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RELATIONSHIP BETWEEN ROCK MASS DEFORMATION AND ENERGY RELEASE OF INTERDEPENDENT MINING TREMORS IN THE AREA OF BYTOM BASIN

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ABSTRACT. The paper presents selected results of studies carried out in 1994 linking the level of induced seismicity with the condition of rockmass in view of deformation and energy, with the rock mass having been formerly subjected to mining which induced the discussed tremors. The studies comprised a group of tremors which have been recorded over last few years in the area of Bytom Coal Basin – an area posing the greatest seismic hazards. For the analysis of tremor interdependence, the method of event clustering was applied [Wanat 1994] dividing them into clusters in accordance to probable reasons for their occurrence. It was suggested that the analytical model used so far should be applied for all resistant rock layers influenced by mining induced deformation. A strict conformity was found between observed and calculated contour maps of seismic event energy release.

1. INTRODUCTION – SUBJECT AND SCOPE OF THE STUDIES

Basic assumptions and study results carried out by J.Białek, D.Drzęzla and A.Jaworski in the proceeding years on the prediction of seismicity induced by multi-bed mining using analytical method were presented in publications [Białek, Jaworski 1989; Białek et al. 1992; Białek et al.]. The aim of those works, as well as the results of author's recent studies presented here is to determine the interdependence between time variable components of rockmass strain tensor and the amount of released tremor energy and the number of tremors.

The works provide the dependencies for calculating the increase of deformation energy by means of which, after specifying the parameters, it is possible to predict the distributions of energy density and the number of tremors along the length of discussed wall fields and in their vicinity.

Having the matrix M of independent variables in each point of the calculation network (calculated with the values of deformation indexes) and the observation vector E (calculated with the values of seismic energy density released through already recorded tremors) the multiple regression coefficients A_i described with a relevant equation are determined using the least squares method.

In the presented approach we try to integrate two problems usually treated separately, that is, seismic activity described with the methods of mining geophysics and deformation around mining workings described with the methods of mining geomechanics.

In the experiments carried out so far, it was assumed that the majority of discussed, recorded tremors had their focal points in a selected, strong rock layer deformed by mining. It is difficult to verify the suggested assumption since there is no reliable data concerning the height coordinate (z) of the focal points of recorded tremors. Furthermore, the above assumption cannot be in any way accepted in numerous situations when there are many strong rock layers within the area subjected to mining influence in question (including deformative influence). Such a situation is characteristic for mining carried out in the area of Bytom Basin, an area posing great seismic hazards, where, between saddle series and also above and below these series, there are strong rock layers including sandstone. In the presented studies, which comprised the areas of intensive seismic activity observed in 7 coal mines of Bytom Basin, the author suggested modifying the analytical model used so far, extending it onto all resistant rock layers subjected to deformative influence of mining. The extension of the model onto m rock layers, with relevantly high numerical efficiency maintained, enables to obtain a considerably better correlation between predicted values E_{φ} and observed ones E_w of seismic energy density and number of recorded tremors. The above can be illustrated by exemplary results of studies carried out on mining induced seismicity in the neighbouring areas of coal mines Bobrek and Miechowice, within the period 1990 – 1994. The Basin area mentioned above was subjected to analysis within the period (90.10.01 – 94.10.01), and also at present it poses greatest tremor (Fig. 1) and cramp hazards. Mining in this region is carried out in extremely changeable mining conditions determined by the influence of complex situation which occurred as a result of mining at the seams 400 and 500.

For over 24 thousand tremors of energy magnitude from 10^2 J to 10^6 J and of total energy release 2×10^8 J, recorded in 7 coal mines of the Basin (Fig. 1), over 3.5 thousand tremors occurred in the analyzed area of coal mines Bobrek and Miechowice (Fig. 2), which constitutes about 50 % (9.5×10^7 J) of total energy release. And the energy release of the strongest tremors (10^5, 10^6 J) recorded in the area of coal mines Bobrek and Miechowice constituted as much as 70 % (3.5×10^7 J) of energy release of all tremors pertaining to this group recorded in the Basin area. In spite of the fact that seismic energy of tremors recorded in the area of coal mines Bobrek and Miechowice within the analyzed period did not exceed 10^6 J, there were as many as 11 cramps recorded during mining works at seams 509 and 510.

