WARSZTATY 2012 z cyklu: Zagrożenia naturalne w górnictwie

Mat. Symp. str. 210 – 220

Joanna KURZEJA, Jerzy KORNOWSKI
Główny Instytut Górnictwa, Katowice

The basic assumptions of quantitative version of Comprehensive Method of Rockburst Hazard Evaluation

Key words

Sockburst, rockburst hazard, mining seismology

Abstract

We describe here some basics and application results of a new, quantitative version of the well-known in the Polish mining industry, so-called Comprehensive Method of Rockburst Hazard Evaluation (CMRHE). The CMRHE – composed of four "particular methods" (i.e. mining seismology, seismoacoustics, drilling and, partly subjective, "expert method of hazard evaluation") – despite its popularity, is not well defined in the mathematical sense. Neither inside the CMRHE nor in the four particular methods, their subject, i.e. the rockburst hazard is quantitatively (or else) defined so that, in fact, the CMRHE tries to predict undefined subject and there is no guarantee that the particular methods seek the same (undefined) hazard and it is not clear, how the four particular results should be combined to get the final hazard prediction. The quantitative version, described here, starts from defining the hazard and all its components as probabilities. Then they can be combined according to probability rules. It is demonstrated that all the relevant pieces of (presumably independent) information – exactly the same as applied by CMRHE – can be expressed as probability distributions, each one dependent on its explanatory variable and each one assuming a scalar value at any concrete local conditions. Their product makes the formal estimator of rockburst hazard with the quantitative version of CMRHE, based on exactly the same information as the original CMRHE. It can be noted that logarithm of this product is the sum of "points", stressing the simple connection of the CMRHE and its quantitative version.

An example with actual (although compressed) data illustrates the simplicity of applications.

1. Introduction

In Polish mining industry, the method called " The Comprehensive Method of Rockburst State-of-Hazard Evaluation" (CMRHE) is known and commonly applied to assess the rockburst hazard. The CMRHE is composed of four "particular" methods i.e. Mining Seismology, Seismoacoustics, Small-diameter Drilling Method and Expert Method of Hazard Evaluation – the last one further abbreviated as MRG (acronym of Polish: "Metoda Rozeznania Górniczego"). When applied, particular methods issue their own (hazard) scores and the CMRHE, weighting them appropriately, generates the final score called "the current state of rockburst hazard", which is communicated to decidents, to facilitate decisions concerned with production and safety. Methods of seismoacoustics, seismology and drilling are based on measurements, but scores issued by the MRG depend on the sum of so-called points $Q(i,\theta_i)$, where "i" denotes a particular hazard shaping factor, HSF(i), θ_i is its local value (e.g. if HFS(1) is the exploitation depth then, according to MRG, $Q(1,\theta_1)=0$ if $\theta_1<400$m, $Q(1,\theta_1)=1$ if $400<\theta_1<700$m and , $Q(1,\theta_1)=2$ if $\theta_1>700$m). We do not discuss here the physical basis of CMRHE or the choice of HSFs, accepting them as presented in the CMRHE and the MRG Instruction. Instead, we convert the "expert" scoring into formal, quantitative method of information expressing and processing as the probabilities of events what, among others, allows for optimization.

Longer (English) description of CMRHE can be found in (Kornowski, Kurzeja 2012) and the full description (in Polish) can be found in the Instruction of the CMRHE (Baranski et al 2007), from now on called the CMRHE Instruction, where individual chapters are devoted to particular methods, eq. ch. 2 makes the MRG Instructions.

Unfortunately, CMRHE Instruction does not quantitatively define the rockburst hazard, nor do it Instructions of particular methods. As a result, we try to evaluate/classify/predict quantities that are not well defined and we cannot be sure that particular scores are commensurate and allow logically justified combinations (to generate the final score of state of hazard). This makes an uncomfortable situation: CMRHE is based on many tens of experience and is – in Polish coal-mining industry – commonly applied with some success, so that it cannot be disregarded, but its logical basis and correctness is unclear.

