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Inżynieria Bezpieczeństwa Obiektów Antropogenicznych

Technical safety of buildings around polish quarries against harmful seismic vibrations caused by rock blasting

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Abstract

This paper presents the results of measurements of the elliptical distribution of seismic vibrations generated during rock blasting.The technical safety of a building in the area of seismic vibrations is determined by the vibration velocity that does not exceed the line B included in zone II of the scale of dynamic influences [SWD]. The hypothesis proved in the paper is that for both elliptical and circular distributions of the vibration velocity in rock mining with blasting material [BM] there is a directionality of the horizontal radial component Vx and the tangential component Vy of the vibration velocity.The magnitude of the components Vx and Vy of the vibration velocity at the same distance from the vibration source depends on the directional angle "α" between the line of the blast holes and the line connecting the centre of the surface of the rock block being mined with [BM] and the place of measurement. The elliptical shapes of the graphs Vx and Vy obtained during the mining of the BM of the basalt deposit, which depend on the value of the directional angle, were compared with the shape of the circular velocity graphs Vx and Vy. New correlations are given that take into account the directional angle when calculating the maximum vibration velocity values needed to determine the damage caused to a bulding by the SWD.A dynamic impact scale [SWD] for the assessment of building damage as the vibration velocity acting on the building increases is given and discussed. Vibration velocity diagrams measured during the excavation of BM rock are presented for circular distributions in accordance with theoretical predictions. A vibration velocity diagram for an elliptical distribution, inconsistent with a circular distribution, measured during the excavation of BM rock is presented. It is shown that the directionality of the horizontal radial and tangential components of vibration velocity exists for both circular and elliptical distribution of vibration velocity in rock excavation with BM. In the conclusions, for the elliptical velocity field of the vibrations, the conditions to be observed in order to be able to direct the smallest vibrations towards the built up area are given.

Keywords: seismic elliptical distribution of vibrations

1 Introduction

Compact rock is mined using blasting materials [BM], which cause vibrations in the mining medium and then in the ground outside the mine. These vibrations are transmitted by seismic waves that propagate in all directions and have harmful effects on road and housing infrastructure. Until now, it has been assumed in Poland and worldwide

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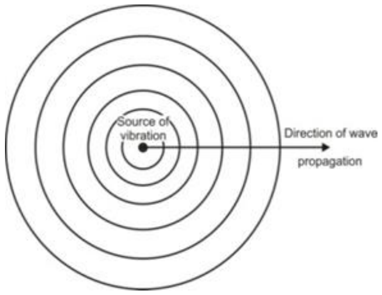
that seismic vibrations generated during rock mining using BM propagate along a circular path with equal energy in each direction, like waves on water caused by a stone thrown into it,(Chrzan 2021).

1)



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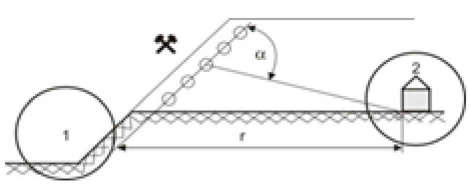


Figure 1. *Circular directional distribution of horizontal velocity Vxyz of vibrations (Chrzan, 2021).*

Figure.2. *Outline of a place of vibration formation / mine "1', bench blasting / and the distance "r "between the mine and the building '2" which is affected by vibrations and the directional angle "α" (Chrzan, 2021).*

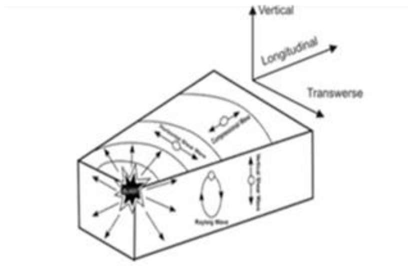


Figure.3 *Types of waves ind their vibration and directions of measurements, longitudinal wave-X, transverse wave Y,(Chrzan, 2021).*

In Figure.2 the directional angle of measurement "α"=90º between the line of blast holes and the line connecting the measurement point/house/ with the central blast hole is marked and the distance between the vibration source and the protected object is marked. The waves that make up a seismic wave and the directions in which they are measured are shown in Fig.3.