The above tremors (low–energy mode), which are responsible for a number of cramps, may be understood as a result of seismicity directly generated by the past and/or ongoing mining, and hence, they can constitute a platform for experiments on the interdependence of induced seismicity level with the parameters describing deformation of rockmass. It has been indicated by many experiments. While analyzing the repeatability of stronger seismic events, a number of authors, [Drzęźla et al. 1985; Kijko et al. 1986], indicated that, in some cases, mining induced tremors may have multimodal distribution.

These works, as well as the studies carried out by [Gibowicz 1989; Lasocki 1990; Zuberek 1992; Idziak et al. 1991], made it possible to sort out two tremor categories

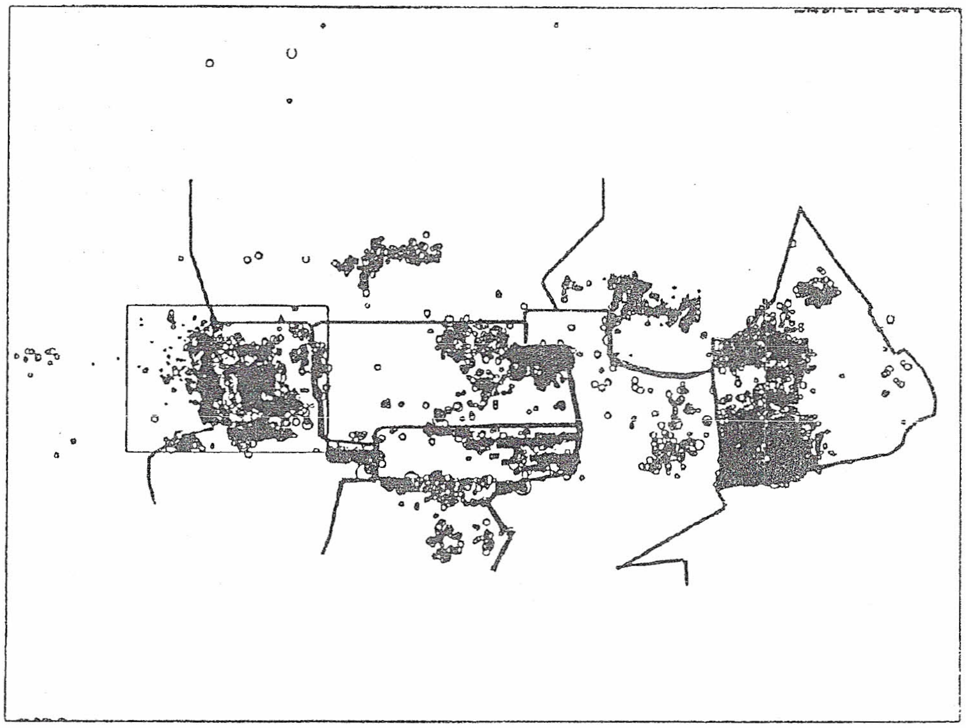

FIG. 1. Distribution of tremor focal points recorded in the area of Bytom Basin within the period 90.10.01 – 94.10.01

from among of all recorded mining tremors, that is very numerous weak tremors and scanty strong tremors. Weak low–energy tremors, of seismic energy, [Gibowicz 1989], lower than 1×10^7 J (magnitude below 3) are induced in the vicinity of mining workings, and their focal points move together with the advance of mining. This low–energy mode may be interpreted as the result of seismicity directly generated by mining. Seismic activity with respect to this low–energy group of tremors depends on the quality of rockmass and on such mining factors as mining advance or the extent of mined–out space; [Marcak 1985; Kijko 1985].