The goal this paper is to describe the proposed logical foundations of the method and to demonstrate that this leads to Quantitative Version of the CMRHE (abbreviated IWMK), where all the (partial and final) quantities and scores have clear probabilistic interpretation and can (and should) be operated exclusively according to probability rules.

The IWMK has been previously described in Kornowski 2010 (in Polish) and in Kornowski, Kurzeja 2012 (in English) and it is time to say more about its possible applications.

As we are interested here in mining-induced seismicity, terms "seismic emission", means "(process of) emission of mining-induced seismic events", unless it is stated otherwise.

2. Basic notions and definitions

Generally accepted risk definition is usually expressed as the product of unfortunate event's probability (P) and economic loss when it happens: (see e.g. Falanesca et. al. 2010; De Groot 1970)

$$\left\{ \textbf{risk} \right\} = \left\{ \begin{array}{c}\textbf{probability}\\ \textbf{of}\\ \textbf{event}\end{array} \right\} \bullet \left\{ \begin{array}{c}\textbf{economic}\\ \textbf{loss due to}\\ \textbf{its occurence}\end{array} \right\} \tag{2.1}$$

(this definition becomes shightly more complicated and includes integration if, instead of probability, one uses its density). To avoid unconclusive and unpopular discussion of costs of human life or disaster, we just omit the second factor (i.e. loss) of (2.1) and – to avoid terminological confusion – we apply the (known and popular) name hazard (*Z*). So, in this paper

$$\left\{ \textbf{hazard} \right\} = \left\{ \begin{matrix} \textbf{probability} \\ \textbf{of} \\ \textbf{event} \end{matrix} \right\} \qquad (2.2)$$

This definition is well and long known e.g. in seismology (e.g. Gibowicz, Kijko 1994, p.301), but the notion of probability seems to be unpopular among industrial users, so its should be stressed that equation (2.2) is to be taken seriously: every formula expressed in terms of probability *P* (for mathematically inclined readers) can also be expressed in terms of hazard *Z* (for industrial users) and vice-versa, simply substituting Z↔P. In this paper both notations are applied.

According to industrial practice, we discriminate tremor (local seismic event, registered by the local seismic network) and rockburst (the tremor with disastrous effects). As stressed by Dubinski (1994), there is no rockburst without a tremor but, very fortunately, only a small fraction of tremors cause rockbursts.

Now we can define hazards we are interested in. The three definitions (D1, D2, D3) listed below should be interpreted together with the Fig. 2.1, illustrating connections among the hazards (or probabilities)

D1 Seismic hazard, Z^S – or $(Z^S)^{12}_{\Delta t}$ or Z^S $[(t,t+\Delta t),(E1,E2),R]$ with *R* being the space segment (e.g. longwall), (*E1,E2*) energy interval, Δt the so called prediction horizon – is the probability of seismic event inside the limits of $[(t,t+\Delta t),(E1,E2),R]$.

Upper index "*S*", in Z^S, means "seismic". Allowing $E2\rightarrow\infty$, we write $(Z^S)^{1}_{\Delta t}$. It should be noted that "time, space and energy" of event is chosen beforehand by the user as "the space of his interests". We do believe that industrial prediction user is always able to approximately define the limits of his interest. From the definition D1

$$Z^S \equiv P(E1 \le E \le E2) \qquad (2.3)$$

Given the archive of seismic events from the observed region *R* and assuming stationary-Poisson emission process (what is observationally confirmed for energies above $1\cdot 10^2$J, (Kornowski, Kurzeja 2008) and (Lasocki 1990) for "strong mining events"), probability (2.2) can be easily estimated as shown in ch. 4. From definition

$$0 \le Z^S \le 1 \qquad (2.4)$$

and "the space of possible hazards" (i.e. interval 0 – 1) can always be divided into segments (e.g. a, b, c, d), called "states of seismic hazard", to simplify decision – making process. Now we can define

D2 Seismic rockburst hazard, Z^{ST} – or $(Z^{ST})^{12}_{\Delta t}$ or Z^{ST} [$(t,t+\Delta t),(E1,E2),R,\theta_E$] where θ_E is the parameters vector – is the probability of rockburst due to seismic event inside the limits [$(t,t+\Delta t),(E1,E2),R$], given the parameter(s) θ_E.