The direction of vibration measurement parallel to the line of boreholes is usually referred to as Y and perpendicular to the line of boreholes as X. Therefore, the parameters measured in the X direction have the indices Vx, and in the Y direction Vy. During the measurements, the horizontal radial peak particle velocity (PPVx) of vibration, also denoted as Vx in the article and the horizontal tangential peak particle velocity (PPVy) of vibration, also denoted as Vy in the article, are measured. It can be seen from Figure 4,5 that for a circular distribution the tangential velocity Vy and radial velocity Vx have different values depending on the angle of inclination of the measuring direction "α". The horizontal components of the radial velocity Vx and the tangential velocity Vy are measured on the deposit in the X and Y directions

2 Theoretical analysis and measurement results

From the analysis of the unit circular distribution of the radial component Vx and the tangential component Vy of the vibration velocity as a function of the directional angle "α" Fig.4A it follows that the radial component Vx of the vibration velocity for the directional angle in the range "α" = 0-90º has the shape of a semicircle in each quarter of a circle and variable value in the direction of the X-axis, for α =90º, Vx=Vx max, For α =0º, Vx=0. From Fig.4B it follows that the tangential component Vy of the vibration velocity for the direction angle in the range "α" = 0-90º has the shape of a semicircle in each quarter circle and variable value in the direction of the Y-axis, for α =90º, Vy=0, for α =0º, Vy=Vy max.

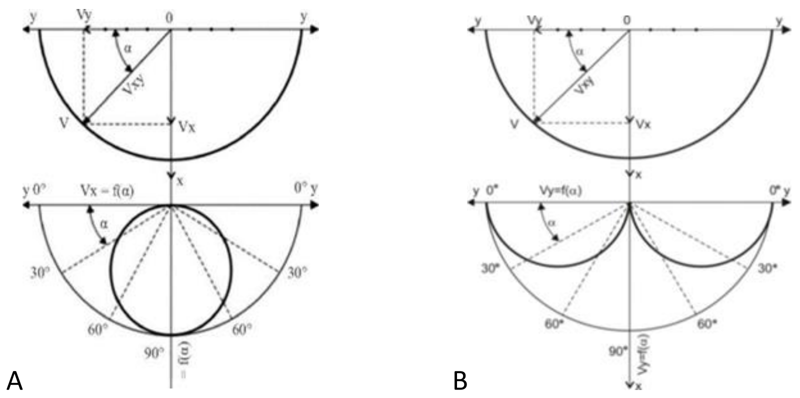


Figure 4A. *Graphical representation of the shape and value of the unit vector of the resultant velocity Vxyz and the radial velocity Vx of the seismic wave as a function of the directional angle "α"/circular distribution,(Chrzan,2,2022).*

Figure4B. *Graphical representation of the shape and value of the unit vector of the resultant velocity Vxyz and the tangential velocity Vy of the seismic wave as a function of the directional angle "α"/circular distribution,(Chrzan,2,2022).*

Fig.4A and 4B shows that the component of the unit vibration velocity vector, the radial vibration unit velocity Vx and the tangential vibration Vy have different values depending on the measurement angle "α". The Y axis is in line with the direction of the blast hole lines and the velocity Vx is perpendicular to the Y axis. The unit value of the resulting velocity vector for a circular distribution can be written as the sum of the component vectors,

Chrzan,1,2022); $V1xy^2 = V1x^2 + V1y^2 = R^2 = 1$ (1)

From Figure 4 it follows that

$V1x = V1xy * sin\alpha = 1 * sin\alpha, V1x = V1y * tg\alpha$ (2)

and $V1y = V1xy * cos\alpha = 1 * cos\alpha, V1y = V1x/tg\alpha$ (3)

R- Radius of the unit velocity vector V1xy. V1x,V1y - component of the unit velocity vector. The actual distribution of the radial Vx and tangential Vy components of the vibration velocity measured during the excavation of the BM of the inhomogeneous overburden in the Adamów lignite deposit ,(Chrzan,2,2022),Fig. 5, is similar to the theoretical Fig. 4A and 4B.