On the other hand, it is difficult to find direct relationship of high–energy tremors (group of strong tremors of seismic energy exceeding as a rule 1×10^7 J) with the parameters of ongoing mining; [Idziak et al. 1991; Zuberek 1993]. It is supposed, that the occurrence of these tremors is connected with tectonic discontinuities, such as major faults, and it may result from the superposition of the mining field stress upon the field of tectonic stress, [Teisseyre 1983], or, they are created, [Ryder 1988], as a result of abrupt slips in fault planes. The discussed groups of mining tremors from the area of coal mines Bobrek and Miechowice, as well as other tremors characteristic of low–energy modes, comprise events whereof mechanism of creation may be different. It may turn out that a considerable part of tremors of this mode may have no relationship with the condition of rockmass affected by deformation in the areas of strong rock strata deposits subjected to the influence of ongoing mining. Hence, it is advisable to find a method allowing an effective segregation of

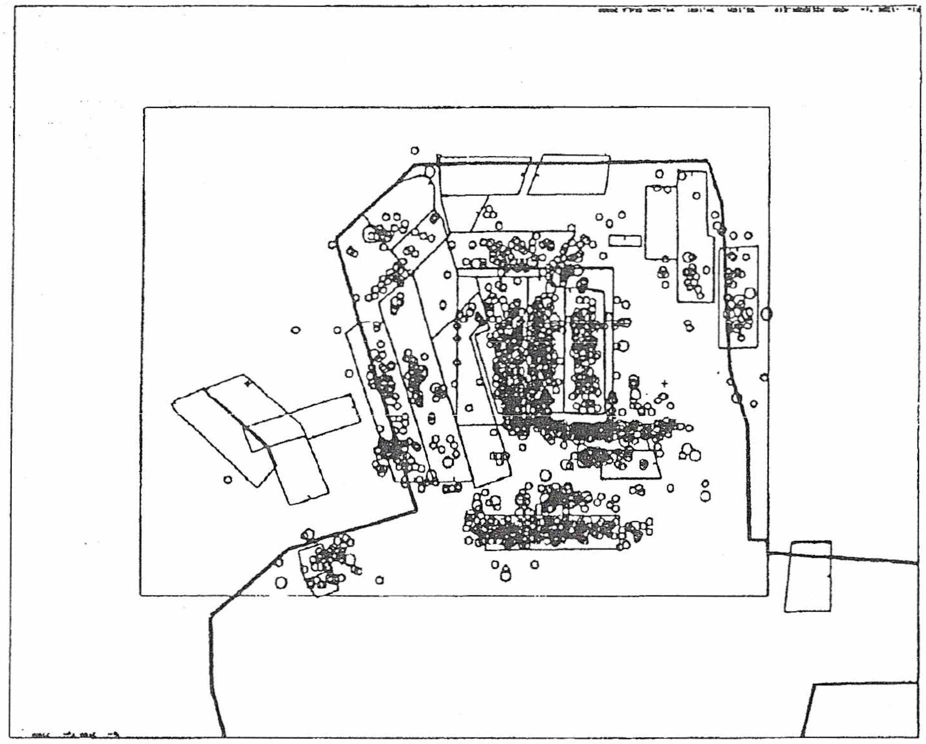

FIG. 2. Distribution of tremor focal points of en. $\geq 1 \times 10^4$ J recorded in the area of walls 7a, 4, 5 – seam 509, coal mine Bobrek, within the period 90.10.01–94.10.01.

the tremors of low–energy modes into groups according to most probable reasons (mechanisms) for their occurrence. The attempt to segregate mining tremors from the analyzed area of coal mines Bobrek and Miechowice was carried out according to the method worked out by [Wanat 1994], who uses the method of event clustering to analyze the interdependence of tremors. As a result, two groups of mining tremors effected by mining process, but caused probably by different mechanisms of rock deformation, were separated. Disregarding the separated group of tremors (group I) viewed as hardly dependent on the extent of rockmass deformation in the areas of strong rock deposits, a better correlation between predicted values and the observed values of seismic energy density has been obtained.

