Materiały Wysokoenergetyczne / High Energy Materials, ***2021****, 13, 123 − 142; DOI 10.22211/matwys/0203*
ISSN 2083-0165

Research paper / Praca doświadczalna

Creation of a database for the design of blasting works using the signature hole (SH) method *Budowa bazy danych dla projektowania robót strzałowych z wykorzystaniem metody signature hole (SH)*

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Abstract: *The use of modern systems for initiating explosives charges should be associated with a conscious choice of millisecond delay. This is especially important when firing multi-row blasting patterns. The electronic initiation system offers great opportunities for the design and selection of millisecond delays. However, given the high precision of setting delays, its use must be well thought out. Research on the effect of millisecond delay on the frequency structure of vibrations has shown that the seismic effect significantly depends on the geological conditions, both of the deposit and the environment. It was shown that these conditions are best characterized by the analysis of vibrations induced by single explosives charges and this was the basis for the development and implementation of the signature hole (SH) method. The effectiveness of the method contributed to its application in computer programs supporting the design of blasting works.*

The article presents the procedure of preparing a database for the Paradigm software, based on the results of vibration analyzes recorded during the firing of single charges of explosives, taking into account the conditions related to the assessment of the impact of vibrations on buildings. The result of the program calculations is a proposal reaching even over a thousand or more combinations of delays between explosives loads and between rows of holes. Choosing the optimal solution is the most important moment in the designer's work. It should also be remembered that the project summary should be the verification of the selected variant by measuring the vibrations and comparing the predicted effect with the real one.

Streszczenie: *Stosowanie nowoczesnych systemów inicjowania ładunków materiałów wybuchowych (MW) powinno wiązać się ze świadomym wyborem opóźnienia milisekundowego. Jest to szczególnie istotne przy odpalaniu wieloszeregowych siatek strzałowych. Elektroniczny system inicjowania stwarza ogromne możliwości w zakresie projektowania i doboru opóźnień milisekundowych. Jednak biorąc pod uwagę wysoką precyzję zadawania opóźnień, jego użycie musi być dobrze przemyślane. Badania prowadzone nad wpływem opóźnienia milisekundowego na strukturę częstotliwościową drgań wykazały, że efekt sejsmiczny w istotny sposób zależy od warunków geologicznych, zarówno złoża jak i otoczenia. Wskazano, że najlepiej warunki te są charakteryzowane przez analizę drgań wzbudzanych od pojedynczych ładunków MW i to było podstawą do opracowania i wdrożenia metody signature hole (SH). Efektywność metody* *przyczyniła się do jej aplikacji w programach komputerowych wspomagających projektowanie robót strzałowych.*

W artykule przedstawiono procedurę przygotowania bazy danych dla programu Paradigm, w oparciu o wyniki analiz drgań rejestrowanych w czasie odpalania pojedynczych ładunków MW z uwzględnieniem uwarunkowań związanych z oceną oddziaływania drgań na budynki. Efektem obliczeń programu jest propozycja sięgająca nawet ponad tysiąca i więcej kombinacji opóźnień między ładunkami MW i między szeregami otworów. Wybór optymalnego rozwiązania jest najważniejszym momentem pracy projektującego. Należy również pamiętać, że podsumowaniem projektu powinna być weryfikacja wybranego wariantu przez pomiar drgań i porównanie efektu prognozowanego z rzeczywistym.

Keywords: *blasting operation design, millisecond delay optimization, signature hole method*
Słowa kluczowe**:** *projektowanie robot strzałowych, optymalizacja opóźnień milisekundowych, metoda signature hole*

1. Foreword

The application of explosives in rock deposit blasting requires the use of a suitable initiation system for detonating explosive charges at millisecond delay intervals. This method of charge detonation shows excellent possibilities when designing single-row and multi-row blast patterns and minimises the effects of blast on buildings in the area surrounding the quarries. In many studies, including those carried out in Poland, the authors highlighted the need of carrying out preliminary tests before introducing new initiation systems. The tests need to consider the basic vibration characteristics induced in the heading and propagated to the surrounding areas. The millisecond delay interval should be based on seismograms of vibrations induced by detonation of a single explosive charge and an analysis of the frequency structure of the vibrations [1, 2]. This course of action is referred to as the *signature hole* technique.

The effects of vibration on buildings in areas surrounding open cast mines were the subject of research carried out in the 1940s by the US Bureau of Mines. Based on that research, a peak particle velocity (PPV) induced by explosive detonation was used as a parameter directly related to the damage to the building structures [3]. The study showed that, based on a known distance (*D*) between the blasting site and the measurement point (receiver), and the explosive weight (*W*) per the delay interval, the vibrations can be predicted by determining and using the propagation equation:

$$PPV = A \cdot SD^{-B} \tag{1}$$

where:
PPV – peak particle velocity [mm/s],
SD – scaled distance, as $D/\sqrt{W}$ [m kg $^{-0,5}$],
D – distance between blasting site and measurement point [m],
W – explosive charge weight per delay interval [kg],
A, B – experimental constants.

This is a very popular form of the propagation equation, preferred in western literature.

The scaled distance in the propagation equation yields a simplified solution because of two assumptions, namely: using the explosive charge mass parameter means that all explosives induce identical vibrations, irrespective of the force of explosion or the interactions with the rock mass and, using the distance parameter, means that no effect of geological structure on the propagated waves is allowed for and the only result is the reduction or attenuation of vibrations. These assumptions are a considerable simplification. The waveform and duration (including its frequency spectrum) are not well defined by the scaled distance. The structure of the frequency is a key component, since vibration is not a scalar quantity unlike, for example, temperature, but a propagating wave, expanding in space, moving in time and changing as it propagates through the medium [4].

It should be noted that, as a result of explosive detonation, an impulse with a duration of several milliseconds interacts with the rock and is propagated as a wave in multiple directions, reflected and refracted by the internal boundaries present in a given medium. The boundaries (cracks, parting planes) become a new source of waves which propagate further, interfering either additively or subtractively with each other. Thus, it is not the scaled distance but the local geological structure which affects the final waveform and its amplitude, to the greatest degree [4].

It can be assumed that the local geological conditions in the propagation equation are partially represented by the parameter A, often referred as the coefficient of geological and mining conditions.

The effect of a millisecond delay interval on the intensity of vibrations induced by explosive detonation was also a subject of research by the US Bureau of Mines [5]. The scientific community was convicted that a correctly set millisecond delay interval can control the vibration intensity. In the 1940s, those were just preliminary considerations, since the available initiating systems were rather limited. The precision with which the delay interval was set has been relatively low, resulting in a significant scatter of the detonation times of individual detonators in relation to the nominal times. The tests showed that the induced vibrations are characterised by a highly irregular frequency spectrum which, combined with the low accuracy of available detonators, would vary with each detonation, even with the same nominal detonation times of individual detonators.

Further studies by Fish [6], Frantti [7], Pollack [8] or Greenhalgh [9] found more evidence of the significant effect of the millisecond delay interval on the frequency structure of ground vibrations.

Anderson, referring to his research from the 1980s [4], showed the observations based on the results recorded for vibrations induced by the blasting works in one of the open-cast mines. An analysis of the vibration frequency spectrum of a detonation of a series of explosives at 100 ms delay intervals showed 10 Hz as the dominant frequency – a clear indication of a correlation between the millisecond delay interval and the vibration frequency. New studies showed that it is a natural frequency of the millisecond delay which may have a significant effect on the vibration intensity.