The name "Seismic rockburst hazard" has been coined to stress that mining and geological "hazard shaping factors" (described in the MRG Instruction, Baranski et al 2007 ch. 2) are not taken into account. Only the probability of the tremor ($E1<E<E2$) and probability that the tremor of energy E results in rockburst – decide on Z^{ST}. Z^{ST} is not an another real hazard: it is only convenient partial result (see Fig. 2.1) in estimation procedure (because $Z^T = Z^{ST} \cdot Z^{MRG}$).

According to probability rules and as shown in Fig. 2.1

for discrete energy E^*: $$Z^{ST} = P(E^*) \cdot P(T|E^*) \tag{2.5a}$$

for energy density $p(E)$: $$Z^{ST} = \int_{E1}^{E2} p(E) \cdot P(T|E) dE \tag{2.5b}$$

Conditional probability $P(T|E)$ is a mathematical phrase. In engineering terminology it is called "rockburst-energy characteristics" analogously to "amplitude-frequency characteristics" (known in oscillation measurements) and can be simply denoted $F(\theta_E)$. With a given E^* value, $P(T|E^*) \equiv F(\theta_E|E^*) \equiv F(\theta_E^*)$ becomes a scalar, multiplicatively „amplifying" (despite that $0 \leq F(\theta_E) \leq 1$) the probability of rockburst.

This characteristics can be approximated with logistic curve of parameters (θ_E) estimated from the catalogue of tremors and rockbursts. The procedure of θ_E estimation from data is called calibration of characteristics and is discussed in ch. 3. One more definition is needed:

D3 Rockburst hazard, Z^T – or $(Z^T)^{12}_{\Delta t}$ or Z^T [$(t,t+\Delta t),(E1,E2),R,SCN$] where SCN is a general scenario, including $P(T|E)$ and all the others locally active „hazard shaping factors", enumerated in the MRG Instruction – is the probability of rockburst inside the limits [$(t,t+\Delta t),(E1,E2),R$], given the full, quantitative description of SCN.

It should be repeated that the "time, place and energy" are specified beforehand and only the value of probability is predicted. This construction of definition makes it operational: given the data, scalar Z^T value can be calculated. Again, the interval (0 – 1) can be divided into segments (e.q. $0\text{-}10^{-5}\text{-}10^{-4}\text{-}10^{-3}\text{-}1$) called states of rockburst hazard (e.g. A, B, C, D) which are communicated to users.

According to probability rules – and as shown in Fig. 2.1

$$Z^T = Z^{ST} \cdot Z^{MRG} \tag{2.6a}$$

$$Z^{MRG} = F(\theta_1) \cdot F(\theta_2) \cdot \ldots \cdot F(\theta_M) \tag{2.6b}$$

or, equivalently $$P(T) = P(E) \cdot P(T|E) \cdot P(T|\theta_1) \cdot \ldots \cdot P(T|\theta_M) \tag{2.6c}$$

With terminology of probability:

$$\underline{P(T)} = \underline{P(E1 \le E \le E2)} \cdot \underline{P(T \mid E1 \le E \le E2)} \cdot \underline{\{F_1(\Theta_1^*) \cdot \ldots \cdot F_M(\Theta_M^*)\}}$$

$$\left\{\begin{matrix}\text{rockburst}\\ \text{probability}\end{matrix}\right\} = \left\{\begin{matrix}\text{tremor}\\ \text{probability}\end{matrix}\right\} \bullet \left\{\begin{matrix}\text{probability that}\\ \text{the tremor}\\ \text{causes rockburst}\end{matrix}\right\} \bullet \left\{\begin{matrix}\text{marginal probs.}\\ \text{of hazard amplification}\\ \text{due to (local) HSF's}\end{matrix}\right\}$$

