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Protecting the Environment Around Polish Quarries from Harmful Seismic Vibrations Caused by Rock Blasting

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***Abstract*. The paper presents the legal and scientific conditions for Polish researchers to determine the vibration velocity and the radius of the safe zone of seismic vibrations generated during rock blasting. Until now, in Poland and worldwide, it has been assumed that seismic vibrations generated during rock blasting with explosives [BM] propagate circularly with equal energy in each direction. However, this is not always the case. A theoretical analysis of the variation of the tangential magnitude Vy of the vibration velocity as a function of the change of the direction angle was carried out for a circular distribution of the vibration velocity. It was shown that the value of the vibration velocity component at the same distance from the vibration source depends on the directional angle between the line of the blast holes and the line connecting the centre of the surface of the excavated BM block and the measuring point. New relationships have been given that take into account the directional angle in the calculation of the maximum values of vibration velocity necessary for the determination of the resulting damage in the building from 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 have been 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 tangential component of the vibration velocity exists for both circular and elliptical distribution of vibration velocity in rock excavation with explosive BM. The technical safety of the building in the area of seismic vibrations is determined by the vibration velocity included in zone II of the scale of dynamic influences [SWD] Fig.6A, 6B.**

Keywords: ground vibrations, seismic vibrations, circular, elliptical, distribution of vibrations.

I. INTRODUCTION

Compact rocks are 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 propagating in all directions and have harmful effects on road and housing infrastructure. So far in Poland and worldwide is believed that seismic vibrations generated during mining rocks using BM propagate along a circular path with equal energy in each direction, like waves on water from a stone thrown into it [1].

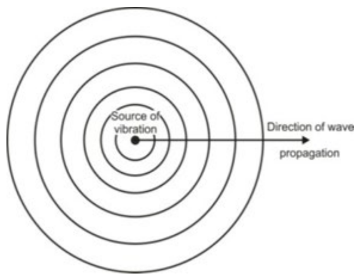

Fig. 1. Circular directional distribution of horizontal velocity Vxyz of vibrations [1,6,7].

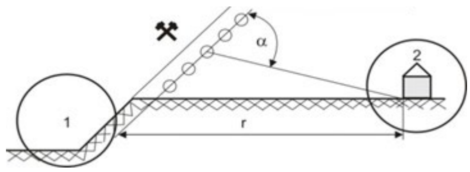

Fig.2. Outline of a place of vibration formation / mine "1', bench blasting / and the distance "r "between the mine and the building '2" which is affected by vibrations and the directional angle "α".[1].

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In Fig.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.

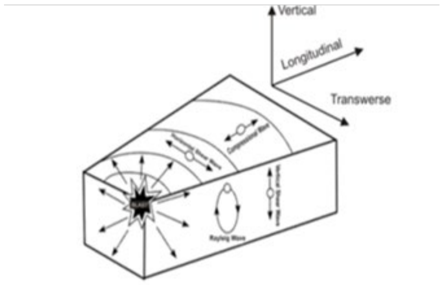

Fig.3 Types of waves ind their vibration and directions of measurements [1,7,8], longitudinal wave-X, transverse wave Y.

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. 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"

II. Polish Legal Basis For Determining The Safe Zone In Relation To Seismic Vibrations

In Poland, the area of harmful seismic vibrations for the first blasting in a rock deposit is determined on the basis of the formula given in the Ordinance [2] and for subsequent blasting on the basis of field tests carried out by an authorised research and development unit. The radius of the dangerous seismic zone based on the regulation is determined by the formula [2]:

$$rs = [Q]^{½} / Ø \quad (1)$$

where:Q - instantaneous BM load or maximum BM load per deceleration /millisecond delay/ for deley fired in a series of holes, [kg]; rs - distance from the explosion point to the protected structure, [m]; the coefficient Ø is: for Cm < 2,000 m/s, Ø = 0. 030 - 0.026 for Cm = 2,001 - 3,000 m/s, Ø = 0.025 - 0.020; for Cm > 3,000 m/s, Ø = 0.019 - 0.015; where Cm - longitudinal seismic wave velocity characteristic of the ground on which the object stands, -1) sand, gravel, clay; Cm= 1000-1500 m/s, -2) soft moraine formations, limestone shale; Cm= 2000-3000 m/s, -3) granite, gneiss, sandstone, hard limestone; Cm = 4500-6000 m/s. If an explosive charge is fired in series, the radius of the zone increases by 1.5 times with a deceleration of 2 to 15 degrees. The determination of the safe charge per millisecond delay requires the correct assumption of the Ø value. The determination of the longitudinal velocity of a seismic wave requires an appropriate measurement under real conditions, or the assumption of this value from under real conditions, or the assumption of this value on the basis of data from the literature. The ministerial decree does not specify whether it is the radial or the tangential component of the seismic longitudinal wave. Polish research institutes [4] use the following relationship to predict the seismic radial velocity Vx and tangential velocity Vy=PPVy and the range of harmful seismic vibrations:

$$Vx=Vy=k * Qz^{a} / r^{n} \quad (2)$$

where: Vy or Vx - vibration velocity at the measuring point, tangential or radial, [cm/s], k, a, n - coefficients defining the conditions of emission and propagation of vibrations, determined on the basis of measurements, taking into account the effects of variations in technological parameters and 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, it is obtained that 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 MW load size, the safe distance of the ignition point Qz from the protected object is calculated using formula (2). 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 building is determined using the SWD. In the case of circular distribution, the equations (1) and (2) 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".

III. Theoretical Analysis And Measurement Results

From the analysis of the unit circular distribution of the tangential component Vy of the vibration velocity as a function of the directional angle "α" Fig.3 it follows that the tangential component Vy 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 a variable value in the direction of the Y-axis, for α =90º, Vy=0, for α =0º, Vy=Vy max.

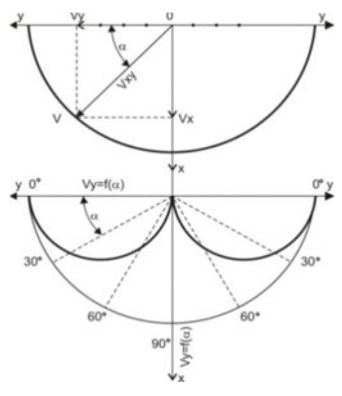

Fig.4 Fig.4 Graphical representation of the shape and value of the unit vector of the resultant velocity Vxyz and the tangential velocity Vy of the seismic wave as a function of the directional angle "α"/circular distribution [3].

Fig.4 shows that the radial vibration velocity Vx and the tangential vibration velocity 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 horizontal components of the radial velocity Vx and the tangential velocity Vy=PPVy are measured on the sample in the X and Y directions. The unit value of the resulting velocity vector for a circular distribution can be written as the sum of the component vectors, $Vxy^2 = Vx^2 + Vy^2 = R^2 1$ (3) From Figure 4 it follows that Vx=Vxy*sinα=1*sinα, Vx=Vy*tgα (4) and Vy=Vxy*cosα=1*cosα, Vy=Vx/tgα (5) R- radius of the unit velocity vector Vxy. The actual distribution of the tangential vibration velocity Vy measured during the excavation of the BM of inhomogeneous overburden in the Adamów brown coal deposit [4], Fig.5, is similar to the theoretical Fig.4.

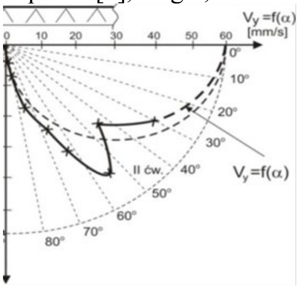

Fig.5 Circular directional distribution of horizontal tangential velocity Vy of vibrations as a function of directional angle α-II quadrant. [4].

In Figure 5, α=55⁰ is the angle of inhomogeneity of the medium with the highest value of the horizontal tangential peak particle velocity (PPVy)=Vy of the vibration. The dashed line is the theoretical circular distribution for (PPVy)=Vy, as in Fig.4, x-marked values of measurement points-Vy.

IV. Vibration Velocity Hazard Scale, Polish Standard [5]

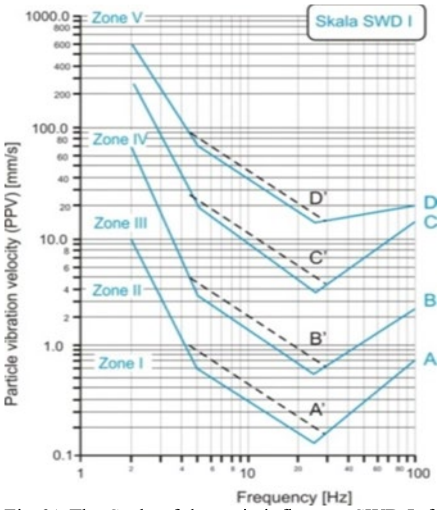

Fig.6A.The Scale of dynamic influence, SWD I, for buildings up to two storeys [5].

