intensity depends mainly on the charge mass per delay Q_z, and to a lesser degree on the charges of hole series Q_c.

Analysis of long-term research in limestone mines justifies the assignment of $n = 2/3$, hence equation (2) is presented as:

$$u = K \cdot \left(\frac{Q^{\frac{2}{3}}}{r} \right)^{\beta} \tag{5}$$

and the formula for calculating acceptable charges:

$$Q = \left(\frac{u}{K} \right)^{\frac{3}{2\beta}} \cdot r^{1,5} \tag{6}$$

The basis of further considerations is equation (5), in which there are two unknown arguments: coefficient K characterizing the firing conditions; and coefficient b expressing the change in vibration intensity with distance.

The unknown values K and b are determined by taking into consideration the ground vibration measurements which were taken at various distances from the blast works, with different charges Q_c and Q_z, as well as using methods of statistical calculation.

Determining the propagation equation is the starting point for establishing safe rock blasting conditions under specific field, geological, and mining circumstances.

3. Explosive charges safe for the environment

3.1. Determining the propagation equation

In 2003, propagation equations were derived, and acceptable charge masses for blast works carried out in a mining site were determined. Figure 1 shows the plotted results of vibration velocity and relative charge mass, as well as designated equations of propagation for the charge of millisecond delay (Q_z – green) and a charge of the total series (Q_c – blue), which can be written as:

$$u = 19{,}11 \cdot \rho_c^{\,1{,}21} \tag{7}$$

$$u = 205{,}85 \cdot \rho_z^{\,1{,}38} \tag{8}$$

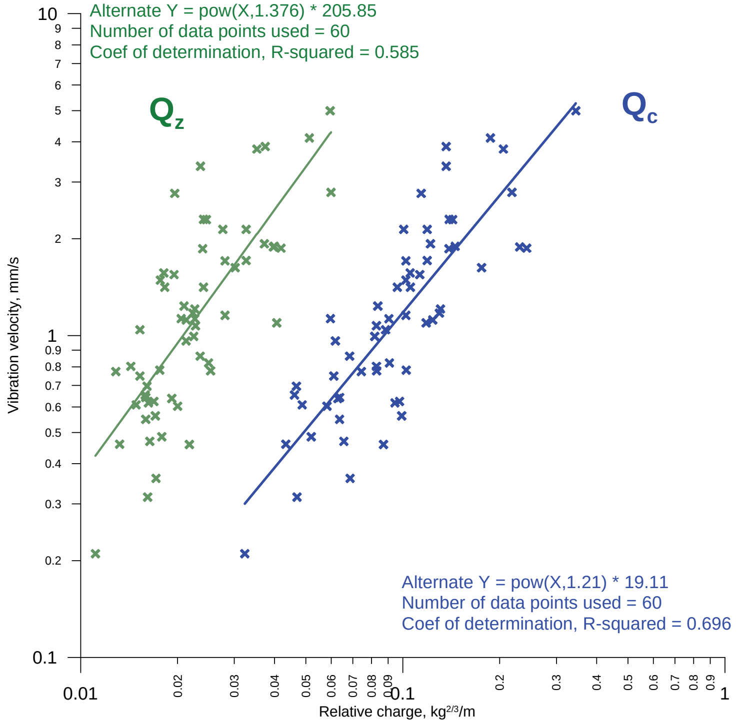


Fig. 1. Relationships $u = f(\rho_c)$ i $u = f(\rho_z)$ determined in 2003

The relationships shown in figure 1 constitute a starting point for further considerations on the subject of geological conditions and how they affect the determination of acceptable charge masses.

In 2011, control measurements were taken in accordance with existing restrictions, and were compared with the results from 2003 (Fig. 2). It can be noted firstly that the vibration level did not fundamentally change, and secondly that the existing restrictions on the weight of charge mass are still current.

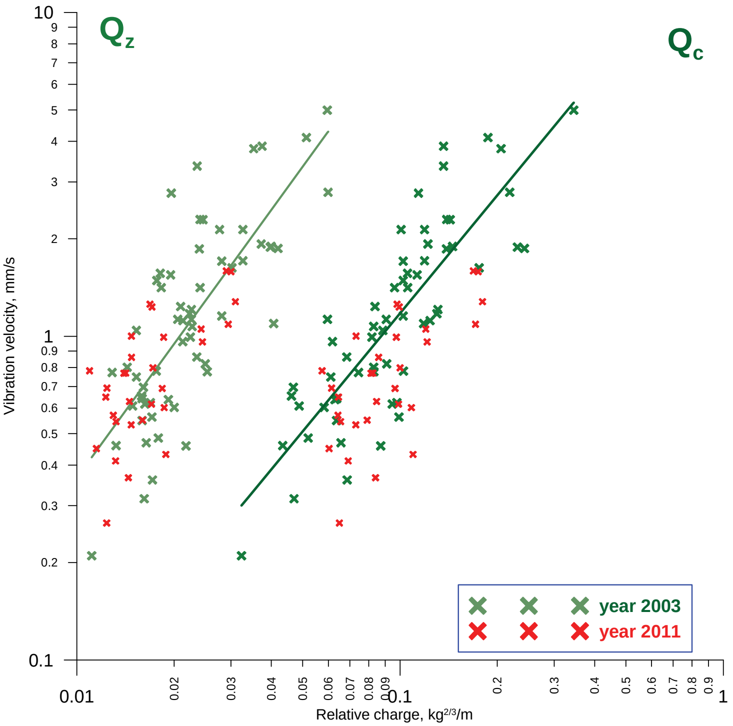


Fig. 2. Comparison of measurement results from 2003 and 2011

In 2012, the level III of the exploitation floor was opened. To determine the conditions of rock blasting for the floor, a series of measurements was conducted, the results of which were compared with the existing ones (Fig. 3).

