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APPLICATION OF PPV METHOD FOR THE ASSESSMENT OF STABILITY HAZARD OF UNDERGROUND EXCAVATIONS SUBJECTED TO ROCK MASS TREMORS

1. Introduction

Longwall 3/503 in the Bobrek-Centrum mine was extracted in the period from May 2009 to July 2010 and was characterized by a very high level of seismic activity as well as high energies of mining seismic tremors. The first period of the increased seismic activity accompanied longwall start-up and was connected with the vicinity of residual area capable to accumulate energy and generate strong seismic events up tu energy 10^7 J (Figure 1). Another increase of seismic activity was registered when face line of longwall 3 in seam 503 was gradually coming out of the mined area of seams 509 and 510 (October 2009 to February 2010). During the time longwall 3 exploitation was being carried out there were also strong tremors not only directly connected with mining, but also those, which were of a regional character and where mining was a trigger factor of low magnitude seismic events. These seismic events took place during the period when face line of longwall No 3 was approaching the bottom of Bytom Syncline. The strongest tremor of regional character during mining of longwall panel No 3/503, occurred on 16.12.2009 and was of seismic energy of $8 \cdot 10^8$ J (local magnitude M = 3.5). Figure 1 presents distribution of seismic energy during mining of longwall panel No 3/503, i.e. in the period from 2009.06.01 to 2010.07.01.

After such a strong tremor took place, there was a problem with the assessment of hazard stability of mine excavations of longwall 3/503. In January 2010, geophone probes were installed with the aim of assessing the level of peak amplitudes of vibration velocity (PPV) occurring in side walls of longwall excavations as the result of the influence of strong tremors of rock mass. The first seismologic analyses of strong tremors of regional character indicated a considerable depth of their foci of tremors, even up to several hundred meters

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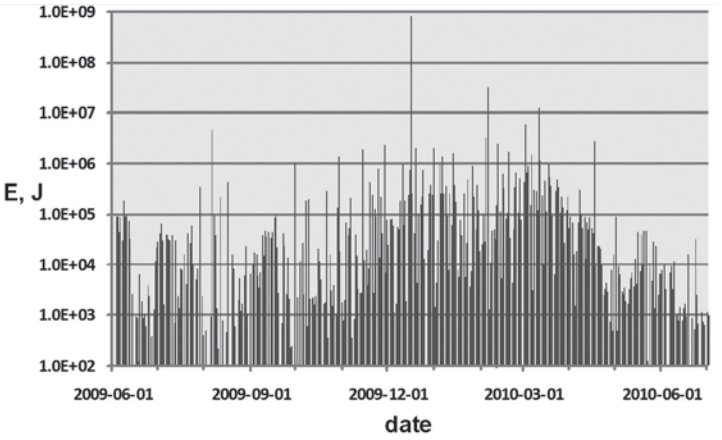

Fig. 1. Distribution of seismic energy during mining of longwall panel No 3/503

under the level of exploitation. This fact might have suggested that these tremors are not able to cause high level of vibrations in mine excavations of longwall panel 5 No 5/503, because of long hypocentral distance and strong dampening of vibrations in the area of the near wave field [3]. Physically low level of PPV vibrations means an appropriately lower level of dynamic stress and strain causes by rock mass tremors (PPV is proportional to stresses and strains [1]. Confirmation of such a scenario would mean a lack of stability hazard of mine excavation of longwall 3/503 connected with seismicity in longwall 3 and in its vicinity, according to elaborated criterion. This criterion has been developed by means of correlating results observed in mine excavations after 120 rockbursts had taken place in the Upper Silesian Coal Basin (Polish: GZW), with a calculated value of PPV parameter [4]. From this criterion it is visible that rockbursts for vibrations PPV below 50 mm/s have not been observed, and only sporadically for vibrations PPV < 200 mm/s depending on local conditions (quality of support, local high concentration stress zone, etc.). In 2011, the PPV method was elaborated, enabling the assessment of the degree of potential stability hazard of mine excavation subject to influence of rock mass tremors in the mines of GZW [6]. In the PPV method, the relevance of this hazard, expressed by the appropriate level of weighted magnitude of PPV_w, was taken into account. The levels of potential hazard determined by the value of PPV amplitude revised by means of weight function W, are as follows [6]:

a — lack of hazard: $PPV_w \leq 0.05$ m/s,

b — low hazard: $0.05 < PPV_w \leq 0.2$ m/s,

c — medium hazard: $0.2 < PPV_w \leq 0.4$ m/s,

d — high hazard: $PPV_w > 0.4$ m/s.

Weight function were selected depending on the local mining-geological conditions and seismologic characteristics of the tremors, taking place in the observed area and it is a linear function. Weights are selected on the basis of the analysis of corner frequency of tremors set from the region of the examined exploited longwall and corner frequencies calculated for tremors which caused rockbursts in the mines of GZW. Weights allow the eliminating

of these high values of raw PPV parameter, which results from very low energy and high frequency local dynamic events (e.g. blasting works with explosives in mine excavation) and they have not significance for harmful reaction of underground excavation on dynamic load.

In this article, the results of continuous registration of PPV parameter after seismic tremors which occurred since 27 January 2010 until the end of longwall 3/503 run as well as back-analysis of measurement data with PPV method are presented.

2. Description of field site in bobrek-centrum mine at longwall panel no 3/503

In accordance with the assumptions of the PPV method, test probes were installed ahead of longwall 3/503 front in the roof of heading 3 (position no. 3) and in the roof of heading 4 (position no. 8). Geophone probes started registration on 27.01.2011 in the course of going out of longwall 3/503 from the area located above the goafs of seam 510. Test probes enabled the registration of PPV parameter in the amplitude range to 300 mm/s and in the frequency range from 1 to 250 Hz. These probes were connected to seismologic apparatus SOS and included measuring positions into seismological network of hard coal mine Bobrek-Centrum. Irrespectively from the possibilities of registration without over steering high amplitudes of vibrations velocities PPV, probes 3 and 8 allowed a more precise location of the tremors foci from the region of longwall 3/503. A very well configured measurement network in Bobrek--Centrum hard coal mine in the area of longwall 3/503, also enabled the analysis of distances of tremors foci from the above mentioned measuring positions in longwall gates 3 and 4. Seismic activity during exploitation of longwall 3/503 is presented in the table 1.

TABLE 1

Seismic activity at field site study of PPV parameter in the are of longwall panel 3/503 in "Bobrek-Centrum" Mine

Seam	Longwall	10^2	10^3	10^4	10^5	10^6	10^7	10^8	Total
503	3	1 355	1 072	490	98	13	2	1	3 031

Location of epicentres of tremors foci since the day of starting measurements with geophone probes in longwall gates 3 and 4 is presented in figure 2.

At the time of measurements of PPV parameters in mine excavations of longwall 3, 1960 tremors were registered of seismic energy ranging from 10^2 J to $3 \cdot 10^7$ J.

3. Measurement results and analysis

For each tremor which took place in the area of longwall 3/504, values of the peak amplitude of particle velocities (PPV) were registered, at the longwall gates 3 and 4 in seam No 503. A graph of registered peak values of PPV parameter is presented in figure 3. Generally, raw peak values of amplitudes of vibrations velocity PPV are not high and in