Information source: (geophysics) (statistics) (mining and geology)

With „hazard terminology"

$$Z^T = Z^S \bullet P(T \mid E1 \le E \le E2) \bullet Z^{MRG}$$

$$\left\{\begin{matrix}\text{rockburst}\\ \text{hazard}\end{matrix}\right\} = \left\{\begin{matrix}\text{seismic}\\ \text{hazard}\end{matrix}\right\} \bullet \left\{\begin{matrix}\text{rockburst}\\ \text{hazard conditional}\\ \text{on tremor}\end{matrix}\right\} \bullet \left\{\begin{matrix}\text{"potential"}\\ \text{rockburst hazard}\\ \text{due to HSF's}\end{matrix}\right\}$$

Or equivalently:

$$Z^T = Z^{ST} \bullet Z^{MRG}$$

$$\left\{\begin{matrix}\text{rockburst}\\ \text{hazard}\end{matrix}\right\} = \left\{\begin{matrix}\text{rockburst hazard}\\ \text{resulting from}\\ \text{tremor only}\end{matrix}\right\} \bullet \left\{\begin{matrix}\text{"potential"}\\ \text{rockburst hazard}\\ \text{due to HSF's}\end{matrix}\right\}$$

Fig. 2.1. Basic decomposition forms of rockburst hazard estimator, Z^T. HSF – hazard shaping factor.
Rys. 2.1. Podstawowe formy dekompozycji estymatora zagrożenia tąpnięciem Z^T. HSF – czynnik kształtujący zagrożenie

3. Factorial characteristics, or conditional probabilities of rockburst

According to (2.6c), rockburst probability $P(T)$, – called also the rockburst hazard (Z^T) – is the product of $P(E)$ – or seismic hazard – and a series of factors $P(T|E), P(T|\theta_1), \ldots, P(T|\theta_M)$ which, except of the first one, are collectively called, "hazard shaping factors" (HSFs) in the MRG Instruction.

Estimating relation $P(T|\theta_i)$ between the hazard amplification and the HSF(*i*) – with its independent variable θ_i – can be generally seen as a complicated inverse problem (Tarantola 1987; Marcak 2009) where the data are sparse (yearly a few rockbursts in the Polish mining industry) and results are very sensitive to observations inaccuracies.

The problem becomes simpler taking into account that the characteristics $P(T|\theta_i)$ for any "*i*" must – from definition – have two asymptotes and that – if HSFs are approximately independent – the probabilities can be simply multiplied and $P(T|\theta_i)$ interpreted as "factorial characteristics" with values generalizing the "points" of MRG Instruction. This is the way of IWMK developing.

HSFs may be interpreted (Kornowski, Kurzeja 2012) both as conditional (and marginal) probabilities of rockburst given θ_i or as characteristics $F(\theta_i)$, expressing amplification of rockburst probability as a function of θ_i. For example, in the MRG Instruction, HFS(1) is the local depth (H, [m]) of exploitation. Then $F(\theta_1)= F(H)$ is a function expressing the dependence of $P(T)$ on the exploitation depth only, provided a tremor has occurred. Any factorial characteristics $F(\theta_i)$, can be also interpreted as probability: $F(\theta_i) \equiv P(T|\theta_i)$, and as a result, it can be very conveniently approximated with a logistic function, (e.g.):