2. An Attempt to Segregate the Tremors from the Area of Coal Mines Bobrek and Miechowice into Groups Characteristic of Particular Mechanisms of Rock Deformation

As it was mentioned above, to analyze the interdependence of tremors from the area of coal mines Bobrek and Miechowice, the method of event clustering was applied. The events were segregated according to the method worked out by [Wanat 1994], into groups characteristic of particular, different mechanisms of rock deformation. In general, speaking about the experiments aiming to determine different, potential methods of seismic energy release in a given area, [Wanat 1994], two basic reasons of rockmass instability resulting in tremors may be distinguished. The first reason has its source in nonlinearity of relations between forces and movements of adjoining rock strata along their borders and along the boundaries of mining workings. Instability of that kind may be called contact and boundary instability. The second reason of rock mass instability can be explained simply by nonlinearity of relationships between displacements u (strains ε) and forces F (stresses δ) i.e. nonlinearity of constitutional equations of rocks. This is a physical instability. A qualitative model of tremor in the case of contact and boundary instability, as well as in the case of physical instability is identical. It can be illustrated by a respective model [Wanat 1994], in which the interactive fragments of rockmass are replaced by springs of different elasticity constants joined in series. Possible occurrence of contact and boundary instability will result in the generation of mining tremors in the vicinity of mine working – group I of mining tremors. The disturbances of stress field, occurring as a result of mining works, will, first of all, result in breaking of interlayer constraints and stratification of rock strata adjoining side walls, roof and working bottom, or they will induce the dislocation of rock blocks in the planes of rock cracks.

Physical instability may occur when there is a weak group of rocks surrounded by rocks of high resistance. It is a basic condition for the occurrence of tremors effected by physical nonlinearity of material – group II of mining tremors. Under appropriate stress condition modified by mining factors, the weakened part of rocks will be destroyed, and the energy of tremor will be determined by the extent of destroyed area, and naturally, by the stress condition of the medium immediately before the tremor. Due to inhomogeneity of rock material, with the occurrence of great master stress, tremors of that kind may be provoked e.g. by low–energy seismic waves coming up to the weakened area (seismic noise, blasting). Energy of such tremors may be of considerable magnitude, and the tremors may occur even far from working face.

The problem of segregation of recorded tremors into groups characteristic of different mechanisms of rock deformation is particularly important in view of typical, separate area of seismic activity, where a number of destruction zones may be generated. Potentially interdependent, or effected by the same cause, the events must be limited in time and space. The selection method of such statistical events consists in their clustering.

While clustering the events, spatial distances and time distances are assumed to be equivalent. In reality, physical, mechanical or biological configurations are not characterized by such properties. While defining particular tremors, relaxation processes should be taken into consideration; as a result of these processes, destroyed fragments of rockmass narrow down in time. In consequence, it leads to a gradual reduction of spatial range of their influence.

A complex of spatial clusters, whereof rays fade when retracting from the present moment to the past, may be a simplest design which will take into account the effect of finite memory of rockmass [Wanat 1994].

Two events belong to the complex of clusters if they occurred between times

T_{initial}, T_{final}, which mark the beginning and the end of cluster complex, and they lie inside one of the intersecting spheres

$$\sqrt{(x_i - x_{ok})^2 + (y_i - y_{ok})^2 + (z_i - z_{ok})^2} \leq R$$

where:

symbols (x_{ok}, y_{ok}, z_{ok}) define the position of spatial cluster centre.
Retreating in time by ΔT, we come across spheres of smaller and smaller rays, we can assume that $R_i/R_i + 1 = \delta$, $\delta < 1$, which means exponential fading of spatial cluster rays.