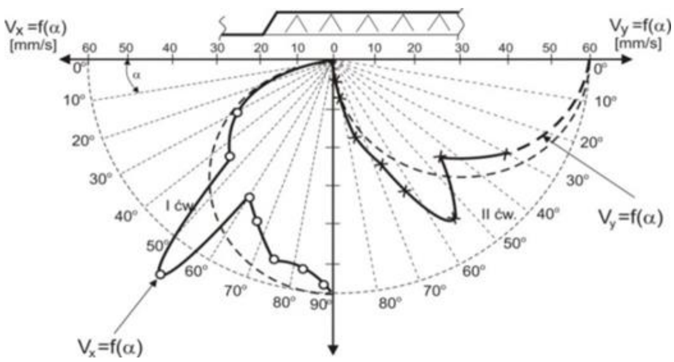
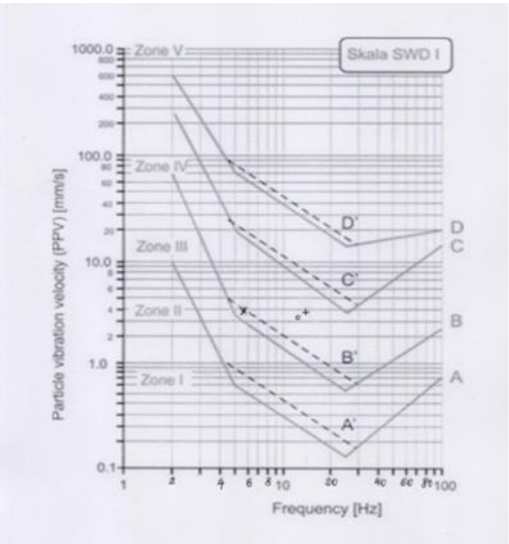


Figure 5. *Circular directional distribution component of the unit velocity vector of horizontal radial Vx and tangential velocity Vy of vibrations as a function of directional angle α, I and II -quarter of a circle,(Chrzan,2,2022).*

In Figure 5, the angle α=55° is the inhomogeneity angle of the medium with the largest value of the horizontal component of the particle radial peak velocity PPVx=Vx and the tangential horizontal component of the particle peak velocity PPVy=Vy of the vibration. The dotted line indicates the theoretical circular distribution for the horizontal component of the radial velocity Vx and Vy, similar to the circular distribution in Fig.4A, 4B; o - marked values of measurement points-Vx, x - marked values of measurement points-Vy.

3 Scale of Vibration Velocity Hazard, Polish Standard (Norma,2016)

The dynamic impact scale [SWD] SWD I and SWD II for buildings was developed as a Polish standard and has been in force since 1985. The Scale of dynamic influence, SWD I, for buildings up to two storeys snd scale SWD II, for buildings up to 5 stories (Norma,2016). The scale is a drawing with lines drawn to define individual damage zones from vibration velocity values. In Figure 6 shows the magnitude of the greatest horizontal component of the vibration velocity measured on the building at ground level and the corresponding frequency. The point of intersection of these data defines the zone number and describes the resulting damage to the building in that zone: - Zone I - Vibrations not perceptible to the building -Boundary A - Lower limit of perceptibility of vibrations to the building-Zone II - Vibrations perceptible to the building and harmless to the building structure-Zone II - Vibrations that can be felt in the building but are not harmful to the structure, accelerated wear of the building, resulting in cracks in the lining, plaster, etc. - B Limit - the lower limit for the occurrence of cracks and fractures in structural elements. Zone B - the upper limit of technical safety of the building - Zone III - vibrations harmful to the building, causing local scratches and cracks, possible loss of plasterwork and plaster - Zone C - the lower limit of serious damage to the building - the limit of resistance of individual elements of the building - Zone IV - vibrations harmful to people, causing numerous cracks, local destruction of walls and falling of individual elements - Zone V - collapse of walls. The vibration velocity in zone III is harmful to the building, causing local scratching and cracking of structural elements. The level of permissible vibration velocity acting on the building without visible damage to structural elements and ensuring its technical safety is the B limit (Figures 6A, 6B). Other velocities cause strictly defined damage to buildings, which are specified in the Polish standard (Norma,2016). On this basis, it is assumed that the technical safety of the building in the range of seismic vibrations can be determined by the vibration velocity marked by the B line included in Zone II of the Dynamic Influence Scale [SWD], Fig. 6A, 6B. The damage limits of each zone are given in two variants: A, B, C, D solid line and A', B', C', D' dashed line,(Norma,2016).