$$F(H) = \{1 + \exp[-\alpha_H (H - \beta_H)]\}^{-1} \tag{3.1}$$

with parameters α_H, β_H (or $\alpha_{\theta i}$, $\beta_{\theta i}$ generally) estimated from local catalogue of tremors and rockbursts in various depth intervals. Process of parameters estimation is called the calibration (of factorial characteristics). Given local information in the form of events catalogue, one can find optimally calibrated factorial characteristics and, for a given value of θ_i^*, optimal factorial amplification coefficient, $F(\theta_i^*)$, which multiplicatively modifies probability of rockburst. We believe that optimal values of $F(\theta_i^*)$ - for any i-th HSF(i) and its local value θ_i – can and should be used in practice (of hazard evaluation), instead of "points" mentioned earlier (with the exception of the case of equation (3.3b) mentioned later). By the way it can be noted, that logarithm of (2.6a,b) – or (2.6a,c) – results in the sum of scalar values which may be rounded (each one to the nearest integer) and called the "optimal points", stressing the simple connection between the original MK and our IWMK, but we do not recommend any such operation. There is no reason to round the optimal values of amplification coefficients $F(\theta_i)$: they can be used as they are, simply inserted into (2.6b) or (2.6c).

To illustrate the calibration procedure, below we show the short table (3.1) (see Kornowski, Kurzeja 2008) of tremors, rockbursts and "observed" probabilities (i.e. proportions) of rockburst in Polish coal mines during the period 1997 – 2006, in various energy intervals.

Table 3.1. Tremors, rockbursts and "observed" probabilities $P(T|E)$ of rockburst in Polish coal mines in various energy intervals

Tabela 3.1. Statystyka wstrząsów i tąpań w polskim górnictwie węgla kamiennego dla wstrząsów w kolejnych przedziałach energii

	Energy interval, [J]			
	$1\cdot10^5$-$1\cdot10^6$	$1\cdot10^6$-$1\cdot10^7$	$1\cdot10^7$-$1\cdot10^8$	$1\cdot10^8$-$1\cdot10^9$
Number of tremors, N^W	9255	1555	158	6
Number of rockbursts, N^T	9	14	11	2
Observed proportion	0,000972	0,009003	0,069620	0.3333

Well-known logit transformation changes the fitting problem into a linear one and allows for approximate but simple fitting of the logistic function to the data. From this we obtain

$$P(T|E) = \frac{1}{1+\exp[-2.1(\log E - 9)]} \tag{3.2}$$

as a semioptimal rockburst-energy characteristics or conditional (marginal) probability of rockburst if the tremor of energy E has occurred, no matter what the other geological or mining conditions are.

Analogous table and procedure has been applied to the observed probabilities of rockburst, expressed as the function of exploitation depth, resulting in semioptimal rockburst – depth characteristics (for a few coal-mines of KHW S.A. Holding)

$$P(T|H) = \frac{1}{1+\exp[-0{,}0128(H - 1128)]} \tag{3.3a}$$

The same method can be applied to any HSF from MRG Instruction, resulting in semioptimal local factorial characteristics, which – for any local value of θ_i^* – becomes scalar and can be inserted into (2.6a,b) to allow semioptimal hazard evaluation. When there is not enough data to calibrate the HSF(i) characteristics, the points $Q(i,\theta_i)$ from the MRG Instruction can be applied in the form

$$0 \le P(T|Q(i,\theta_i)) = \frac{1}{1+\exp[-Q(i,\theta_i)]} \le 1 \tag{3.3b}$$

which is not optimal (and can be far from optimal) but can be interpreted as roughly approximated probability of $P(T|\theta_i)$ and applied in (2.6b,c) formulas. Now, to evaluate Z^T, we need an estimate of Z^S.

4. Seismic hazard estimation and Z^{ST}

Assuming the well-known Pareto (or, in logarithmic form, the Gutenberg – Richter) law of energy – frequency distribution (Utsu 1999; Lasocki 1990) and uncorrelated, Poissonian tremors' sequence ([1]), (Lasocki 1990; Kornowski, Kurzeja 2008), the expected value of the seismic hazard $(Z^S)_{\Delta t}^{12}$, see D1, can be estimated according to formula (Lasocki 1990)

$$(Z^S)_{\Delta t}^{12} = 1 - \exp[-\lambda \cdot \Delta t \cdot (E_\bullet)^{-B}] \tag{4.1}$$

where $(Z^S)_{\Delta t}^{12}$ is the probability of seismic event inside the predefined limits: ($E1$,$E2$), (t, t+Δt), where $E_\bullet = E / E\_$ is the normalized energy, B is the (so-called) G-R parameter and the emission intensity, denoted λ, is the mean number of events (E>$E\_$) per time unit.