Parameters δ, $R_{\max}$, which define the rate of fading of spatial clusters and the ray of the greatest cluster, i.e. the cluster corresponding to the present moment, are parameters of the model. Their definite values should be determined basing on the properties of rocks in which the tremors occur.

The times T_{initial}, T_{final} are determined by movement of the complex in the investigated group of events. To define the group, it is necessary to determine the complex velocity vector V, which should be determined basing on physical data describing possible mechanism for the occurrence of searched interdependent events.

Precise determination of the parameters of the complex allows to select accurately the interdependent events from the group of all elementary events. Very inaccurate determination of these parameters will result in the situation where, apart from interdependent events, the complex will comprise purely random events. While investigating mining tremors, due to great inhomogeneity of the medium, it is not possible to determine precisely the parameters of event complex. As a result, the analysis of events, which are only potentially interdependent, is carried out.

For the analysis of tremor interdependence in the area of coal mines Bobrek and Miechowice, clusters of assigned radius $R = 50$ [m] and very weak constant of cluster fading $\delta = 0.99$ were used. The sense of cluster velocity was determined through averaging the velocities of successive tremors inside the cluster, calculated as a ratio of distances of successive events and time between these events. The value of 3 [m/24h] was accepted for the velocity module, which is comparable to the pace of mining advance. 20 clusters were led from each event subjected to analysis, assigning each of them random initial velocity. When the number of seismic events recorded by the cluster was higher than 2, the events were assumed to be interdependent. Hence, the investigated groups of tremors were divided into two described above subgroups of interdependent events – tremor groups I and II. The table below presents data pertaining to the number N and energy release E [J] of the tremors of the groups I and II.

The data presented in tables 1 and 2 show that, in the area of coal mines Bobrek and Miechowice, within the analyzed time period, independently of the size of investigated area, tremors of the group II prevailed (assuming that the selection method is proper) in all energy sections.

Tremors of the group I are characteristic of the presence of upper threshold of energy. Maximum energy of the tremors does not exceed 5.2×10^5 [J] – area of coal

TABLE 1. Separated tremors recorded within the period 90.10.01 – 94.10.01 in the area of coal mines Bobrek and Miechowice.

	N; 10^2–10^3 J	N; 10^4 J	N; 10^5 J	N; 10^6 J	N; 10^2–10^6 J	E; 10^2–10^6 J
gr.I	306	142	7	—	455	7.8×10^6
gr.II	1695	1241	158	3	3097	8.5×10^7
gr.I/gr.II	5.5	8.7	22.5	—	6.8	10.9

TABLE 2. Separated tremors recorded within the period 90.10.01 – 94.10.01 in the area of caving fields of walls 7a, 4 and 5, carried out in seam 509 of coal mine Bobrek.

	N; 10^2–10^3 J	N; 10^4 J	N; 10^5 J	N; 10^6 J	N; 10^2–10^5 J	E; 10^2–10^5 J
gr.I	78	48	6	—	132	3.3×10^6
gr.II	324	479	73	—	976	3.2×10^7
gr.I/gr.II	5.4	9.9	121	—	7.4	9.6

mines Bobrek and Miechowice, and 5.4×10^5 [J] – area of walls 7a,4 and 5 of coal mine Bobrek (Fig. 3).

In order to satisfy the Gutenberg–Richter law [Gibowicz, Kijko 1994] it should be possible for the relationship presented in this way to be approximated with a straight line. In the case of tremors from group II, such a relationship is not satisfied (Fig. 3).