Analyzing figure 3, we can notice the crucial difference between the level of the registered vibrations, and the significantly higher damping of vibrations as we move further away from the firing spot. To answer the question of what might be causing these changes, figure 4 shows results of measurements from 2012 with numbers indicating the positions of measurement.

Resulting from figure 4 is a clear separation between individual positions. Positions from 20 to 24 form a one group of variables, and positions 31 to 34 form a second group of variables.

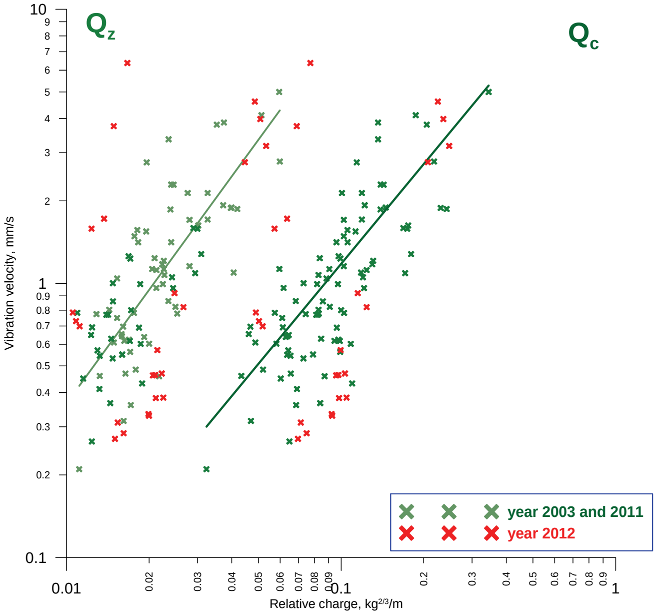


Fig. 3. Initial comparison of measurement results from 2012 with existing results

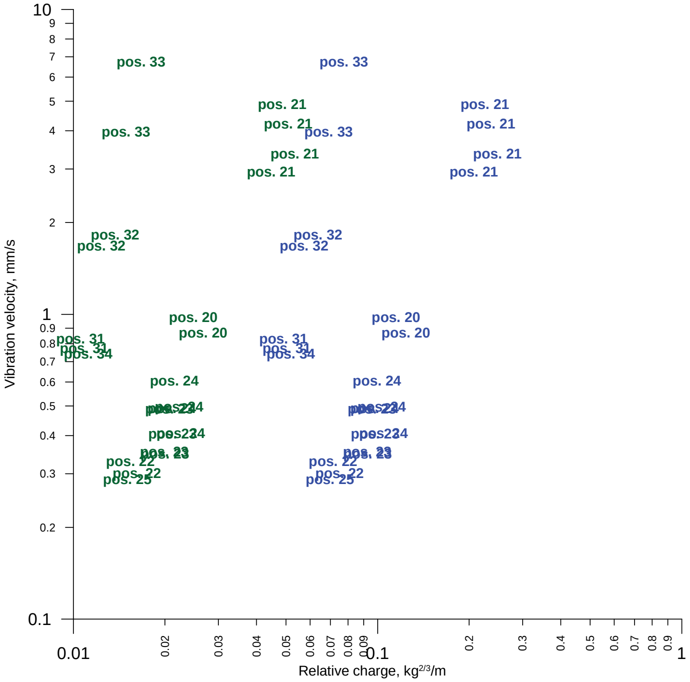


Fig. 4. Results of measurements from 2012 with numbers indicating the positions of measurement

This separation coincides with accepted measurement profiles. Accordingly, propagation equations were determined in two directions (north and south):

- north direction (purple and red in figure 5):

$$u = 1387816 \cdot \rho_c^{4,832} \tag{11}$$

$$u = 2312001693 \cdot \rho_z^{4,832} \tag{12}$$

- south direction (green and blue in figure 5):

$$u = 98{,}8 \cdot \rho_c^{2,285} \tag{13}$$

$$u = 3298{,}8 \cdot \rho_z^{2,285} \tag{14}$$

Measurement results along with the determined propagation equation $u = f(\rho)$ are shown in figure 5.

Figure 5 shows a clear difference between the propagation of vibrations both north and south of the excavation site. This is due to the geological structure of the rock mass on the path of ground vibration wave. To obtain additional information, calculations were carried out allowing recognition of the frequency structure of vibrations registered in the ground and in the foundations of protected structures.