The observations and test results have led to a concept and a technique referred to as the signature hole [10-15]. In 1988, Crenwelge *et al.* [16] patented a method of controlling the intensity of vibrations induced by the explosive detonation based on the signature hole technique using the signal induced by the detonation of a single explosive charge recorded at a given measuring point.

Anderson also highlighted an important statement included in one of the publications, saying that the seismic effects of the detonation of individual blast holes (single explosive charge) are different. A test was carried out by detonating individual explosive charges at different heading locations and in different mines. Analysis of the results showed that at relatively low frequencies, below 30 Hz, the induced waves showed relatively high repeatability. Andrews, Crenwelge and Hinzen have reported similar observations [13-15].

The principle of the signature hole method is that each hole in a blast will generate, essentially, the same vibration at a given location. It would mean that all the charges are detonated at the same location (the distance covered by the waves to the receiver is identical), the explosive type and weight in all holes and the interactions between the explosive charge and the rock mass are identical – and it can be assumed that the source impulse is identical [4]. In reality, such ideal conditions do not exist.

Based on the signal recorded after detonating a single explosive charge, the signal can be delayed (shifted in time) by setting a millisecond delay interval, and based on a linear superposition, the resulting individual signals can be added together to form a predicted total signal generated by the series of charges. The process of delaying and adding individual signals is repeated, depending on the planned number of blasting holes in the series. The desired effect is to find the delay interval of the blast pattern which generates vibrations with a minimum peak particle velocity (PPV).

The discussion can also be related to observations made by other authors. Bernard [5, 17] highlighted several points which indicated that:

- the signature hole technique involves a sequential detonation of explosive charges,
- the method requires a single signal for each type of detonated explosive,
- the position of each individual explosive charge in relation to the receiver and to the measurement point can be allowed for by correcting the delay interval between the charges by the time of wave propagation between the explosive charge and the receiver,
- the vibration level can be predicted at a distance corresponding to the distance from the hole with a single explosive charge to the measurement point at which the signal induced by the detonation of a single explosive charge is recorded,
- Equation 1, allowing for the effect of the weight of explosive charge on the delay interval, was determined based on the assumption that the delay between subsequent charges will be higher than 8 ms. Based on this assumption, the effect of overall charge mass on the vibration intensity is not analysed, however, advanced computer simulations can predict the seismic effect even at smaller millisecond delay intervals. This will require the signature hole technique, meaning that the predicted vibration intensity is based on the actual oscillogram of the detonation of a single explosive charge.

As a continuation of Bernard's discussion [5], by assuming that the blasting series signal is a sum of individual signals induced by subsequent explosive charges detonated with a delay, the following relationship (2) can be used:

$$SG(t) = \sum_{i=1}^{N} s_i(t) \tag{2}$$

where:
$SG(t)$ – seismic signal of the detonated series (expressed in the time domain),
$s_i(t)$ – basic seismic signal induced by the detonation of subsequent explosive charge (expressed in the time domain),
N – number of explosive charges per series.

Assuming that as a result of detonation, each explosive charge induces a practically identical signal (except for the amplitude), relationship (2) can be expressed as (3):

$$SG(t) = \sum_{i=1}^{N} a_i S(t - \Delta t_i) \tag{3}$$

where:
$S(t)$ – seismic signal of the detonated series (expressed in the time domain),
Δt_i – charge delay in sequence [ms],
a_i – amplitude coefficient of the single seismic signal.

This is a representation of the signature hole technique expressed in the time domain, since it uses a linear superposition of the signals recorded as a function of time, mathematically expressed as a convolution (Figure 1) [4, 18, 19].

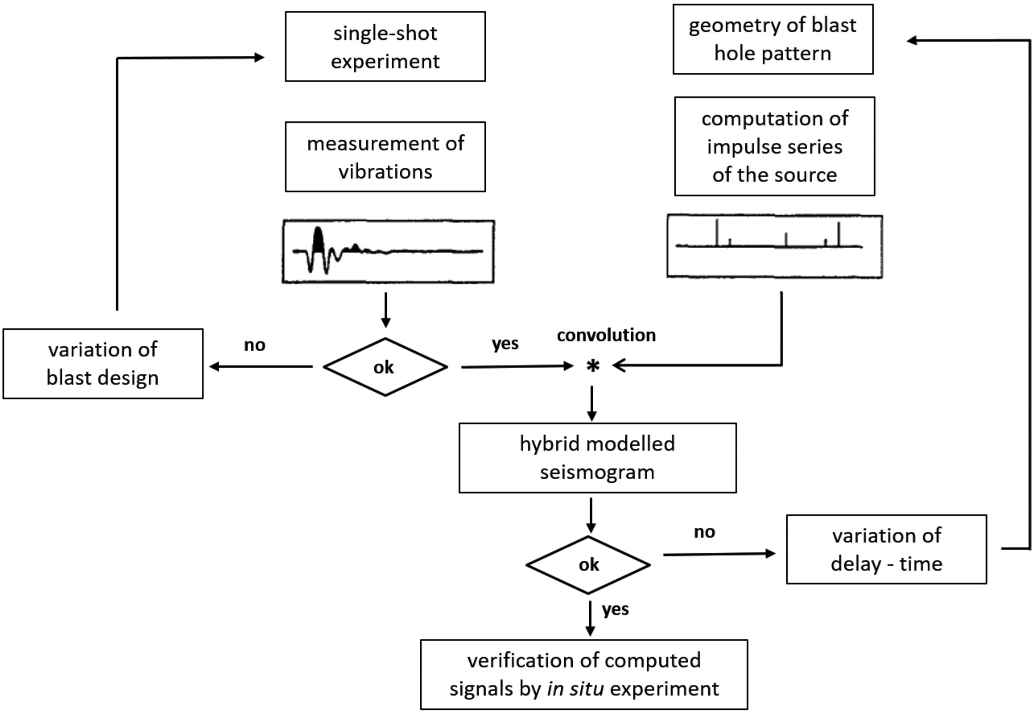

Figure 1. Block diagram of the model of vibrations expressed in the time domain [18]

As mentioned previously, as a result of linear superposition, the signals (waves) delayed by a specific time sequence are added together. The vibrations measured in a spatial system using three components x, y and z where the signal adding procedure must be identical for the three components. The signal from a single explosive charge must be recorded at a distance from the blasting site where the recorded x, y and z signal is identical, irrespective of the charge. Based on the above, the signature hole technique can be used to determine the solutions with the lowest PPV values.

2. Using the signature hole technique in planning blasting operations

A key component of using advanced ignition systems is the accurate setting of a millisecond delay interval, particularly in cases where the blasting operations include multiple rows using a large number of explosive charges [20, 21]. It should be noted that using an electronic system is not a solution in itself, since incorrect use of electronic detonators with a high-precision delay may have its own undesirable effects [1, 22].

In the 1990s, the planning of blasting operations using electronic systems was supplemented by software for setting the millisecond delay intervals for the conditions of a given mine, allowing for site location and blast pattern. The software requires a database of vibrations recorded after the detonation of individual explosive charges. This technique was used in the *Paradigm* software algorithm developed by Austin Powder [1].