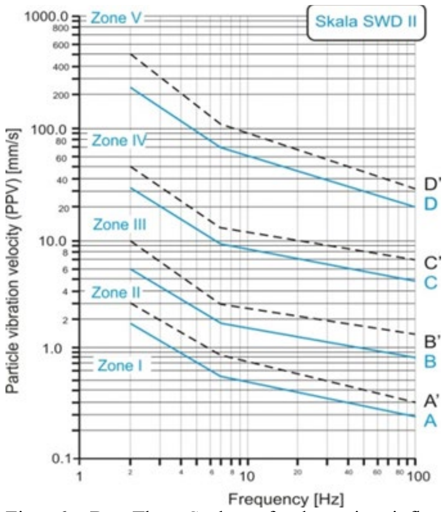

Fig 6 B. The Scale of dynamic influence, SWD II, for buildings up to 5 storeys [5].

The magnitude of the permissible vibration velocity acting on the building without visible damage to the structural elements ensuring its technical safety is the B limit (Figures 6A, 6B). Other velocities cause strictly defined damage to buildings, which are given in with the Polish standard [5]. On this basis, it is assumed that the technical safety of the building within 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. 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 apply to undamaged buildings with no structural changes. The solid brick walls, the reinforced concrete foundations, the walls connected by an edge with the edges of the ceilings, all carefully constructed.Rigid ground - hard plastic clays, flat foundations.

V. Ellipsoidal Tangential Velocity Field Of The 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 Uplands [4]. The basalts belong to the Central European Tertiary volcanic province. The basalt found in the deposit is a predominantly massive, poorly weathered rock, so aggregates made from it are of high quality. The building vibration values were measured for the tangential peak particle velocity (PPVy). 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, the distance between the vibration source and the measurement point, and the physical properties of the MW and the excavated BM rock [4]. The blast induced vibrations were recorded using a seismograph. The seismograph also recorded the vibration frequency of the peak PPVy, the horizontal tangential vibration velocity of the medium particle. 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 [4] 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 tangential peak particle velocity (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.7.

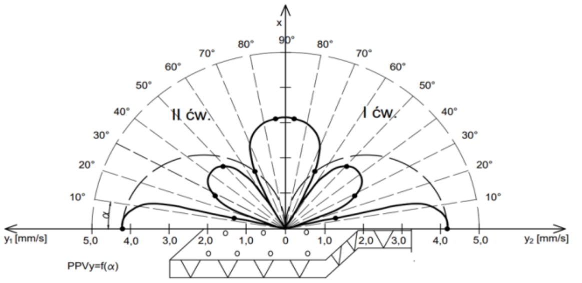

Fig. 7. Ellipsoidal dependence of the value PPVy of the tangential vibration velocity as a function of the direction angle "α"[4].

Fig.7 shows the ellipsoidal distribution of PPVy as a function of the directional angle "α" occurring during blasting operations in a basalt deposit. Fig.7 shows the directional characteristics of the vibration source: a) - axes Y1 and Y2 with marked measuring points "x" 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) graph of the unit vector of the tangential velocity Vy Fig.3 - 7.0 times larger, semicircular theoretical distribution of the unit ground vibration vector Vy marked with a thin dashed line with two semicircles of 7.0 [mm/s] velocity 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 an acute directional angle "α" is marked. The ellipsoidal diagram of the PPVy tangential vibration velocity 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 circle are symmetrical about the X axis and are similar.

VI. 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 7 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 tangential horizontal vibration velocity PPVy 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 tangential velocities PPVy according to SWD do not cause scratching or cracking of structural elements. Figure 7 clearly shows the main directions of the ground motions in relation to the lines of the blast holes. From Figure 7 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 direct the direction of rows of blast holes and direct the highest vibrations in the direction of undeveloped terrain. The value of the vibration velocity depends on the directional angle α and should be taken into account during measurements.

When BM rock is excavated, there is a circular and ellipsoidal distribution of the velocity vibration of the medium particle through which the seismic wave passes. With a circular and ellipsoidal distribution of the vibration velocity, in order to ensure the technical safety of buildings, the value of the vibration 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 direction 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 with a circular distribution of the tangential vibration velocity for a seismic wave can be performed on the basis of measurements taken at any directional angle, taking into account its influence on the predicted value of the vibration velocity.

3. The assessment of the technical safety of the building in the case of an elliptical distribution of the tangential velocity vibration of the seismic wave shall be carried out on the basis of measurements made at the directional angles α=0° and α=90°

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

Declaration of competing interests
The author declare that has no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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