For the areas of coal mines Bobrek and Miechowice, the dependence of the number of tremors from group I on the energy logarithm, calculated with the least square method, is as follows:

$$\mathrm{Log}\,(N) = 2.06 - 0.45[\log(E/E_0)]^2\,; \quad E_0 = 3.87 \times 10^3\,[\mathrm{J}]$$

Analogous relation for the area of walls 7a,4 and 5 of coal mine Bobrek (Fig. 3) is as follows:

$$\mathrm{Log}\,(N) = 1.43 - 0.33[\log(E/E_0)]^2\,; \quad E_0 = 4.04 \times 10^3\,[\mathrm{J}]$$

Maximum energy of tremors from group II does not exceed 4.9×10^6 [J] – area of coal mines Bobrek and Miechowice, and 8.1×10^6 [J] – area of walls 7, 4 and 5 (Fig. 3). Stronger tremors from group II with a certain approximation satisfy the Gutenberg–Richter law, yet, for the area of coal mines Bobrek and Miechowice the relationship has the following form:

$$\mathrm{Log}\,(N) = 6.99 - 1.04\,\log(E)$$

and for the area of walls 7a, 4 and 5 (Fig. 4) it has the form

$$\mathrm{Log}\,(N) = 6.45 - 0.93\,\log(E)\,.$$

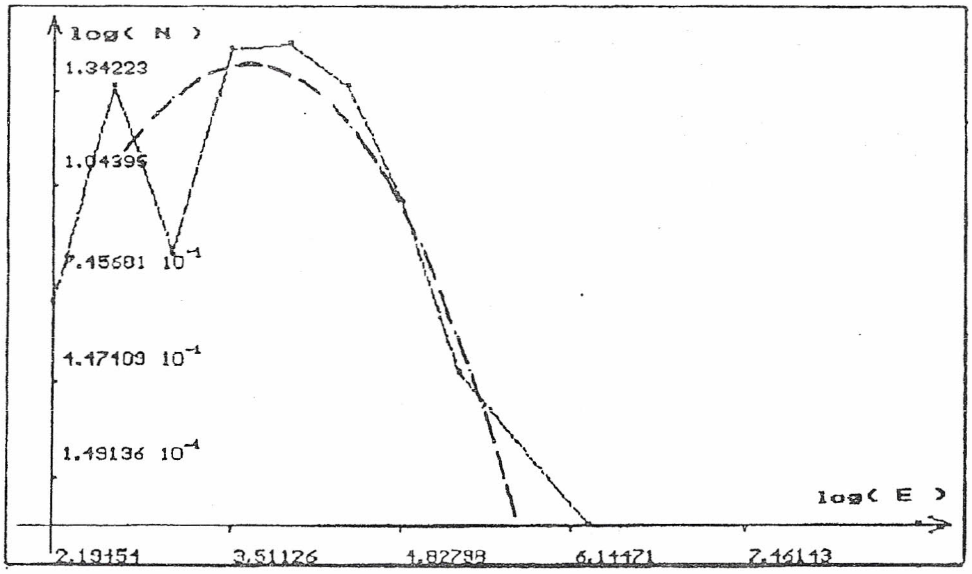

FIG. 3. Dependency of the logarithm of number of mining tremors from group I on the energy logarithm, for the area of walls 7a, 4 and 5 of coal mine Bobrek.