A hole pattern design in the electronic system starts with an introduction of base information in the *Paradigm* software:

- rock parameters – apparent density, Young’s modulus, longitudinal wave velocity,
- location of the blast hole series and location of protected buildings,
- parameters of planned explosion, including:

  (i) length, number and arrangement of holes,
  (ii) burden, blast hole and row spacing,
  (iii) explosive type, explosive charge in the hole, its design, stemming and subdrilling length,
- record of vibrations induced by the detonation of a single explosive charge at a location close to the area of the designed blast hole pattern,
- seismic effect of a series at similar location.

Next, the results can be further improved by introducing other blasting operation parameters, for example, a range of variability of delay interval between the detonation of subsequent explosive charges (e.g. the minimum delay interval must be at least 8 ms and the maximum up to 200 ms). A key addition to the base information for the software is to determine the method of detonating the charges – a side or middle cut – and to determine the values of parameters defining the propagation of vibration based on previous experience.

The software, based on input data, simulates the ground vibrations using different combinations of delay intervals, and yields the maximum vibration velocities and correlated frequencies, the spatial vector of velocity and the minimum millisecond delay interval. The calculated result can also be supplemented with coefficients which can aid in selecting the optimal solution. The result of software calculations is a set of over 1000 delay interval combinations between the explosive charges and the rows.

3. Considerations resulting from the Polish standard

Choosing the optimal solution is the most important task in the planning of blasting operations. Making a choice from among a thousand solutions must be based on thorough analysis and requires the verification of the chosen solution by measuring vibrations at a given point in the vicinity of the mine and a comparison of the predicted and actual effects.

Records of ground vibrations at a given point, taken during the detonation of a single explosive charge, are used in the software, which means that the predictions apply to the ground vibrations. According to the provisions of the Polish standard [23] the effects of vibrations are evaluated using the SWD scales by analysing the structure of vibrations recorded at the building foundations (third-octave filtering) at the frequency range between 2 and 100 Hz, which requires a wider approach to the signature hole method. The base measurements must be carried out both for the ground and for the building foundations to allow a preliminary evaluation of the interactions between the building and the ground at different frequency ranges and to identify the natural frequencies of the building and the ground. This approach also allows certain procedures to be developed which, as a result, can be used to avoid inducing ground vibrations within a range close to the natural frequency of the building which may lead to resonance and reinforce the vibrations at the transition point between the ground and the building foundations.

Identifying the interactions between building and ground is a key factor in selecting the optimal solution. As shown in a series of publications [21, 22, 24], the millisecond delay interval significantly affects the form of vibrations, i.e. using the delay interval between the detonations of subsequent explosive charges can change the form of induced vibrations and allows solutions to be sought which result in a significant vibration attenuation at the transition point between the ground and the building foundations or change the form of vibrations recorded at the building foundations.

The course of vibrations induced by the detonation of a single explosive charge is key information for the software. The software simulations are based on records of ground vibrations, however, the most important information for the planner is the record of vibrations in the building foundations. The analysis of the signals and comparison of the form of vibration in the ground and in the building foundations can be used to select the optimal solution. Examples of seismograms recorded in the ground and in the building foundations for specific different geological conditions, are presented and discussed later in the article.

4. Tests in shale deposit

In the process of developing a database for the planning of blasting operations in shale deposit, 15 individual explosive charges were detonated at five different operating levels and at different heading locations. The vibrations were recorded in the ground and in the building foundations at 4 measuring points in the area surrounding the mine. Generally, the vibration records depend on the position of the explosive charge and on the location of the measuring point. Figure 2 shows the seismogram of the vibrations in the ground and in the building foundations recorded after detonating a single explosive charge in the shale deposit; Figure 3 shows the form of the vibrations.

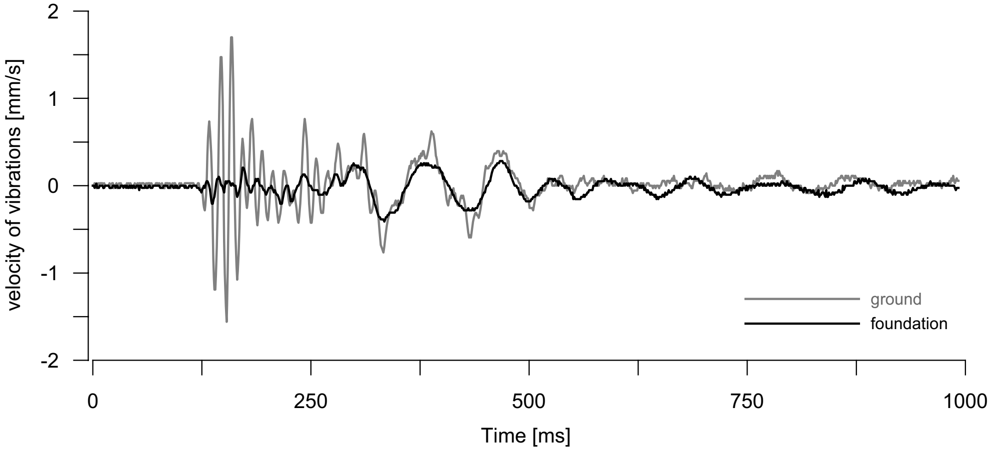

Figure 2. Seismogram of the vibrations in ground and building foundations after detonating a single explosive charge in the shale deposit

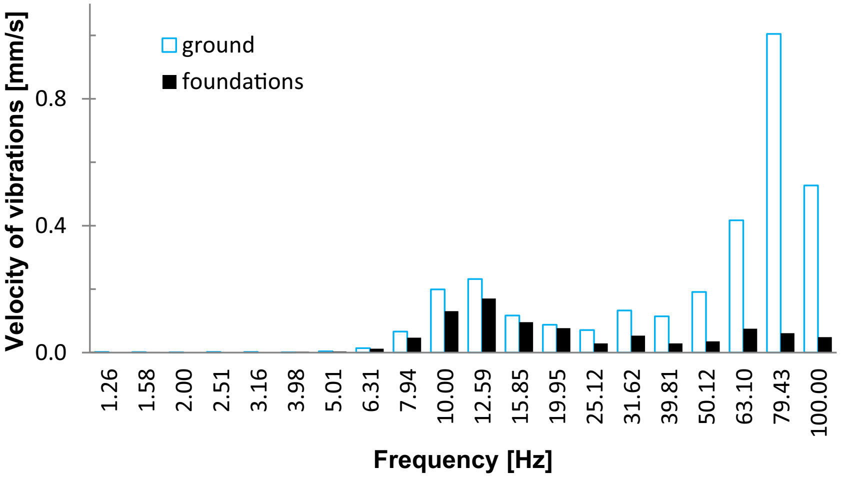

Figure 3. Seismogram of the vibrations in ground and building foundations induced by a single explosive charge

Based on Figures 2 and 3, the vibrations observed in the shale deposit are composite vibrations comprising two phases: an initial phase with dominant higher frequencies: 79.43 and 100.00 Hz; and a later phase with dominant lower frequencies: 10.00 and 12.59 Hz. At the transition point between the ground and the building foundations, the higher frequency vibrations are strongly attenuated, whereas in the lower frequency range, the attenuation is practically non-existent.

An analysis of the vibrations induced by a single explosive charge provides a direction for seeking the optimal solution for specific conditions, for example, to induce high frequency vibrations in the ground, since they will be attenuated, and avoid the vibrations within the frequency range from 10.00 and 12.59 Hz, since most probably, those will be propagated to the building foundations without any attenuation.