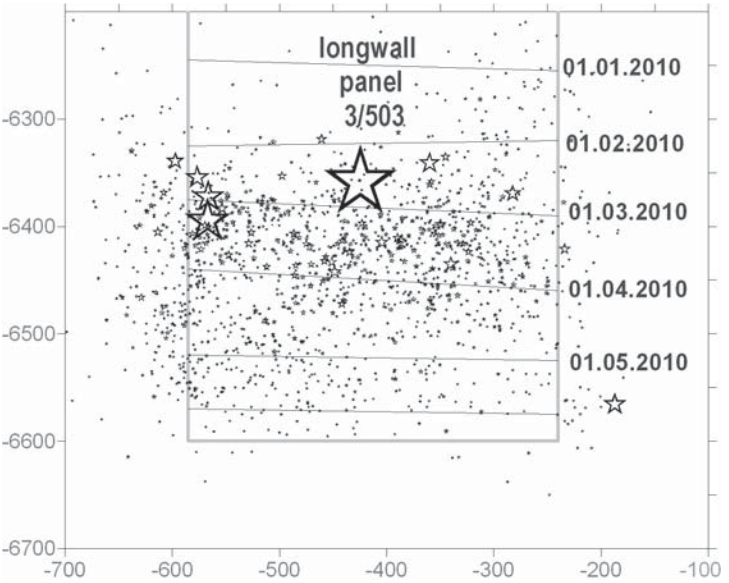

Fig. 2. Distribution of epicentres of tremors foci during field study of PPV parameter in the are of longwall panel 3/503 in "Bobrek-Centrum" (from 27.01.2010 to 06.2010)

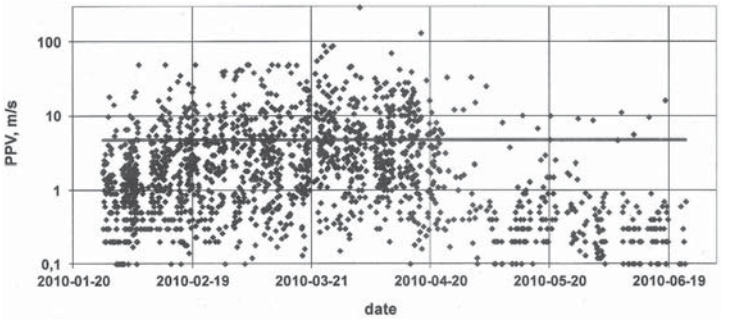

Fig. 3. Raw values of peak particle velocities, PPV registered in heading 3 for tremors which occurred in the period from 27.01.2010 to 25.06.2010

overwhelming numbers are located below the limit of 50 mm/s. In heading 4 they have not exceeded this criteria value at all, whereas in the heading 3, threshold value 50 mm/s from 1960 registrations has been exceeded slightly 7 times (PPV between 50 and 100 mm/s). However, once raw value PPV reached 140 mm/s for the tremor of seismic energy $3 \cdot 10^6$ J and in one case a value of 200 mm/s was exceeded, i.e. 290 mm/s, after a tremor caused by blasting works with explosives of energy amounting to 10^3 J. PPV equal to 290 mm/s, which was caused by blasting works, does not constitute a threat for excavations, due to high frequencies of vibrations (short length of wave of frequencies predominant in the record), thereby a minor part of rock mass and as a consequence relatively small forces of inertia acting on mine excavation.

Registered values of parameter PPV (Fig. 3) are not subject to be increased with longwall face line approaching the end line of mining of panel No 3, although tremors foci are approaching the depth level of seam 503 at that period of mining (Fig.5). The reason for such registrations result is a systematic decrease of seismic energy with the face line approaching the line of end mining (Fig. 4).

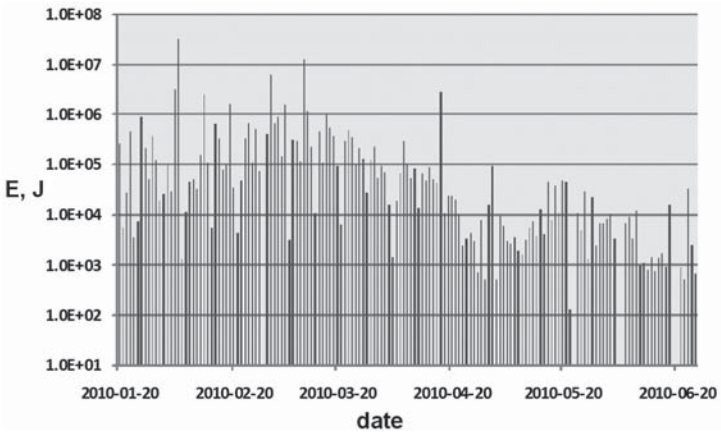

Fig. 4. Distribution of seismic energy during carried out PPV measurements in mine excavation of longwall panel No 3/503