A 

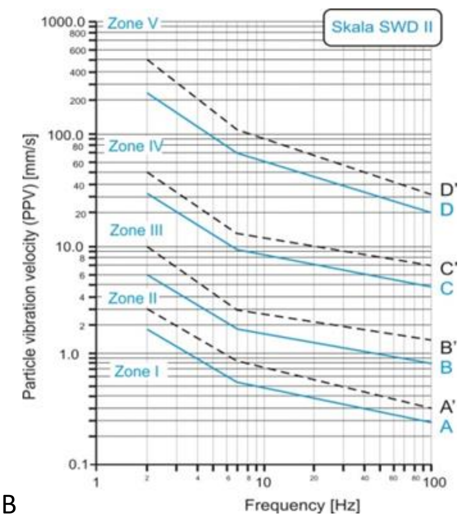
B 

Figure 6A. *The Scale of dynamic influence, SWD I, for buildings up to two stories.*
Figure 6 B. *The Scale of dynamic influence, SWD II, for buildings up to 5 stories. (Norma,2016).*

The solid line applies to old, damaged, converted buildings. Buildings of masonry, cinder block, stone elements, without foundations, large openings or irregularities in the walls, not carefully constructed, low stiffness substrate (silty or loose sands), discontinuous foundations of varying height. Dashed lines indicate undamaged buildings with no structural alterations. The solid brick walls, the reinforced concrete foundations and the walls connected to the ceilings are all carefully constructed. Rigid ground - hard plastic clays, flat foundations, (Norma,2016).

4 Determination of the safe zone in relation to seismic vibrations

Polish research institutes (Chrzan,2021) use the following relationship to predict the seismic radial velocity Vx=PPVx and tangential velocity Vy=PPVy and the range of harmful seismic vibrations:

$$Vx = Vy = k * Qz^{a}/r^{n} \tag{4}$$

where:

Vy or Vx – tangent or radial vibration velocity [cm/s] at the measurement point,

k, a, n - coefficients defining the conditions of emission and propagation of vibrations, determined on the basis of measurements, taking into account measurement errors,

Qz - size of the detonated MW charge, per one delay /one detonator number/, [kg],

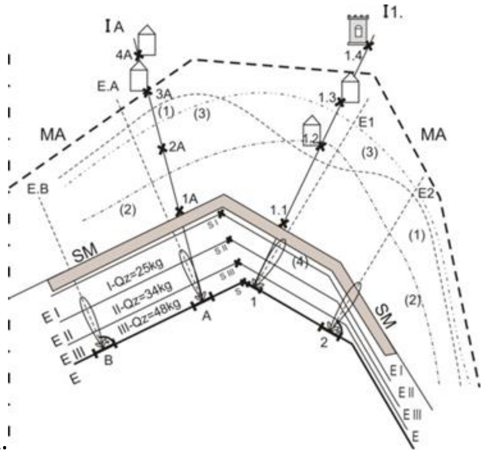
r - distance between the location of the detonated charge Qz and the object where vibrations occur, [m].

Assuming that a=1/2 for long hole firing and n=1, we get ρ=[Qz]^(½)/r. Depending on the type of deposit, it is also assumed that a=1/3. Substituting ρ in relation 2. we obtain V=c*ρ, where c is the constant determined on the basis of the statistical characterisation. Using the safe value of the seismic velocity from the scale of dynamic actions [SWD] for the planned BM load size, the safe distance of the detonated charge Qz from the protected object is calculated using formula (4). Depending on the maximum value of the horizontal, tangential or radial vibration velocity vector and its frequency, the degree and type of damage caused to the structure is determined using the SWD.In the case of circular distribution, the equations (4) used to calculate the tangential velocity Vy and radial velocity Vx do not take into account the value of the angle of inclination of the measuring direction "α". On the basis of equation (4), with a constant mass of the explosive charge [Qz], for the assumed value of the distance "r" from the source of vibrations, can be determined with an accuracy of up to + - 40%; - the value of the vector of the velocity of the horizontal, radial and tangential vibrations it is; - the effect of the velocity of the vibrations, for a radius equal to the assumed value of the distance, on the whole area adjacent to the exploited deposit; - the seismically safe distance from the blasting site for the protected objects.