5. Tests in marl deposit

In the process of developing a database for the *Paradigm* software and the marl deposit, 10 individual explosive charges were detonated at different heading locations and the vibrations were measured at 5 measuring points in the surrounding area.

Figure 4 shows a sample seismogram of vibrations in ground and building foundations (horizontal component *x*). Analysis of the structure of vibrations in Figure 5 provides a comparison of the histograms of maximum detonation velocity for the frequencies in the third-octave band, the vibrations in the ground and in the building foundations.

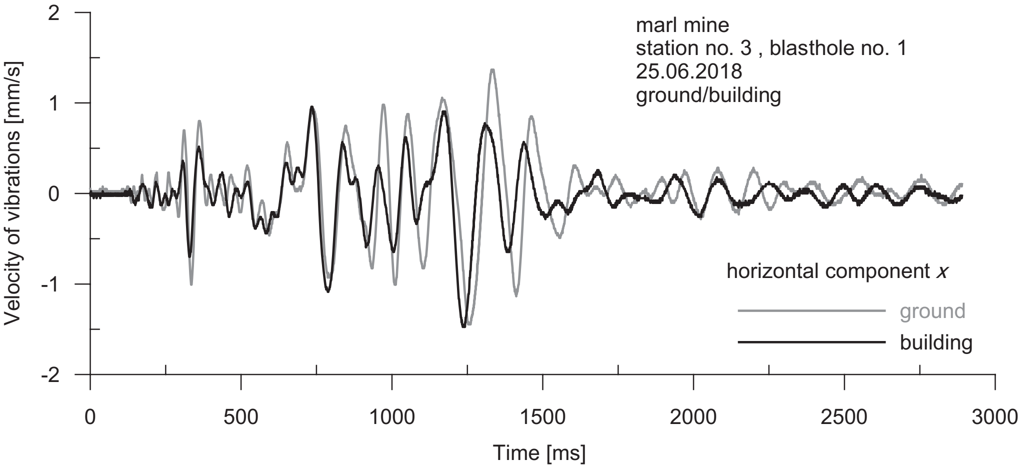

Figure 4. Seismogram of vibrations in ground and building foundations after detonation of a single explosive charge

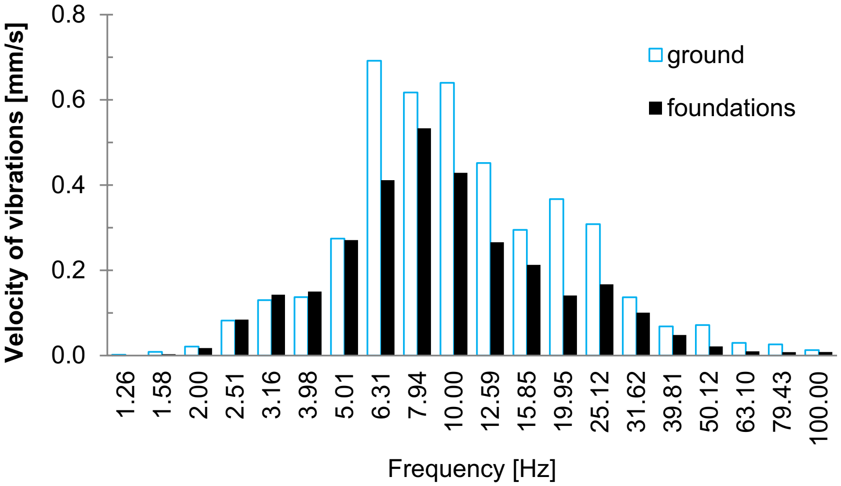

Figure 5. Comparison of the structure of vibrations in ground and building foundations as per Figure 4

Figures 5 and 6 show that the vibrations in ground and building foundations have similar characteristics, indicating a minor attenuation at the transition point between the ground and the building foundations. Analysis of seismograms and the structure of vibrations, shows the presence of two phases of vibration propagation. The exact structure of vibrations can be observed using a matching pursuit time-frequency analysis (Table 1 and Figure 6 show the result for the horizontal *x* component).

Table 1. MP analysis result for the first five atoms for ground vibrations – *x* component

Atom no.	**Amplitude [mm/s]**	**Frequency [Hz]**	**Signal energy [(mm/s)^2]**	**Share in signal energy [%]**
0	1.58	6.4	230.8	47
1	0.78	9.3	84.2	17
2	0.70	13.5	38.1	8
3	0.76	18.1	23.6	5
4	0.54	4.5	22.0	5
% of explained total signal energy by 5 Gabor atoms			–	82.0
energy of signal reconstructed by 14 Gabor atoms			481.2	–
% of explained signal energy				96.0
total signal energy			486.8	

Analysis of the results included in Table 1 shows that Gabor atoms at a frequency of 6.4 and 9.3 Hz contribute up to 64% of the signal energy and play the predominant role in the structure of vibrations. The atoms are related to the lower frequency phase of the vibrations. The higher frequency phase represented by the Gabor atom at 18.1 Hz, contributes up to 5% of the signal energy.

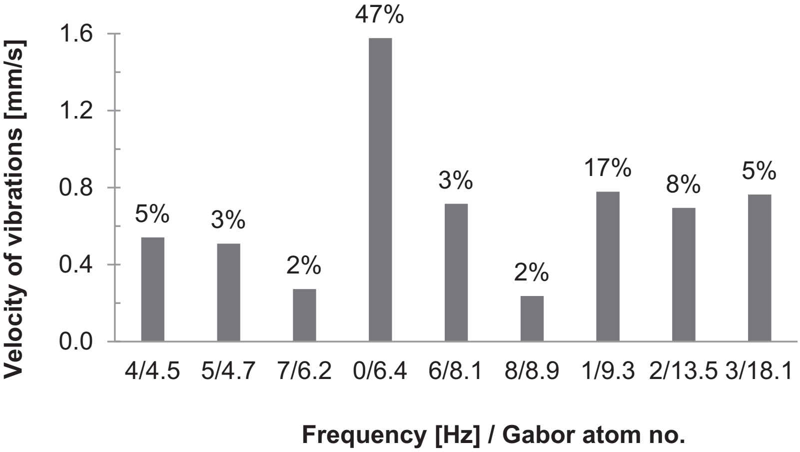

Figure 6. Histogram of Gabor atoms of vibrations in the ground – *x* component

Figure 7 shows the result of the frequency-time analysis as a spatial image to better visualise the changes in the frequency of vibrations in the ground with time. This representation of the results from the analysis of the structure of vibrations allows the changes in frequency in time to be identified.

The accumulation of vibration energy within the lower frequency range indicates that there can be difficulties in increasing the attenuation at the transition point between the ground and the building foundations, and other solutions other than those used in the shale deposits, might be required.