[1] These assumptions constitute the Pareto – Poissonian Model (MPP) of events sequences

It should be noted that values of $(E1,E2)$ and Δt are predetermined by the user but values of λ and B are estimated from the information base (i.e. archive of local events $E>E\_$).

Taking the derivative of (4.1) as the hazard probability density and "weighting" it with the conditional probability $P(T|E)$ of rockburst (3.2), see (2.5b), it can be obtained, according to known "total probability" theorem,

$$0 \le (Z^{ST})_{\Delta t}^{12} = \lambda \cdot \Delta t \cdot B \cdot \int_{E1\bullet}^{E2\bullet} \frac{(E_\bullet)^{-(B+1)} \exp[-\lambda \cdot \Delta t \cdot (E_\bullet)^{-B}]dE}{1+\exp[-\alpha_E(\log E_\bullet - \beta_\bullet)]} \le 1 \tag{4.2}$$

the estimator of the rockburst hazard in stationary MPP, abbreviated Z^{ST} and called "the seismic rockburst hazard", see D2. It estimates the rockburst hazard (or its upper limit) neglecting any local information possibly present in HSFs. The integral in (4.2) should be calculated numerically in finite interval $(E1_\bullet, E2_\bullet)$. As the values of λ and B are estimated from observations, the Z^{ST} value is always uncertain and should be treated as the mean value of random variable.

5. Rockburst hazard estimation

Rockburst hazard $(Z^T)_{\Delta t}^{12}$ estimator of IWMK – specifying the rockburst probability (i.e. $P(T) \equiv Z^T$) inside the predefined limits $[(E1,E2), (t, t+\Delta t)]$ assuming the MPP and the local scenario SCN ([2]) – can be written as (2.6a,b) with Z^{ST} specified in (4.2):

$$0 \le (Z^T)_{\Delta t}^{12} = \{F(\theta_1) \cdot F(\theta_2) \cdot \ldots \cdot F(\theta_M)\} \cdot \lambda \cdot \Delta t \cdot B \cdot \int_{E1\bullet}^{E2\bullet} \frac{(E_\bullet)^{-(B+1)} \exp[-\lambda \cdot \Delta t \cdot (E_\bullet)^{-B}]dE_\bullet}{1+\exp[-\alpha_E(\log E_\bullet - \beta_\bullet)]} \le 1 \tag{5.1}$$

As it has been argued, all the elements of this estimator can be (approximately) evaluated and the resulting hazard estimate, Z^T, can be interpreted as the (uncertain) estimate of the mean probability of rockburst, given $[(E1,E2), (t, t+\Delta t)$, SCN]. It should be stressed that the density distribution of Z^T interpreted as random variable, is neither normal nor symmetric and its standard uncertainty (defined as the distance between of order 0,84 and 0,5) strongly depends both on quality and on the size of our data archives, but this subject is beyond the scope of this paper.

To illustrate the simplicity of (5.1) application to real rockburst hazard estimation, let assume that

● in a coal mine of KHW S.A., $(Z^T)_{\Delta t}^{12}$ is to be estimated for Δt=2 days and energy limits $E1=5\cdot10^5$J, $E2=5\cdot10^7$J, for scenario SCN{θ_1=600 m; θ_2: in the seam, rockburst has been previously observed so $Q(2,\theta_2)=0$ according to MRG; seam thickness θ_8=3,1 m, so that $Q(8,\theta_8)=1$; no other HSF active}. From the data base it has been estimated: $E_=1\cdot10^4$J (so

[2] Scenario SCN is quantitatively defined if locally active HSFs are known and their parameters have been estimated. In the worst case (of lacking the date), equation (3.3b) can be applied but then the estimation result is not optimal.