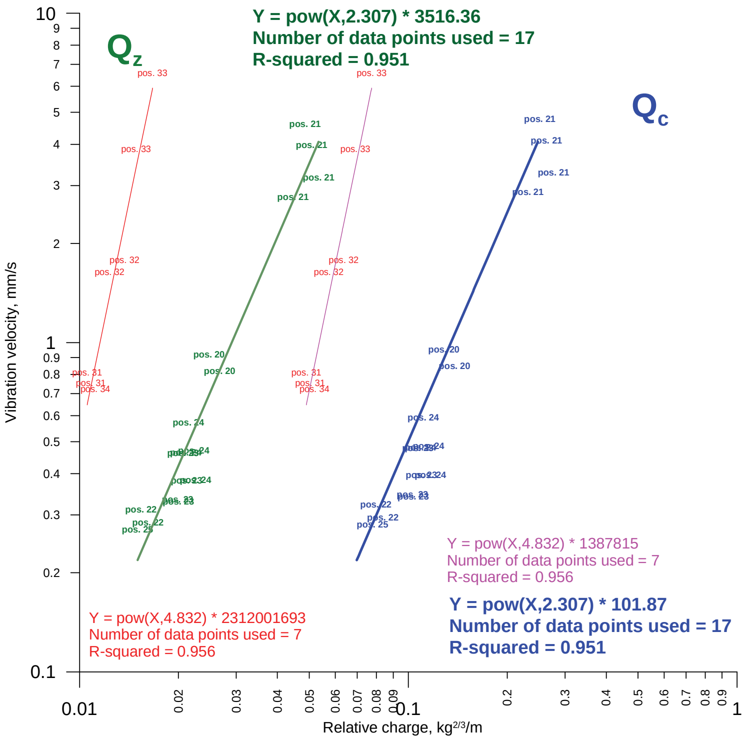


Fig. 5. Relationships $u = f(\rho_c)$ i $u = f(\rho_z)$ divided into directions

3.2. Analysis of frequency structure of ground vibrations

In order to identify the frequency structure of vibrations registered in the ground and their changes with distance, an octave analysis of registered seismic signals has been carried out. For example, figure 6 shows a comparison of vibration structures recorded during the same firing (series III) in positions 33 (north) and 21 (south). These are the positions closest to the blasting – positions 33, 793 m to the north; and positions 21 – 32 to the south. Visibly, the difference in distance is 561 m, and the vibration intensity is comparable.

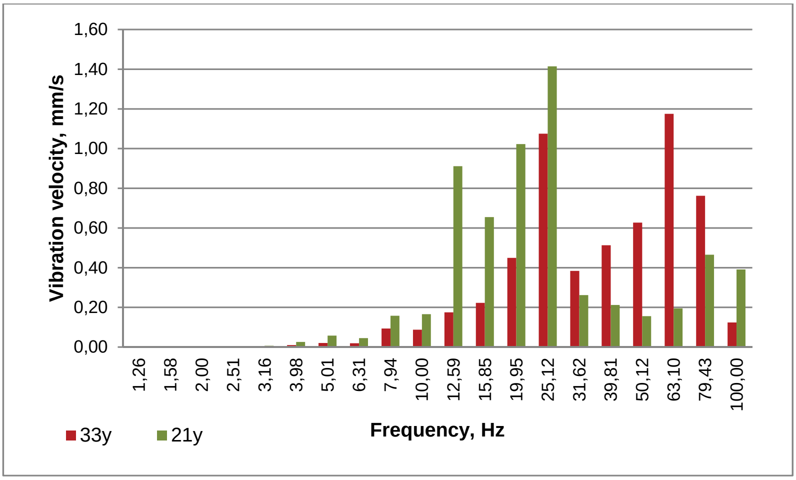


Fig. 6. Comparison of vibration structures – test stands 33 and 21

Analysis of the structure of vibrations registered in the indicated directions allows us to compare the decrease in their intensity with respect to changes in distance from the blasting area and frequency ranges. Figures 7 and 8 show comparisons of the structure and intensity of vibrations in positions 33 and 32 (north), as well as 21 and 24 (south). Visible in the southern direction, the change in distance of 300 m caused a sevenfold drop in intensity, with vibration structure remaining in the dominant intensity range of 25 Hz. However, in the northern direction at stand 32, a frequency of 50 Hz was dominant, and this range of intensity was not significantly reduced in comparison with a test stand 33 (with a change in distance of 173 m); although the dominant frequencies at position 33 were damped. This is important information that should be taken into account when determining the critical values of vibration velocity in the ground.

Analysis of figures 7 and 8 shows that north of the blasting area we can expect the ground to be elastic, hence within the vibration structure higher frequencies are dominant – 25 Hz, 63 Hz, and 80Hz. In the vibration structure north of the blasting area, lower frequencies are dominant – 12.6 Hz and 25 Hz.

As we can see, change in the quality of the ground is the reason for the clear difference between vibration intensity in the north and the south. This is why similar analyses were performed for measurements taken in 2003 and 2011. Figure 9 shows the characteristic structure of vibrations for one of the positions.

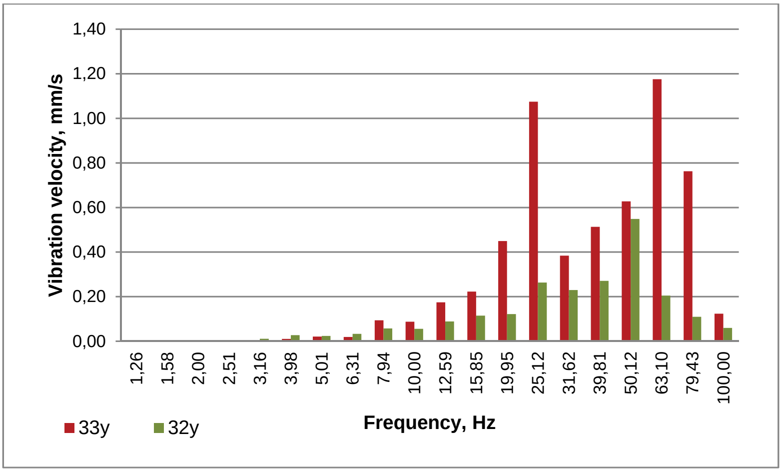


Fig. 7. Comparison of structure and intensity of vibrations – test stands No. 33 and 32

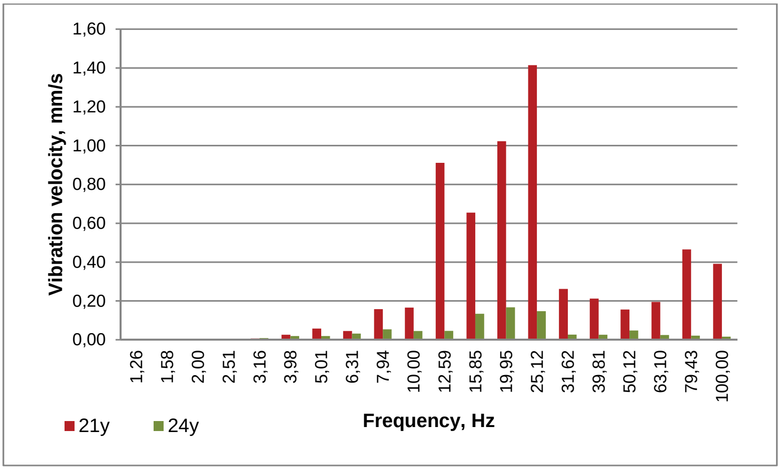


Fig. 8. Comparison of structure and intensity of vibrations – test stands No. 21 and 24

The analysis indicates that the dominant frequencies from the 2003 profile were more similar to the southern profile.