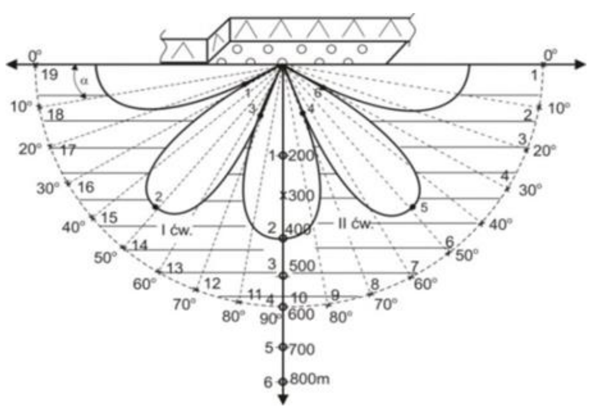
A disadvantage of the calculations used so far (relation 4) is that they do not take into account the change in the value of the vector of the horizontal, radial and tangential vibration velocity with a change in the direction angle.

5 New measurement method and its analysis in relation to the ellipsoidal directional distribution

At present, measurements and their analysis are carried out only for a measurement profile A or I, Fig.7A. In the new measurement method, Fig.7B, related to the analysis of the type of directional distribution, the measurements are carried out at directional angles selected every few degrees, located on half the circumference of the circle, at a fixed distance behind the face of the block being worked. This requires an additional number of vibration sensors, an additional effort. Therefore, it is wrongly assumed that the value of the horizontal, radial and tangential ground vibration velocity vector calculated from the correlative equation (4) for the same distance and the same mass of MW load does not depend on the angle and is constant. For industrial rock excavation [BM] with the same blasting parameters, the horizontal components can be measured for 2 directions with the highest local vibration velocities Fig.7B. Directional angles "α" with the highest local vibration velocities are α=0º and α=90º, Fig.7B.



A.



B

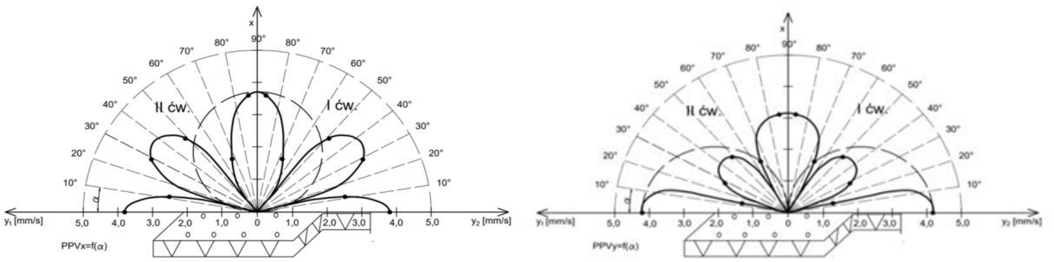
Fig.7A The current practice

Fig.7B Example of new method

Fig. 7A shows the current method of determining the measurement profiles 1-I1 and A-IA and the selection of measurement points 1.1;1.2;1.3;1.4 and 1A,2A,3A,4A for the measurement of seismic vibrations for a circular distribution for objects during blasting operations at points A and 1 on mine level E. Fig. 7 B is an example of the deployment of vibration sensors according to the new measurement methodology on a basalt deposit, in a semicircle every 10 degrees and perpendicular to the rock wall during the first accurate elliptical directional distribution and seismic wave vibration measurements for vibration prediction calculations.