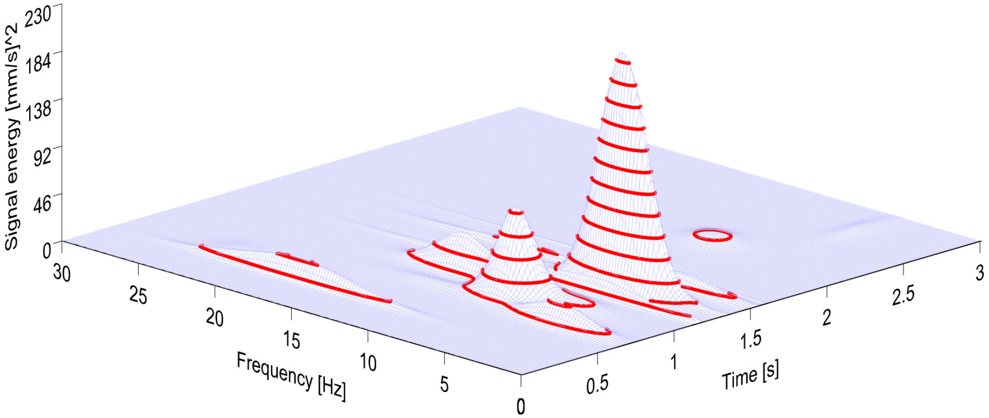

Figure 7. Spatial image of ground vibrations – *x* component

6. Tests in limestone and melaphyre deposit

During the process of developing a database for the engineering of blasting operations using an electronic system, single explosive charges were also detonated in limestone deposit. Figure 8 shows a typical seismogram of vibrations in ground and building foundations for the horizontal component; Figure 9 shows the structure of vibrations.

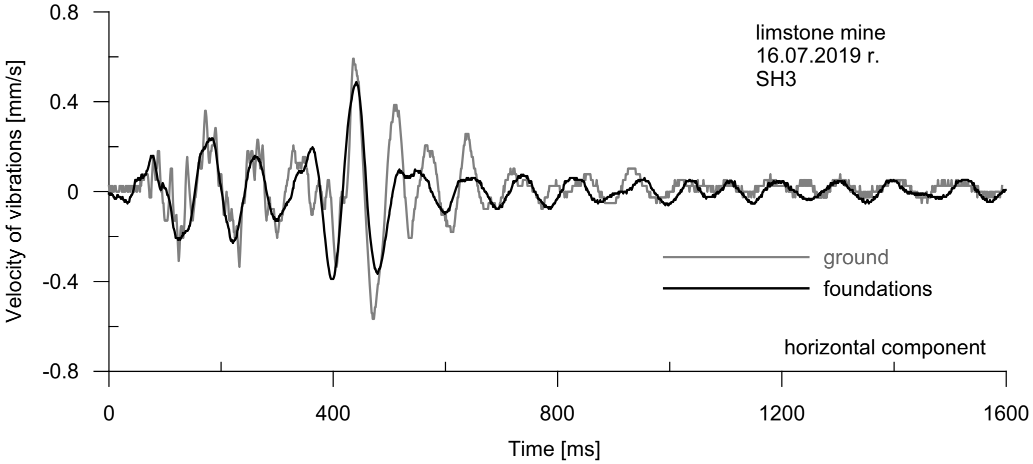

Figure 8. Seismogram of vibrations in ground and building foundations after detonating a single explosive charge in limestone deposit

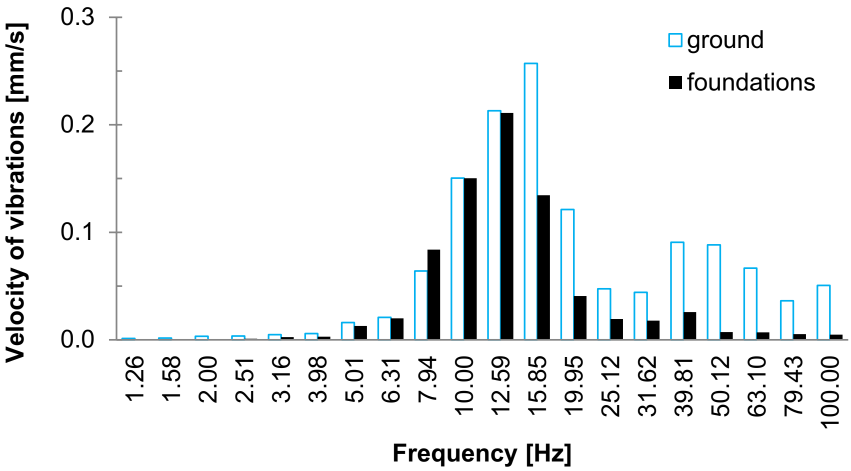

Figure 9. Comparison of the structure of vibrations in ground and building foundations shown in Figure 8

Lower frequencies, 10.00, 12.59 and 15.85 Hz are dominant in the structure of vibrations, however, the frequencies are almost twice as high as those observed in the marl deposit. Similar to the marl deposit, vibration attenuation is minor and will require seeking a change in the structure of vibrations in the direction of lower frequencies or in the direction of higher frequencies with simultaneous increases in attenuation.

The vibrations recorded after detonating a single explosive charge in the melaphyre deposit show a more complex structure (Figures 10 and 11). The vibrations are characterized by shorter duration and clear separation of the two phases of the seismogram at higher frequencies (dominant frequency is 39.81 Hz) and lower frequencies (10.00 and 12.59 Hz). The dominant frequency of 39.81 Hz may indicate possible problems when detonating explosive charges at a 25 ms delay interval.

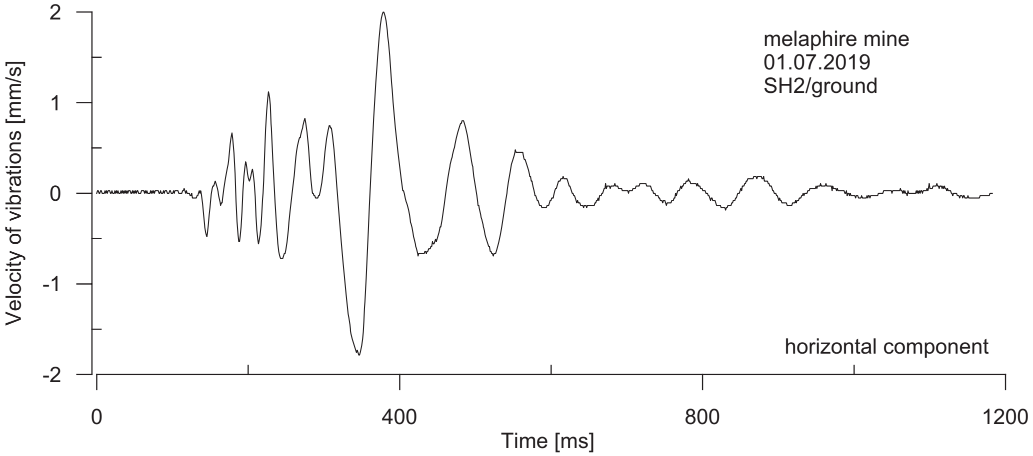

Figure 10. Seismogram of vibrations in the ground – detonating a single explosive charge in the melaphir deposit

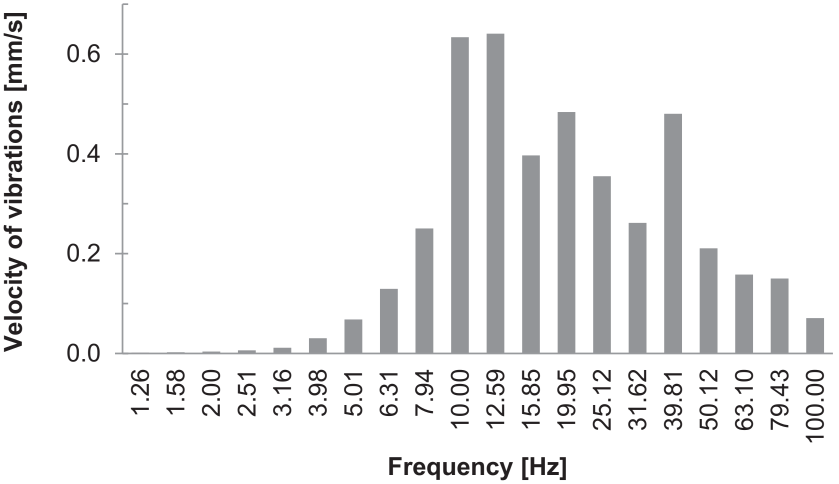

Figure 11. Structure of vibrations in the ground – detonating a single explosive charge in the melaphir deposit

7. Developing a database for the SH method – an analysis of test results

Detonating single explosive charges for use in the SH method requires sufficient data about the deposit and its surrounding area. The differences in the structure of recorded vibrations requires detailed analysis and determination of certain areas, in which the obtained vibration characteristics are valid.