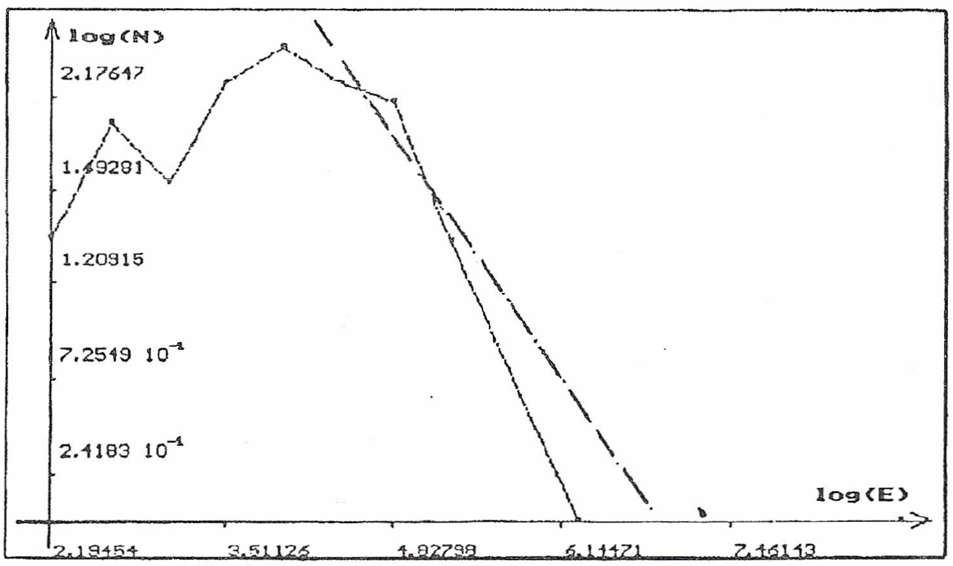

FIG. 4. Dependency of the logarithm of the number of mining tremors from group II on the energy logarithm, for the area of walls 7a, 4 and 5 of coal mine Bobrek.

Mining induced tremors from group II (occurring as a result of physical instability of the medium) of energy values determined by the size of destroyed area, as opposed to tremors from group I induced in the immediate vicinity of workings, may be strongly, indirectly related to the analytically calculated indexes of rock mass deformation in the areas where strong rock layers are deposited.

3. STATE OF DEFORMATION OF STRONG ROCK LAYERS IN VIEW OF ENERGY RELEASE OF MINING INDUCED TREMORS

In great rockmass areas, the changing–in–time influence of multi–bed mining is in practice possible to define effectively through space–time distributions of rockmass deformation indexes [Bialek, Jaworski 1989; Bialek et al. 1992]. Taking into account the fact that rock deformation within the area subjected to mining influence is one of main reasons for the occurrence of mining tremors, and accepting that it has been proved by documentary evidence – [Mc Gaar, Green 1975; Wanior 1982; Kijko 1985] – we can try to find function relationship between the deformation process of rockmass in time and the level of seismic activity.

The prediction method for the distribution of seismic energy density [J/m^2, J/m^3] in bed plane or in a definite rock layer was presented in works [Bialek, Jaworski 1989; Bialek et al. 1992]. The above works present also the distributions of observed values E_w and predicted ones E_φ of the above index, in the form of contour maps, which specify the position of areas posing greater seismic hazards with regard to the investigated workings. Between the distributions of observed values of seismic activity index, generated on the basis of the catalogue of recorded tremors, and the distribution of predicted values, a qualitative conformity was found. However, the predicted values of seismic energy density of the calculated increments of deformation indexes (defining the increase of deformation energy), determined through comparison (specification of parameters) with actual energy release of the tremors were often comparatively inadequately correlated with the observed values (correlation index $r \leq 0.5$).

Further investigation works showed – [Bialek et al.], that in some cases better results can be obtained if the increase of deformation energy – whereof part may be released through mining tremors – is associated with the change of octahedral strain.

The above strain occurs in a classical Clapeyron's formula for elasticity potential, and is an invariant of the deviator. Hence, assuming that the rock mass is an incompressible and linearly elastic medium, the energy state of deformed rock will be dependent on the square of octahedral strain. Disregarding the influence of horizontal movements, the above strain can be expressed by vertical strain (ε_z) and sloup tilt components (T_x, T_y), and the index of energy state φ of the rock subjected to mining influence may be expressed by the following function:

$$\varphi(x, y, z, t) = A_1 \left(T_x^2 + T_y^2\right) + A_2 \varepsilon_z^2 \,. \tag{1}$$

If we take into account the fact that rock material in rockmass has been initially deformed vertically by the value ε_{z0}, due to overburden load, the formula (1) assumes the form:

$$\varphi(x, y, z, t) = A_1 \left(T_x^2 + T_y^2\right) + A_2 \left(\varepsilon_z^2 + \varepsilon_{z0}^2\right) \,. \tag{1.1}$$