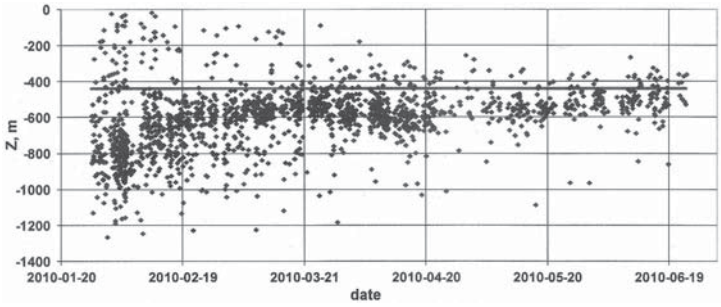

Fig. 5. Depth of the foci tremors below sea level, registered for tremors which took place from 2010.01.27 to 2010.06.25 in the area of longwall panel 3/503 (solid line mean the depth of seam 503 at field site)

4. Assessment of stability hazard of excavations under the influence of tremors with the application of PPV method

In the previous chapter it may have been possible to notice, that a few increased values of PPV registered in the heading 3, didn't harm the excavations in seam No 503. These records were connected with blasting works or low-energy and high frequency local tremors. Thus, in order to exclude the incorrect assessment of the harmfulness of such vibrations on the stability of the excavation, the PPV method was worked out which takes into account

weighting the significance of the value of PPV parameter in the hazard assessment. In order to give a reliable assessment it is preferred to use weight function taking into account the frequency of vibrations, which allows for characteristics of transferring vibrations by rock mass as well as the reaction in terms of effects which can take place in excavation. The registered values of PPV amplitudes, are revised by means of weight function in the following two categories:

— for lower frequencies $f \in (0, f_M)$ weight is equal to 1.0,
— for higher frequencies $f > f_M$ weight is lower than 1.0.

In the case of seismicity occurring in longwall 3/503 the determined parameters of weight function connected with corner frequency of tremors from the region of this longwall as well as the corner frequency of tremors, which caused rockbursts beforehand, were as follows:

— for lower frequencies $f \in (0, f_M)$ weight is equal to 1.0, while f_M = 17 Hz
— for higher frequencies $f > f_M$ weights are lower than 1.0, while weight function decreases in linear way from the value of 1.0 for f_M = 17 Hz to the value of 0.1 for f_{max} = 51 Hz .

An example of a calculation in this scope shows that the value of raw parameter PPV = 290 mm/s registered from blasting works has been revised by weighted function to the value of PPV_w = 87 mm/s.

In the examined case from the area of longwall 3/503, the analysis of tremors as they occur, with regard to observing changes in time weighted peak velocity PPV_w, enabled the assessment describing in this case — a lack of or low tremor hazard for the stability of longwall gates — despite of strong tremors which occurred in the course of conducted measurements.

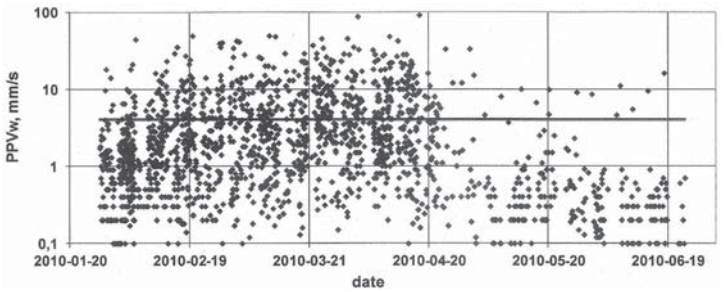

Fig. 6. Values of weighted peak particle velocities PPVW in heading No 3, for tremors which took place from 27.01.2010 to 25.06.2010, after application of weight function