A key factor is the repeatability of the characteristics of vibrations induced in similar locations. Figure 12 shows the comparison of seismograms of vibrations recorded after detonating individual explosive charges in shale deposit in a similar location, but at different heading levels. The vibrations were recorded at the same measuring point. Visual comparison shows high similarity of the recorded vibrations. The similarity was verified by comparison with the structure of ground vibrations for the horizontal component (Figure 13).

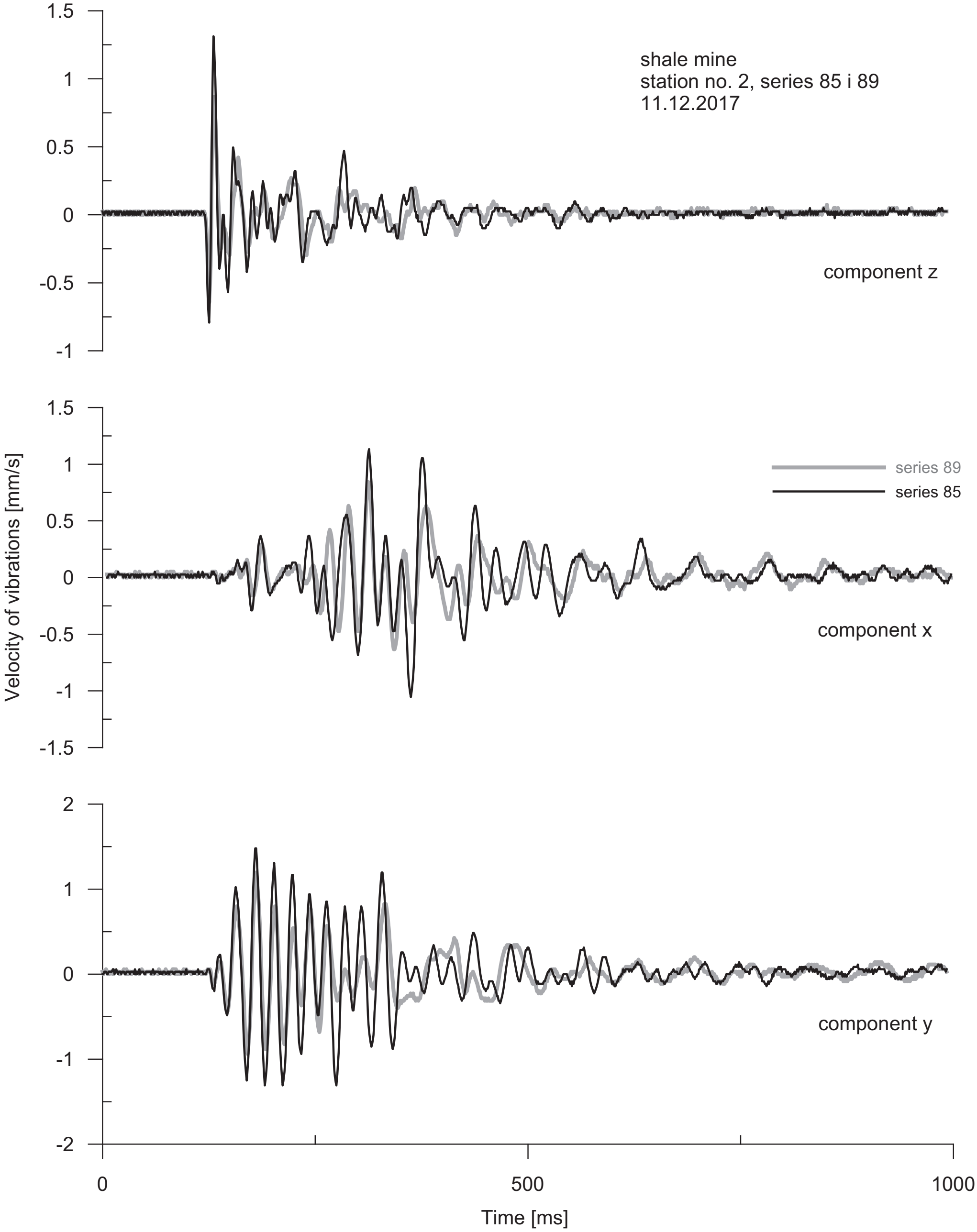

Figure 12. Comparison of seismograms of vibrations in the ground induced after detonating individual explosive charges at similar locations

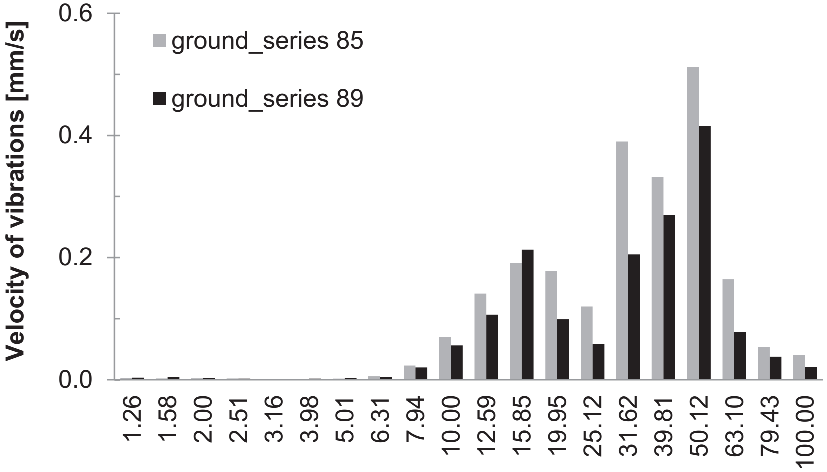

Figure 13. Comparison of the structure of ground vibrations (horizontal component *x*) – single explosive charges at similar locations

As previously mentioned, a key element of the analysis considering evaluation of the effect of vibrations on buildings is the identification of the interactions between the ground and building foundations, i.e. to what degree and at what frequency range are the vibrations in the ground propagated to the building foundations. The study also includes an analysis of the structure of vibrations induced after detonating single explosive charges, recorded in the ground and in the building foundations. Figures 14-16 show the results of the analysis for one of the horizontal components.