A condition for further considerations regarding the determination of explosive mass charges safe for the environment is the evaluation of vibration impact on protected structures (e.g. buildings) in the vicinity of the mine.

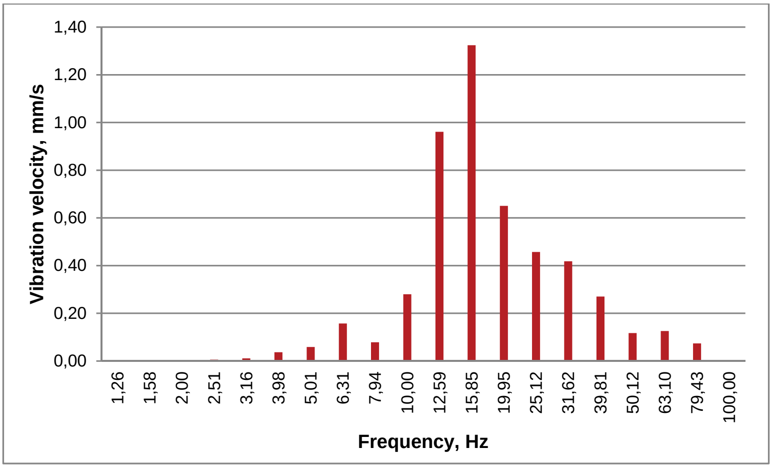


Fig. 9. Vibration structure for measurements taken in 2003

3.3. Evaluating the impact of vibrations on protected structures

The approximate profile of vibration influence on protected structures, according to Polish standard PN-B-02170:1985, ”The severity rating of vibrations transmitted through the ground to buildings,” can be determined using scales of dynamic impact SWD I and SWD II (Fig. 10). These are nomograms (displacement, velocity, or acceleration depending on the vibration fre-

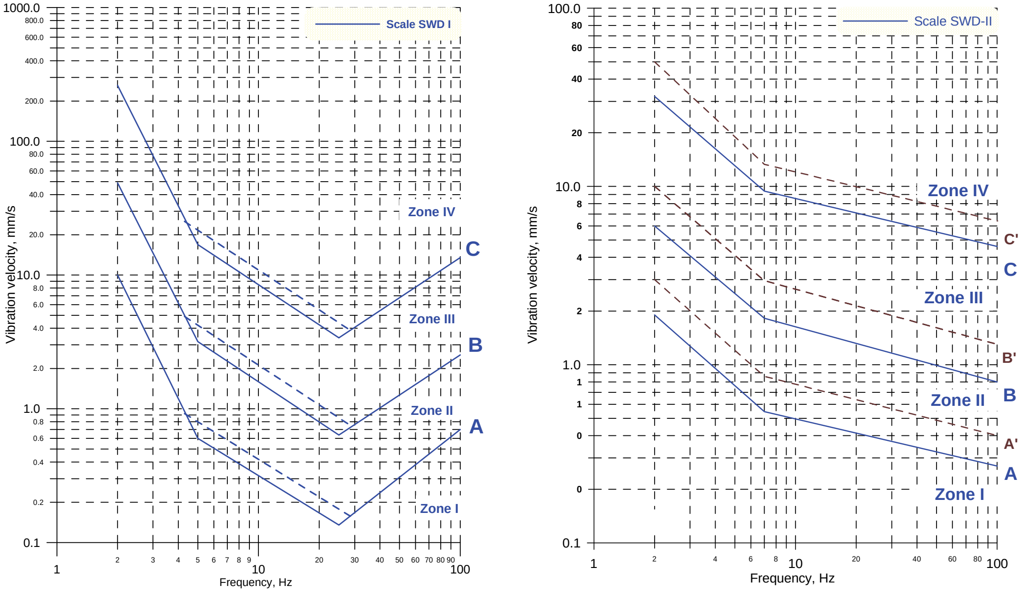


Fig. 10. SWD-I and SWD II scales according to standard PN-B-02170:1985 (velocity version)

quency) which allow, after plotting measurement results, fast orientation as to degree of impact for registered vibrations.

The scales above are presented in the form of logarithmic graphs in which the frequencies of vibration on the horizontal axis correspond to the value of vibration velocity on the vertical axis. When evaluating the impact of vibrations, their horizontal components are taken into account. They have five zones separated by boundaries, which designate their level of severity in relation to a given building. Each boundary is given in two variations (solid line and dashed line), with the SWD scales being developed on the assumption that the vibrations impacting structures are long-lasting (e.g. a few hours daily). The scales also account for the effect of wear.

Diagnosis of vibration impact is based on plotting the maximum measured values of velocity as correlated to their associated frequencies. There are two such methods for analysis – *the direct method and the indirect method*.

The direct method – used for vibrations with a close harmonic profile where two parameters, having a crucial influence on the severity of vibrations, velocity, and frequency, can be determined by plotting measurement results in terms of maximum velocity, and the corresponding frequency for SWD severity scale I, as well as for the location of these results in specific zones of dynamic impact. The analysis is based on peak (maximum) values.