6 Ellipsoidal radial and tangential velocity field of vibration for a basalt deposit

The basalt deposit is located within the pre-Sudetic mountain block in the north-eastern part of the Niemczańsko - Strzeleckie Upland,(Study 2015). The basalts belong to the Central European Tertiary volcanic province. The building vibration values were measured for the radial Vx and tangential Vy peak particle velocity (PPV). The peak particle velocity of the medium is responsible for the magnitude and type of damage to buildings and depends largely on the maximum charge per delay Qz, the distance between the vibration source and the measurement point "r", and the physical properties of the BM and the excavated BM rock [4]. The blast induced vibrations were recorded using a seismograph. The seismograph also recorded the vibration frequency of the PPVx and PPVy peaks and the horizontal vibration velocity of the medium particles. Measurements of vibration velocity and frequency were made at an average distance of 313.0 m from the source of the vibrations using a UVS-1504 instrument. A map of the deposit,(Study 2015) shows the existing houses and the place where the rock was excavated, the line of the blast holes, field survey points on protected houses. From the map of the deposit, the directional angles of the following survey points were measured in front of the excavated rock block on the basalt deposit. The results of the horizontal peak particle velocity PPVx and PPVy of the vibration measurements under industrial blasting conditions in the mining of the basalt deposit for different values of the directional angles are shown in Fig.7A and 7B



A **B**

Figure 7A. *Ellipsoidal dependence of the value of the radial vibration velocity PPVx as a function of the direction angle "α".*

Figure 7B. *Ellipsoidal dependence of the value of the tangential vibration velocity PPVy as a function of the direction angle "α".*

Fig.7A and 7B shows the ellipsoidal distribution of PPVx and PPVy as a function of the directional angle "α" occurring during blasting operations in a basalt deposit. Fig.7A and 7B shows the directional characteristics of the vibration source: a) - axes Y1 and Y2 with marked measuring points "o" PPVx and PPVy [mm/s] on the axes and directional angles on the same scale. b) - slope VVV of the slope, i.e. the face of the rock block made by blasting, c) the unit vector Vx marked with a thin dashed line with two semicircles of 3.8 [mm/s] velocity in quadrants of circle I and II on axis X. Fig.7 A - 3.8 times larger semicircular theoretical distribution of the unit vibration Vy. The vector Vy is marked by a thin dashed line with two semicircles of 4.2 [mm/s] speed in quadrants of circle I and II on axis Y1 and Y2, d) dashed lines; - grid of directional angles from 0° to 90° dividing the semicircle every 10°, e) - quadrant I, "α" - an example of acute directional angle "α" is marked. The ellipsoidal diagram of the PPVx and PPVy vibration velocities measured on the buildings as a function of the directional angle "α" over an area of 180 degrees (semicircle) is presented as the total perimeter of three ellipsoids and two semi-ellipsoids. The largest ellipsoid with the longest axis on the x-axis is the longitudinal wave ellipsoid L, and its maximum value is at an angle of 90°. The longitudinal wave ellipsoid in quadrants I and II passes through two oblique full transverse wave ellipsoids T, with a directional angle of the longer axis of about α = 38°, into two surface wave semi-ellipsoids R. Their longer axes lie on the Y1-Y2 axis of the diagram and have a directional angle of α = 0°. The ellipsoids and semi-ellipsoids in quadrants I and II of the circle are symmetrical about the X axis and are similar. The highest vibration velocities occur on the direction X. An analysis of the effect of the highest vibration velocity on the direction X on the technical condition of a two-storey house was carried out. The effects of the highest vibration velocities and their corresponding frequencies fx on a two-storey house were considered on the basis of the SWD I scale. According to,(Study 2015) at a distance of 313 m from the vibration source, the highest vibration velocities were measured for directional angles α; for longitudinal wave, α = 86º, transverse wave angle α = 29º and surface wave angle α = 0º. In Figure 6A, the measured vibration velocities and corresponding frequencies are marked with the points "x.o,+".-Longitudinal wave, "x" angle α = 86º, PPVx=3.84 mm/s, fx=5.8 Hz, -Transverse wave "o" with medium inhomogeneity, angle α=29º, PPVx=3.40 mm/s, fx=13.5 Hz,-Surface wave "+" angle α= 0º, PPVx=3.85 mm/s, fx=14.2 Hz. By superimposing the values of velocity on the Y-axis and frequency on the X-axis on SWD I Fig.6A, the intersection points of these data were obtained. For both longitudinal wave velocity, angle 86º, transverse wave angle 29º and surface wave angle 0º, the intersection points of these data are located in zone IV. For the Y-direction, the vibration velocity of the surface wave for angle α=0º is slightly higher than for the X-direction, Vy=4.2 mm/sec, but it is also in zone IV. From the analysis of the influence of the horizontal vibration velocity and the corresponding frequencies on the building, it is clear that the effect of each wave on the X or Y direction is almost the same and affects the technical condition of the two-storey building in the same way. The limit state of the technical safety of a two-storey building due to vibrations has suddenly been exceeded. The same conclusions can be drawn for buildings up to 5 storeys high.