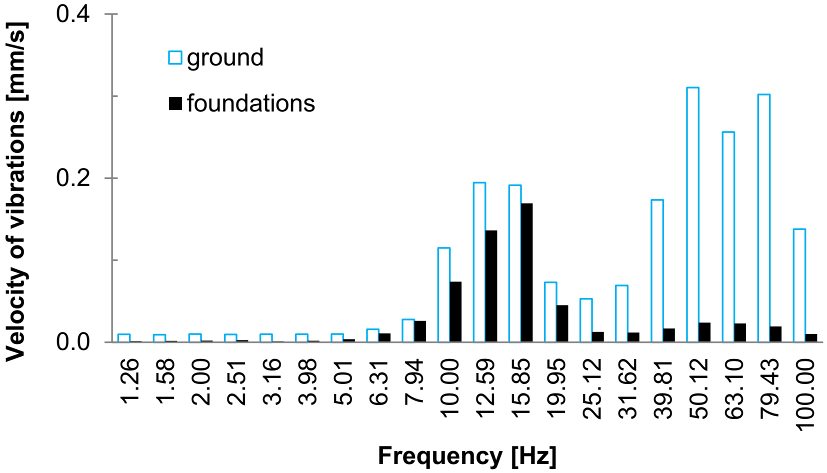

Figure 14. Comparison of the structure of vibrations in ground and building foundations – single explosive charge I

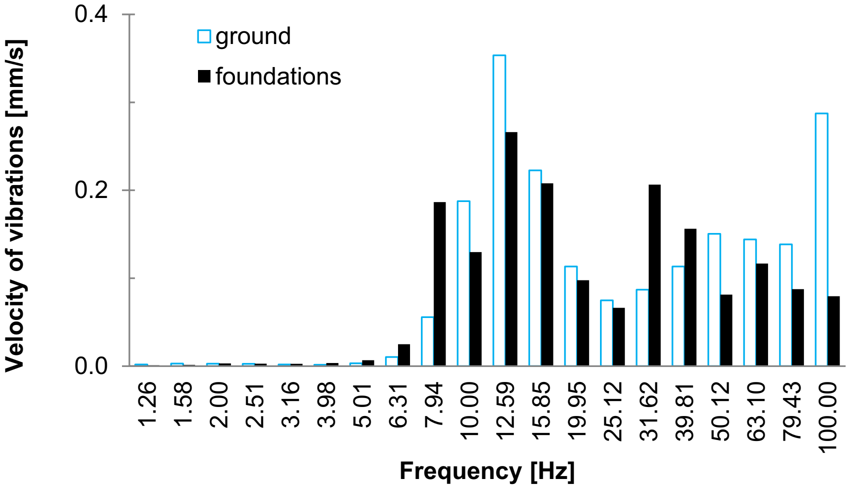

Figure 15. Comparison of the structure of vibrations in ground and building foundations – single explosive charge II

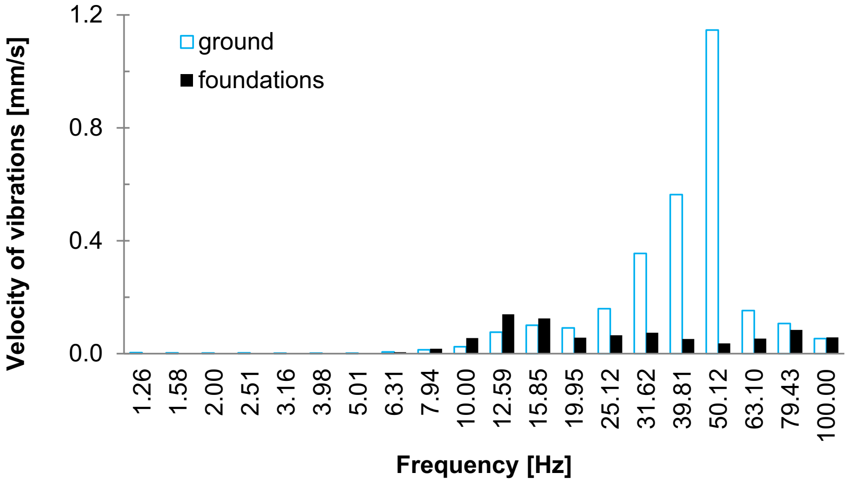

Figure 16. Comparison of the structure of vibrations in ground and building foundations – single explosive charge III

In all three cases, lower frequencies 12.59 and 15.85 Hz are dominant and within those frequencies, the attenuation of vibrations at the transition point between the ground and the building foundations is low. For charges I and III with dominant higher frequencies in the structure, very high attenuation of vibrations can be observed.

The difference in the structure of vibrations induced at different heading locations is a key part of developing a database for the planning of blasting operations using the signature hole technique, since the software requires a record of vibrations characteristic for the location of a series of explosive charges.

For the marl deposit, the analysis also shows significant differences in the structure of vibrations depending on the measuring point. The tests were carried out along the contour leading from the heading to the apartment building at three measuring points located at different distances from the location of the detonating charge (Figure 17).