As aforementioned, the SWD scales were developed for vibrations of long-lasting impact on building structures, which is why applying the direct method for assessing the effects of sporadic vibrations significantly overstates results. In such cases, the direct method is used to visualize the results of registration and to choose the registration of highest intensity for further analysis. However, the assessment of impact for vibrations propagated by blast works on protected structures is done with the indirect method.

Indirect method – used to evaluate complex vibrations with an impulse profile. This includes vibrations propagated by blast works.

In this case, registrations of the entire course of the horizontal components of vibration are required for an assessment of impact according to the SWD scale. Analysis of the full course of vibration components x, y is carried out by filtering the signal via an octave filter. Results are obtained as a bar chart of maximum velocity values corresponding to the middle frequencies of 1/3 octave bands, and are plotted on the SWD scale with an ascription of effects corresponding to a given zone. This is a method of analysis on the basis of which impulse vibrations a final assessment is made.

Analysis results shown in figure 11 – visualization using the direct method. Analysis results shown in figure 12 – assessment of impact using indirect analysis for the event with the highest intensity.

Taking into account the results of indirect analysis, the vibrations registered at the position 32’ should be classified to zone II of the SWD scale I, interpreted as felt vibration, yet unharmful for a structure.

3.4. Analysis of the frequency structure of vibrations in the foundations of protected objects

Analysis of measurements indicates that, after being transferred from the ground to the foundation of a building, the profile of vibrations significantly changes. Accordingly, an analysis of the structure of registered vibrations using an octave filter was carried out. This method

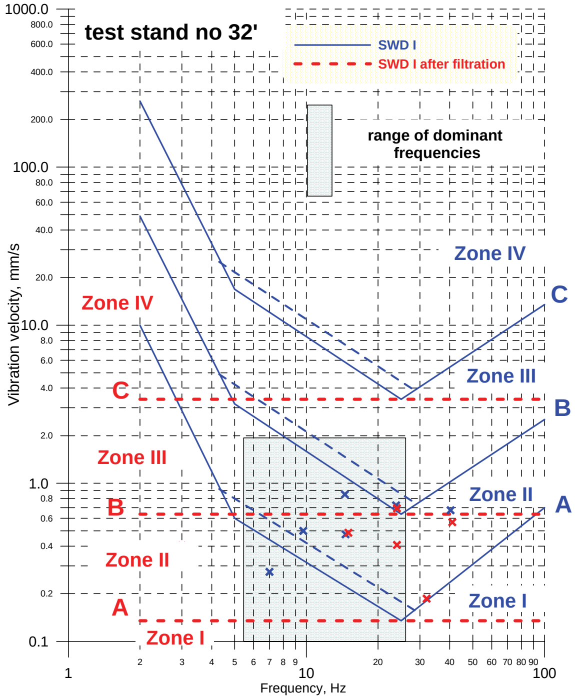


Fig. 11. Visualization of results of registered vibrations at the test stand No. 32’

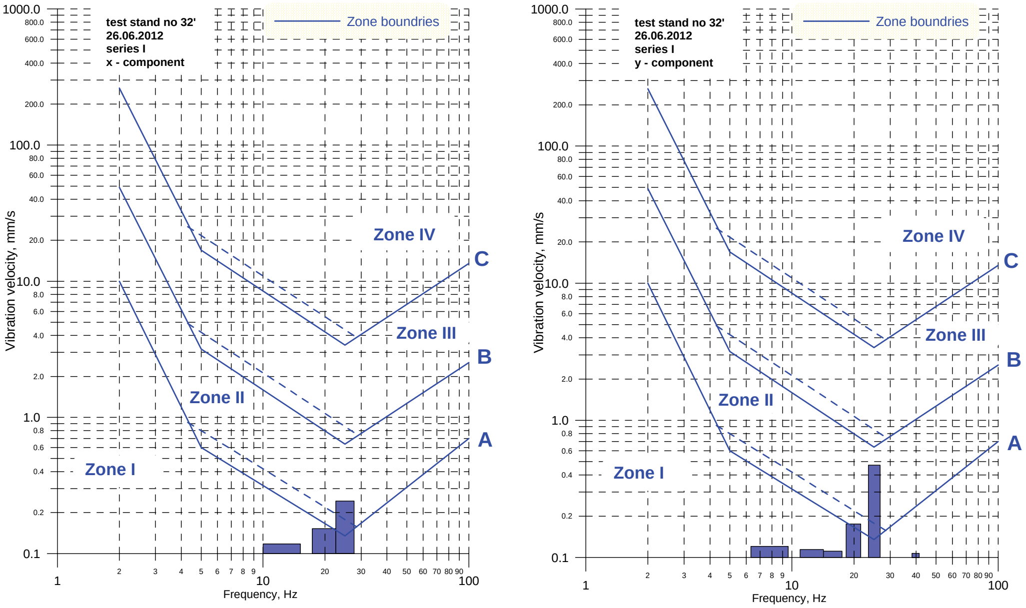


Fig. 12. Assessment of vibration impact on protected structures – series I – test stand No. 32’

provides an indication of which frequencies dominate in the vibration structure, as well as what kind of impact this has on the interaction between the building and the ground.

For example, figures 13 to 15 present the results of vibration structure analysis using histograms with maximum values for specific middle frequencies of octave bands at positions 32 and 32', as well as 34 and 34'.