$E1_\bullet$=50, $E2_\bullet$=5000, $\beta_\bullet$=5), B=0,85 and λ=2,2 (events E>E_ daily). This is an actual but simplified example. ●

Estimation:
With equation (3.3a,b) it can be, for given SCN, calculated

$$P(T|\theta_1^*) = \{1+\exp[-0{,}0128(H-1128)]\}^{-1} = 0{,}00116$$

$$P(T|Q(2,\theta_2)) = [1+\exp(0)]^{-1} = 0{,}5$$

$$P(T|Q(8,\theta_8)) = [1+\exp(-1)]^{-1} = 0{,}73106$$

and with (4.2), for Δt=2, $E1_\bullet$=50, $E2_\bullet$=5000, B=0,85) we calculate

$$(Z^{ST})_{\Delta t}^{12} = 2{,}2\cdot 2\cdot 0{,}85\cdot \int_{50}^{5000} \frac{(E_\bullet)^{-1{,}85}\exp[-2{,}2\cdot 2\cdot E_\bullet^{-0{,}85}]dE_\bullet}{1+\exp[-2{,}1(\log E_\bullet - 5)]} = 0{,}0006639$$

and finally

$$(Z^T)_{\Delta t,SCN}^{12} = 0{,}00116\cdot 0{,}5\cdot 0{,}73106\cdot 0{,}0006639 \approx 2{,}815\cdot 10^{-7}$$

This values is the (uncertain) estimate of the mean value of Z^T at the specified conditions. Whatever the division of “hazard space” (i.e. 0-1 segment of real numbers) into states (*a, b, c, d*), this is a very small probability of rockburst (during the nearest 2 days) and enlarging of the upper energy limit does not change it strongly (e.g. changing energy $E2$ from $5\cdot 10^7$J to $5\cdot 10^8$J changes Z^T from $2{,}815\cdot 10^{-7}$ to $4{,}323\cdot 10^{-7}$).

6. Conclusion

a) Approximate rockburst hazard estimator/predictor called “IWMK estimator” – based on (known and commonly applied in the Polish mining industry) the Comprehensive Method of Rockburst Hazard Evaluation, CMRHE – has been formulated in the form of equation (5.1). Its components are easy to calculate (given sufficient data base) and have simple physical interpretation.
b) Factors of Z^{MRG} can be interpreted as factorial characteristics of so-called Hazard Shaping Factors’ and expressed in parametric forms with parameters optimized to fit the observations. In this way the whole estimator (5.1) can be approximately but easily optimized, rising our hope for better rockburst probability prediction.
c) All the elements of estimator (5.1) can be interpreted as probabilities, so the rules of operation are defined by probability theory. From theoretical point of view this the most important result of our work.
d) There is a simple connection between the CMRHE and our IWMK.
e) The IWMK can be generalized taking into account other sources of information simply inserting other Hazard Shaping Factors or deleting useless ones.
f) Quality of results (in practice) depends not only on size and quality of data archives, but also on physical correctness of the very CMRHE, which is the basis of IWMK.

References

[1] Barański A., Drzewiecki J., Kabiesz J., Konopko W., Kornowski J., Krzyżowski A., Mutke G. 2007: Zasady stosowania metody kompleksowej i metod szczegółowych oceny stanu zagrożenia tąpaniami w kopalniach węgla kamiennego. Seria Instrukcje nr 20. GIG, Katowice.

[2] De Groot M.H. 1970: Optimal statistical decisions. McGraw-Hill.

[3] Dubiński J. 1994: Związki przyczynowe wstrząsów i tąpań. Przegląd Górniczy, Vol. 2, Katowice, 6-10.

[4] Falanesca M., Borio L., Picchio A., Peila D. 2010: QuaRRi: a new methodology for rock-fall risk analysis and management in quarry exploitation. Gospodarka Surowcami Mineralnymi, Vol. 26(4), 149-161.