5. Discussion of research results

For the assessment of the hazard the degree of stability of longwall gates subject to rock mass tremors (dynamic loads) analytical methods, numerical modelling and empirical scales can be used. Analytical methods allow us to determine the forces or displacements occurring in rock mass around the excavation and impact on the support, in order to assess the possibility of the survival of underground openings, as well as to assess the possibility of coal

burst under dynamic loads [2]. Numerical modelling allows for direct simple summation of dynamic and static loads around excavations and a comparison of calculated parameters with strength criteria. For both of these methods, knowledge of PPV parameter occurring around the side walls of these excavations is essential. Parameter PPV can be determined from empirical relationships combining seismic energy of tremor and focal distance. Unfortunately, the weakness of such a solution results from significant deviation of location of tremors foci, particularly in vertical coordinate. Moreover, it ought to be noted that in the near-field wave, error of location has enormous influence on the value of estimated parameter PPV, owing to very strong dampening of vibrations amplitudes with distance ($\sim 1/R^3$). Therefore, the method of direct measurement of PPV parameters is definitely a more reliable method than calculation the method to obtain PPV parameter.

The PPV method adopted for the assessment of stability of mine excavation is a method based on correlation of measured parameter PPV with the results observed in excavations, in the place of vibrations measurement. It is an empirical method of the assessment of the state of the stability hazard of mine excavation which can be adopted in hard coal mines in the Upper Silesian Coal Basin (GZW). Application of the PPV method in the final stage of longwall No 3/503, allowed for the assessment of hazard degree, according to the stability of excavations as low, despite occurrence of very strong tremors of energies higher than 10^6 J.

6. Summary

The degree assessments of a potential hazard of mine excavation stability under seismic loads can be made by the continuous recording of amplitude parameter of vibrations velocity PPV, around the excavations. In the article such study results were presented, obtained during the mining of longwall No 3/503 in Bobrek-Centrum mine. While performing the measurement of PPV parameter in mine excavation from 27.01.2010 to 30.06.2010, more than 1900 tremors were recorded, and the strongest of them reached seismic energies over 107J. Registered and weighted value of ground motion parameter, PPVW, were compared with criterion values determined in PPV method, categorizing four levels of potential hazard. The assessment of the degree of potential stability hazard of excavations in the area of longwall No 3/503 has shown a lack of hazard and in single cases low hazard degree, despite occurrence of very strong tremors. The reason for low values of parameter PPVW in mine excavation was undoubtedly location of foci of the strongest tremors in the region of Bytom Syncline, a few hundreds meter deeper than seam 503. The long distance from the hypocenter to excavations is a reason of strong dampening and low level of PPV at excavations in seam 503. On the other hand, when foci of tremors in the final phase of exploitation approached seam 503, their seismic energy was already significantly lower and high vibrations PPV in excavations from the region of longwall 3 were also not observed.

The proposed method of empirical assessment of a potential stability hazard of mine excavations under seismic loads is easy in practical engineering application, and at the same time has the advantage that values of parameter PPV are measured directly and precisely.

Location of tremor is not necessary for used of PPV method. The method enables to systematically estimate whether strong rock mass tremors can be any harm to the mine excavation and to what hazard degree it is. Very frequently, dynamic load coming from strong tremor is small, when low values of parameter PPVW are registered. It takes place when a focus of tremor occurred in the layers of roof or floor, far from the site of mining. In such a situation it is easier to make a decision concerning further exploitation of longwall panel, knowing that there is a low hazard to mine excavations stability. In a case, when registered and weighted values of PPVW parameter are high, it is easier to monitor the effectiveness of prevention activities.

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