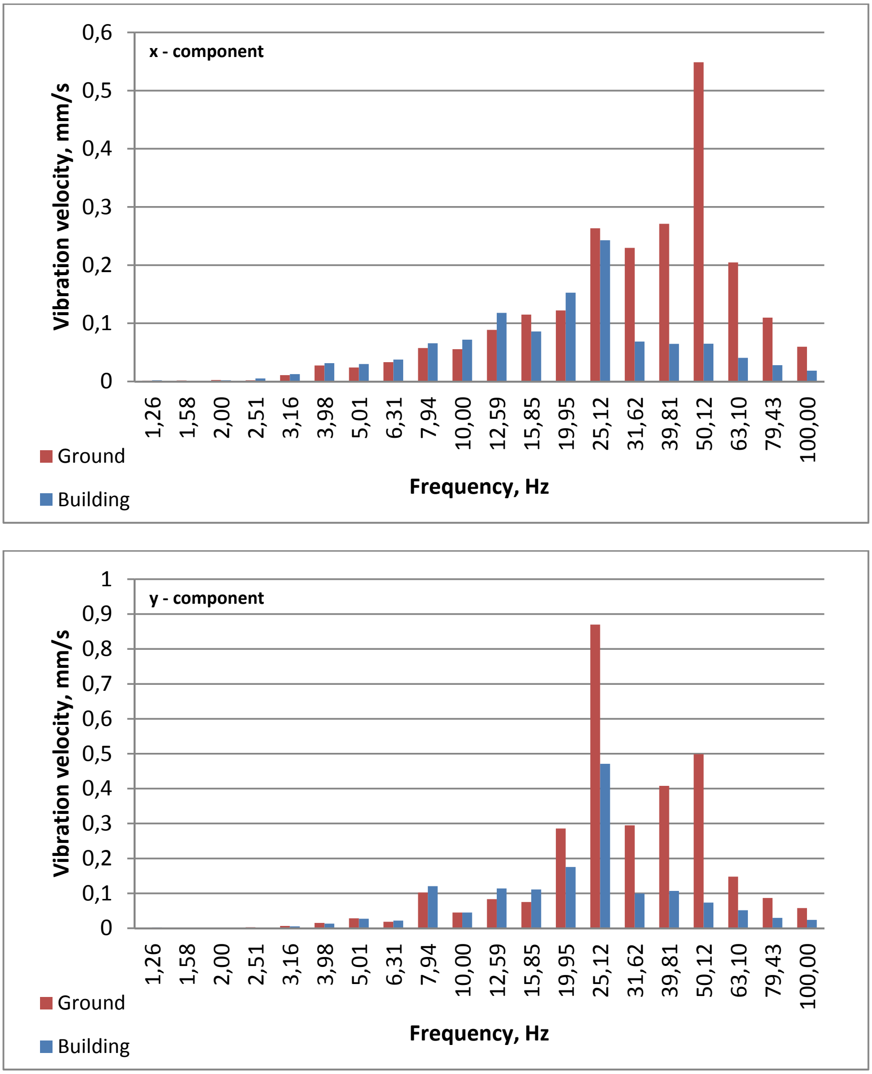
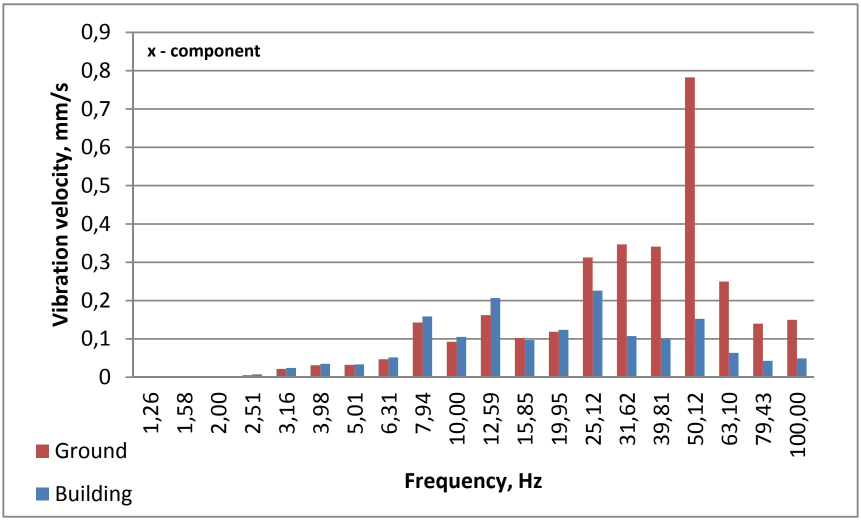


Fig. 13. The octave analysis of vibrations registered at test stands No. 32 and 32' – series III



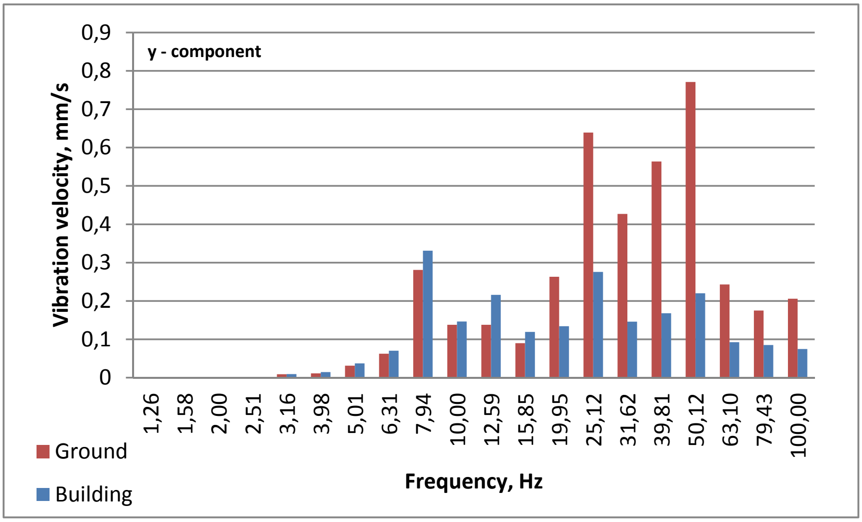


Fig. 14. The octave analysis of vibrations registered at test stands No. 32 and 32' – series IV

From figures 13 through 15, we can observe that the 50 Hz frequencies dominate the profile of ground vibrations near the building at position 32'. This frequency is related to the applied delay, which induces a natural frequency or its multiplicity (FWOP) (Pyra, 2010). It is also attenuated to a significant extent after being transferred to the building foundation. At this point, lower frequencies of 6 to 12 Hz dominate; and as can be seen, the level of ground vibrations of such frequency can even be amplified when transferred to the foundation (frequency similar to the natural frequency of the building).