[5] Kornowski J. 2010: Formalna metoda łącznej oceny zagrożenia tąpnięciem na podstawie informacji geofizycznej i Metody Rozeznania Górniczego, Górnictwo I Środowisko, Nr 2/2010, GIG, Katowice, 47-62.

[6] Kornowski J., Kurzeja J. 2008: Krótkookresowa prognoza zagrożenia sejsmicznego w górnictwie, GIG, Katowice.

[7] Kornowski J, Kurzeja J. 2012: Prediction of Rockburst Probability Given Seismic Energy and Factors Defined by the Expert Method of Hazard Evaluation (MRG). Acta Geophysica, vol. 60, no. 2, 472-486.

[8] Lasocki S. 1990: Prediction of strong mining tremors, Z.N. AGH Geofizyka Stosowana, 7, 1-110 (in Polish with English abstract).

[9] Marcak H. 2009: Inverse problems in modeling mining shocks. Gospodarka Surowcami Mineralnymi Vol. 25(3), 217-225.

[10] Tarantola A. 1987: Inverse problem theory. Elsevier, Amsterdam.

[11] Utsu T. 1999: Representation and Analysis of the Earthquake Size Distribution: A Historical Review and Some New Approaches. Pure Appl. Geophys., V. 158, 1655-1675.

Podstawowe założenia ilościowej wersji Kompleksowej Metody Oceny Stanu Zagrożenia Tąpaniami

Słowa kluczowe:
Tąpania, zagrożenie tąpaniami, sejsmologia górnicza

Streszczenie
W artykule opisano podstawy i wyniki stosowania nowej, ilościowej wersji znanej w polskim górnictwie Kompleksowej Metody Oceny Stanu Zagrożenia Tąpaniami (ang.: CMRHE). W skład Metody Kompleksowej (MK) wchodzą cztery tzw. „metody szczegółowe”: sejsmologii górniczej, sejsmoakustyki, wierceń małośrednicowych i „ekspercka” metoda rozeznania górniczego. Mimo swej popularności, MK nie jest dobrze zdefiniowana w sensie matematycznym: ani sama MK ani żadna z metod szczegółowych nie definiują ilościowo przedmiotu swego zainteresowania, tzn. zagrożenia tąpaniami, wskutek czego usiłują one ocenić lub prognozować niezdefiniowaną wielkość. Nie ma też pewności, że każda z metod bada tą samą wielkość fizyczną i nie jest oczywiste w jaki sposób poprawnie łączyć wyniki metod szczegółowych by otrzymać poszukiwane wynikowe zagrożenie. Opisana tu wersja ilościowa MK, od samego początku definiuje zagrożenie tąpnięciem jak również wszystkie jego składniki jako prawdopodobieństwa, na których wszelkie przekształcenia mogą być dokonywane zgodnie z zasadami rachunku prawdopodobieństwa. W artykule zademonstrowano, iż wszystkie informacje o czynnikach kształtujących zagrożenie, które wykorzystywane są w oryginalnej Metodzie Kompleksowej, mogą być przedstawione w formie rozkładów prawdopodobieństwa – zawsze zależnych od właściwej zmiennej objaśniającej – a dla konkretnej, lokalnej wartości tej zmiennej, każdy rozkład daje skalarną wartość prawdopodobieństwa. Iloczyn tych rozkładów prawdopodobieństwa jest estymatorem zagrożenia tąpnięciem i jest oparty na dokładnie tej samej informacji co oryginalna ocena

z MK. Można zauważyć, że logarytm iloczynu prawdopodobieństw daje sumę składników, analogiczną, lecz nie identyczną względem sumy „punktów" w oryginalnej MK, co podkreśla bezpośredni związek opisanej tu ilościowej wersji z oryginalną MK. W końcowej części artykułu przedstawiono przykład oceny zagrożenia tąpnięciem, ilustrując prostotę metody.

Przekazano: 30 marca 2012 r.