7 Summary and conclusions

There are no formulae in the world mining literature for determining the radius of the safe seismic vibration zone and the size of the safe explosive mass, taking into account the directionality of the vibrations by measuring the directional angles of the measurement points. The results of the seismic vibration measurements presented in Figure 7A and 7B show that there is an ellipsoidal directional distribution during industrial blasting in a basalt deposit in three rows of 11 blastholes each, with a burden of B=3.5m and a hole spacing of a=3.8m at a bench height of H=18.5m. To predict the radius of the safe zone for buildings in relation to seismic vibration and the safe amount of explosives, the highest measured value of the radial PPVx or tangential PPvy horizontal vibration velocity must be used for safety reasons. For an ellipsoidal distribution, this is the higher value of the velocity for a direction angle α; α = 90° or α = 0°. The technical safety of buildings is ensured if the horizontal velocities according to SWD do not cause scratching or cracking of structural elements. Figure 7A and 7B clearly shows the main directions of the ground motions in relation to the lines of the blast holes. From Figure 7A and 7B it is possible to determine the safe angles / areas of lowest vibration /.Knowing the directional characteristics of the source of the vibrations, it is possible to change the direction of the rows of blast holes and direct the highest vibrations towards the undeveloped terrain.The value of the vibration velocity depends on the directional angle α and should be taken into account in the measurements. When BM rock is excavated, there is a circular and ellipsoidal distribution of the velocity vibration of the medium particles through which the seismic wave passes. In the case of circular and ellipsoidal velocity distribution, in order to ensure the technical safety of buildings, the value of the velocity acting on them should not exceed the limit line B, Fig. 6A and 6B.

1. For the same distance, the value of the vibration velocity depends on the type of wave and the directional angle α and should be taken into account when measuring and predicting the vibration velocity.

2.The assessment of the technical safety of a building for a circular distribution of the radial and tangential velocity of a seismic wave can be made on the basis of measurements taken at any directional angle, taking into account its influence on the predicted value of the velocity.

3. The assessment of the technical safety of the structure in the case of an elliptical distribution of the tangential velocity of the seismic wave shall be carried out on the basis of measurements made at angles $\alpha = 0^o$ and $\alpha = 90^o$.

4. For the analysed vibration velocity distribution, the built-up area should be in the directional angle between 13° and 25° and between 50° and 70°, Fig.7A and 7B.

5.From the analysis of the influence of horizontal vibration velocities and their corresponding frequencies on the building, it follows that the effects of each wave on the X-direction equally affect the technical condition of a two-storey building.

6. Measurement on the X-direction may be sufficient to determine the technical condition of a building affected by horizontal seismic vibrations.

Declaration of competing interests

The author declares that he has no known competing financial interests or personal relationships that could potentially influence the work reported in this paper.

References

1 Chrzan T.(2021) Akustyka inżynieryjna w ochronie środowiska przy urabianiu surowców skalnych materiałem wybuchowym, Book. Poltegor Instytut, Wrocław, 2021

2 Chrzan T.(1,2022) A discussion of the research results in the article " Impact of orientation of blast initiation on ground vibrations" Garai et al.,. Journal of Rock Mechanics and Geotechnical Engineering,15/2022 https://doi.org/10.1016/ j.jrmge.2022.10.012

3 Chrzan T.(2,2022) The influence of the circular distribution of radial and tangential seismic velocity on the structural safety of residential buildings. Inżynieria Bezpieczeństwa Objektów Antropologicznych, No 3 (2022), s.48-54. Articles, Published September 30.2022y. https://doi.org/10.37105/iboa.150

4 Norma (2016) Polish Standard. Skala wpływów dynamicznych [SWD], PN-B-02170:2016-12

5 Study (2015) Określenie promienia strefy bezpiecznej względem drgań parasejsmicznych dla złoża bazaltu. Inst. Gornictwa Odkrywkowego-Poltegor. Wrocław.