The frequency structure of vibrations registered in the ground and in the foundation of the building structure at the test stand No. 34' is more complicated (Fig. 16). There is no dominant

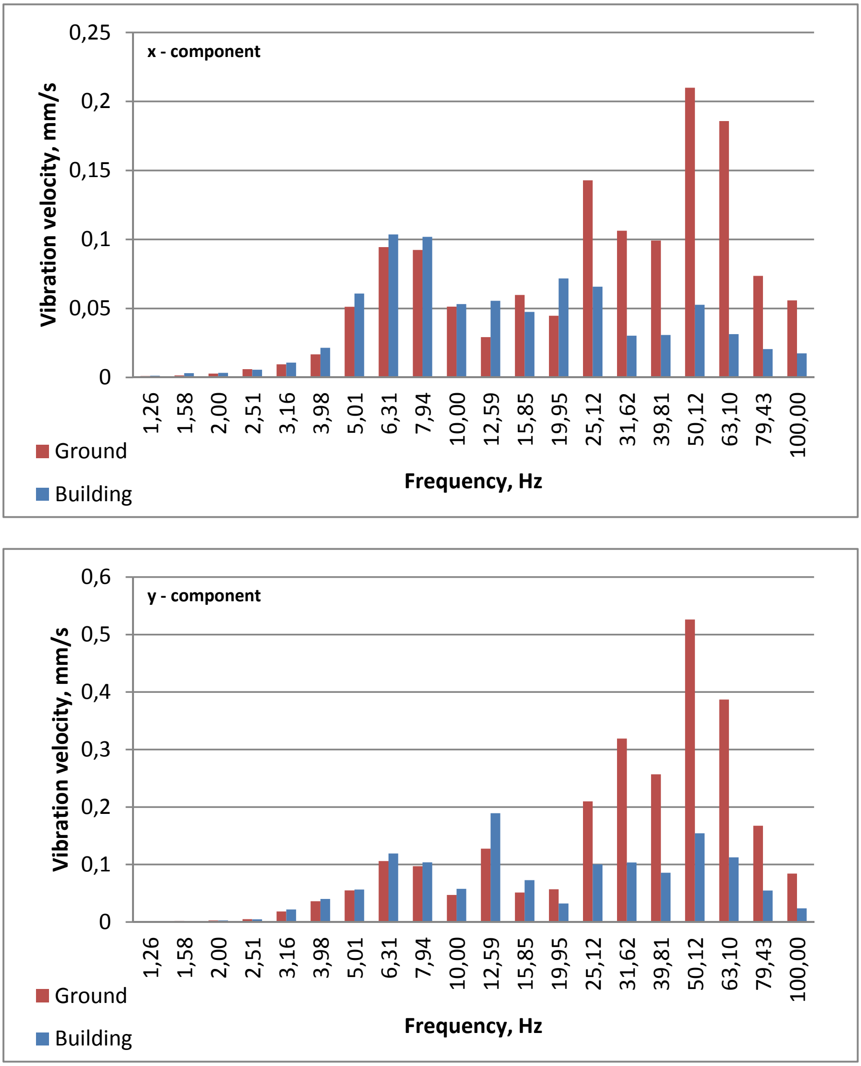


Fig. 15. The octave analysis of vibrations registered at test stands No. 34 and 34’ – series V

frequency either in the ground or in the foundation. Nevertheless, compared to position 32’, the level of registered vibrations in the ground and in the building is substantially lower. We can notice as well the lack of attenuation as the vibrations transfer from the ground to the building.

At both positions, the level of registered vibrations in the building foundation for both frequencies ranged from 0.2 mm/s to 0.5 mm/s.