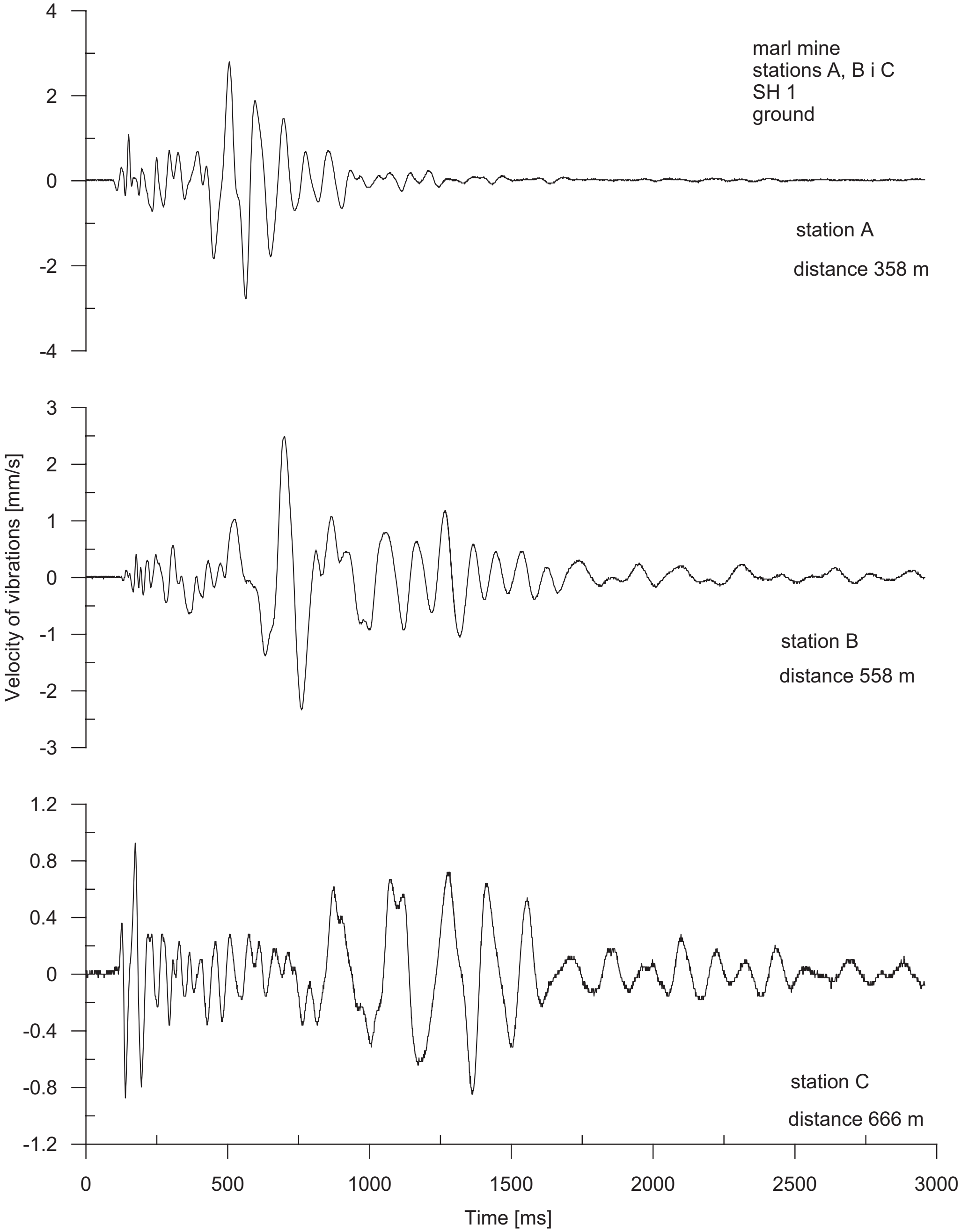

Figure 17. Seismograms of vibrations (vertical component) induced by the detonation of a single explosive charge in the marl deposit

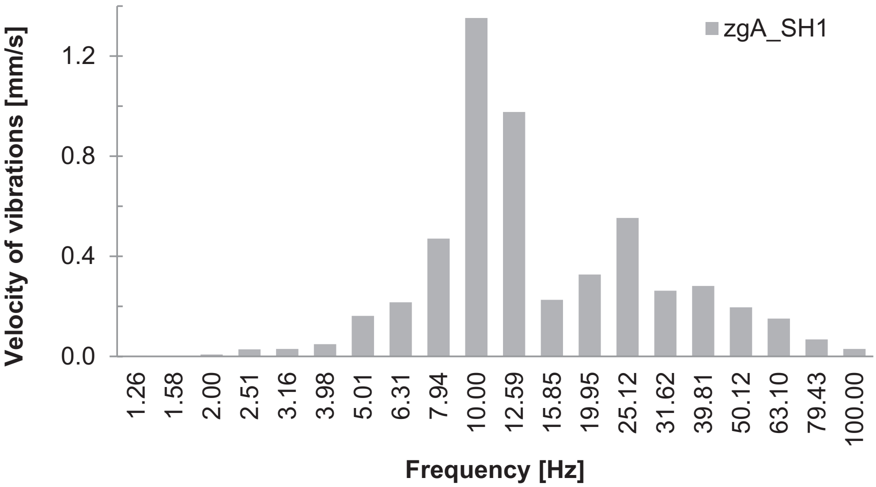

Figure 18. Structure of vibrations in the ground – point A – component *z*

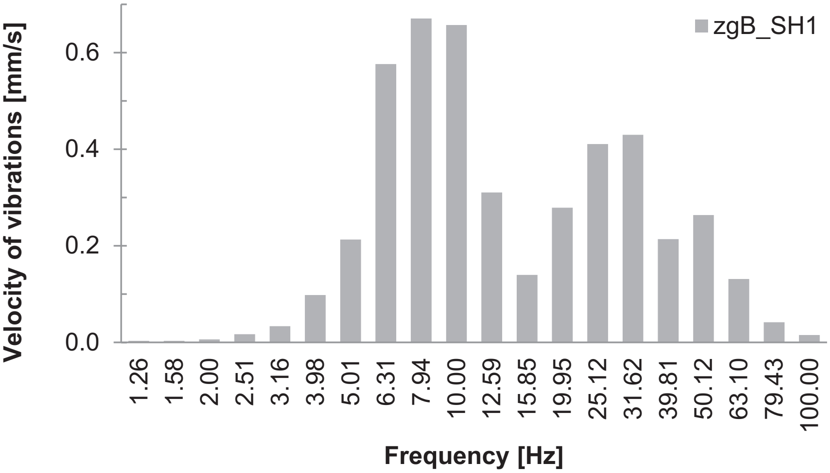

Figure 19. Structure of vibrations in the ground – point B – component *z*

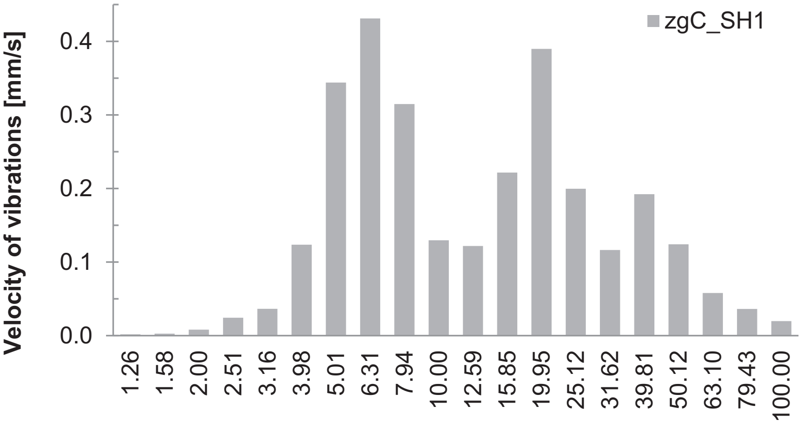

Figure 20. Structure of vibrations in the ground – point C – component *z*

The figures show that changes in the structure of vibrations at subsequent measuring points can be observed both in the lower and higher dominant frequency range. At the lower frequency range:

- point A: 10.0 and 12.59 Hz,
- point B: 6.31, 7.94 and 10.00 Hz,
- point C: 5.01, 6.31 and 7.94 Hz.

The changes are important for evaluating the effect of vibrations on the building, assuming no vibration attenuation at this frequency range. The 25 Hz observed at the higher frequency range indicates that a cautious approach may be required when using a 42 ms delay interval for a series of explosive charges.

8. Summary

- At the turn of the century, a dynamic development of explosive charge detonation systems has been observed. The issue of the effect of blasting operations or seeking optimal solutions aimed at achieving the optimal output size distribution has driven the development of the initiation systems, particularly those aimed at improving the capabilities of detonating the largest number of charges in a series, controlling the blast pattern to obtain the required output size distribution and reducing the impact on the surrounding area. The latest electronic systems are characterised not only by high-precision initiation parameters but also by extensive capabilities of designing multi-hole blast patterns. Using these electronic systems requires the implementation of computer software (computer systems) in the design of blasting operations. In most cases, the software requires a complete database including not only the technical parameters of the initiation system and types and parameters of the explosives used but also the geological conditions of the deposit and its surrounding area, the propagation conditions of vibrations induced by the explosive and the location of protected buildings.
- For the first time, in the 1990s, the signature hole technique started to be implemented to characterise geological conditions and propagation of vibrations in software for planning blasting operations. The technique involves recording the seismic signal induced by the detonation of single explosive charges (similar charge masses to those used in production blasting operations) at different heading locations. The data can be used to simulate the seismic effect which may be induced by a series of charges detonated at certain intervals.
- Developing a database for computer software requires preliminary tests to identify possible variations in the deposit or its surrounding area to improve the reliability of the designed blasting operations and predict their effect on the surrounding buildings.

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Received: January 18, 2021
Revised: October 12, 2021