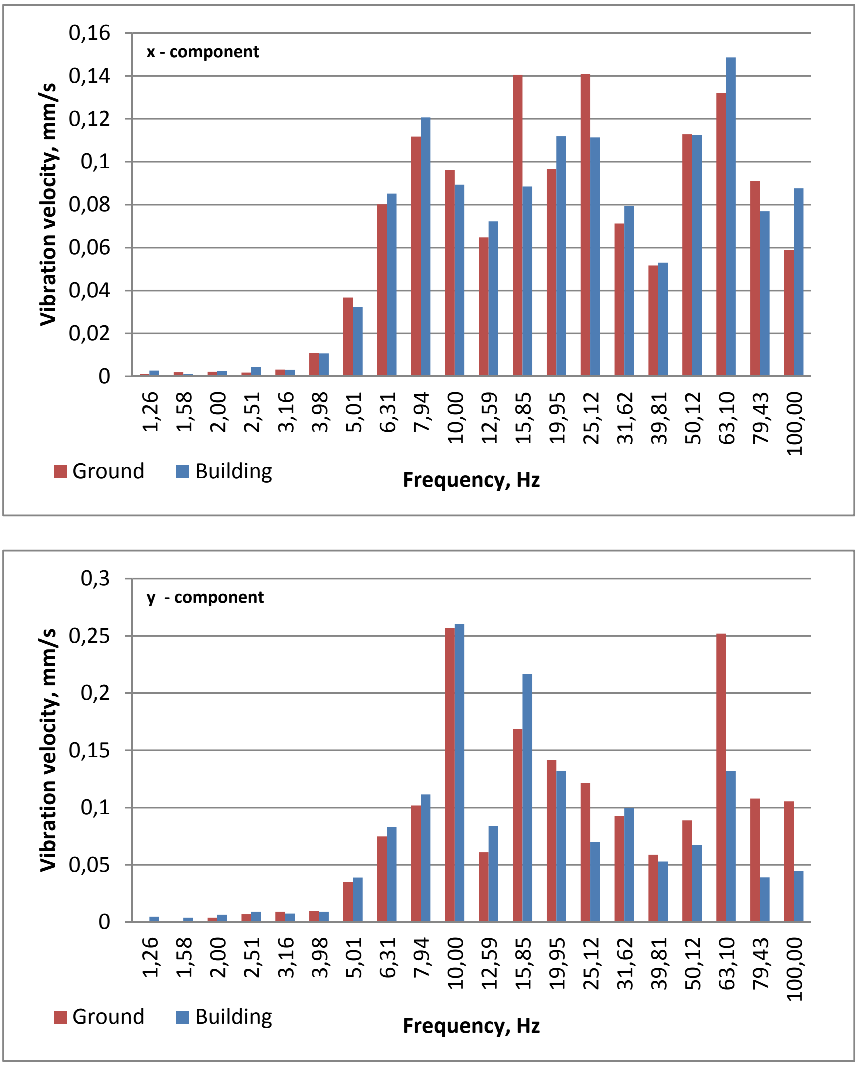


Fig. 16. The octave analysis of vibrations registered at test stands No. 34 and 34' – series III

3.5. Acceptable explosive charge masses

As previously mentioned, determination of the propagation equation is the first step in defining safe working conditions (explosive charge mass), and the specifics of rock blasting as influenced by various terrain, geological, and mining factors.

A very important element of the analyses is the determination of vibration level – *the severity threshold*, which allows for a safe work environment without negative effects on structures in the vicinity of the excavation site. The severity threshold, depending on the structure in question, can be expressed as displacement, velocity, or acceleration of ground vibrations. It can be defined as the intensity of tremors which will not damage buildings. Such a definition, although very general, reflects the difficulty of unambiguously identifying this phenomenon.

Analysis of literature in this field indicates significant discrepancies caused by the consideration – in varying degrees – of specific conditions such as the profile of a building, and the properties of the ground occurring within individual countries.

Conducted on the conditions of a limestone mine, the analyses of vibration frequency and their influence on protected structures provided for an acceptable level of vibration velocity in the ground, such that the vibrations propagated by rock blasting would not inflict damage on objects located in the vicinity. Additionally, assuming the damping of vibrations when transferred from the ground to the building at 30%, for further calculations we can assign u_{kr} = 2.6 mm/s.

Therefore, the acceptable charge masses for the design of rock blasting, due to residential development in the work area, must be defined as follows:

– north direction:

$$Q_z = 0{,}0017 \cdot r^{1{,}5} \tag{15}$$

$$Q_c = 0{,}0167 \cdot r^{1{,}5} \tag{16}$$

– south direction:

$$Q_z = 0{,}0092 \cdot r^{1{,}5} \tag{17}$$

$$Q_c = 0{,}0918 \cdot r^{1{,}5} \tag{18}$$

The calculation results are shown graphically in figure 17.

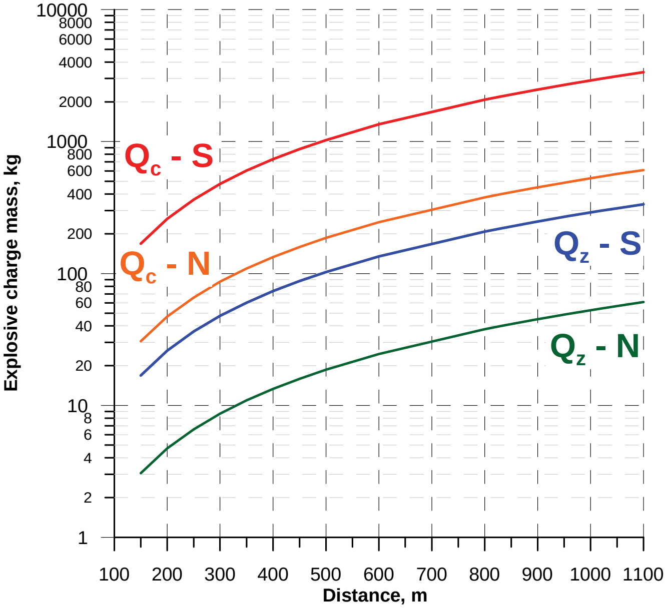


Fig. 17. The relation of the explosive charge mass adjustment with distance

4. Conclusions

Determination of explosive charge masses that are safe for the surrounding area of an excavation site is sometimes a very complicated issue. In large measure, geological makeup determines the wave structure and the manner in which vibrations are propagated into rock mass, as well as the nature of their transfer to protected structures. From the example presented, it is clearly visible that rock blasting in one place of the excavation site can cause totally distinct propagation in different directions. Such a distribution of propagation equations can sometimes hinder rock blasting, but they are determined in a way that guarantees safety to the building structures within the vicinity. With respect to effect on building, crucial is the frequency structure of registered vibrations and their manner of transfer from the ground to those buildings. This determines the acceptable velocity at which vibrations propagated by rock blasting will not harmfully affect objects located in the area.

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