The above dependency may be applied in the attempt to build a model describing the release of energy, or determining the number of tremors emitted per area unit in a definite time period. The pace of energy changes caused by the changes of strain condition in time will be obtained by calculating time derivative t from the index of strain energy condition defined by the formula (1.1)

$$\frac{d\varphi}{dt} = 2\bar{A}_1 \left(T_x \frac{dT_x}{dt} + T_y \frac{dT_y}{dt} \right) + 2\bar{A}_2 (\varepsilon_z + \varepsilon_{z0}) \frac{d\varepsilon_z}{dt} . \tag{2}$$

The value of master strain ε_{z0} is unknown. We may assume that the value ε_{z0} is linearly dependent on depth H and an unknown parameter A_3 which stands for mechanical properties of the rock. To preserve linear character of the formula (2), due to unknown parameters A_1, A_2, A_3, it has been slightly changed:

$$\frac{d\varphi}{dt} = 2A_1 \left(T_x \frac{dT_x}{dt} + T_y \frac{dT_y}{dt} \right) + 2A_2 \varepsilon_z \frac{d\varepsilon_z}{dt} + A_3 H \frac{d\varepsilon_z}{dt} . \tag{2.1}$$

The elements of formula (2.1) can be both positive and negative, since the potential strain energy may increase or decrease. The analysis of numerous mining tremors indicates that their hypocenters occur with different intensities, both before and behind the wall front. If we, by way of analogy, compared it to compressing process of a rock specimen, we could say that seismic energy is released both during loading and lightening of rock layer, yet the intensity of this process is different. It is evident from the above that, depending on the sign of strain products ε_z and derivative $d\varepsilon_z/dt$, and the sign of the sum of products of component inclinations as well as the derivative of component tilts present in formula (2.1) – each of parameters A_1, A_2, A_3 may have two different values. It is necessary, therefore, to specify 6 unknown parameters. Another important problem to be taken into consideration is the observed, significant dependence of the amount and number of energy tremors on the sign of vertical strain ε_z. Although in the formula (2.1) the dependence on ε_z has been taken into consideration, yet, in view of experience gained so far, it is evident that in areas where mining resulted in rockmass relief ($\varepsilon_z > 0$), a considerable decrease of seismic activity of rock mass is observed. Integrating formula (2.1) after time t, and taking into consideration the above remarks, we obtain dependence (3), which, after specifying unknown parameters A_1, describes seismic activity induced by mining.

$$E_\varphi(x, y, z = \text{const.}, t_1, t_2) = A_1X_1 + A_2X_2 + A_3X_3 + A_4X_4 + A_5X_5 + A_6X_6 , \tag{3}$$

where:
E_φ – energy release at the point of rockmass having coordinates x, y, z within time $t_1 < t < t_2$, calculated basing on vertical strain changes and **inclinations/gradients/tilts**.

Components X_i of the linear dependency (3) are integrals after time z of particular components from the formula (2.1)

$$X_i = \int_{t_1}^{t_2} F_i(t)\, dt$$

(with, for example)

$$F_1(t) = T_x \frac{dT_x}{dt} + T_y \frac{dT_y}{dt} \quad \text{for} \quad T_x \frac{dT_x}{dt} + T_y \frac{dT_y}{dt} > 0$$
$$F_1(t) = 0 \quad \text{for} \quad T_x \frac{dT_x}{dt} + T_y \frac{dT_y}{dt} < 0 \tag{3.1}$$

For the analyzed, undivided groups of mining tremors from the area of coal mines Bobrek and Miechowice, the correlation coefficient between predicted values E_φ, determined on the basis of dependency (3), and observed values E_w of seismic energy density did not exceed 0.5 ($r < 0.5$).

The dependence (3) did not take into consideration the fact that the rocks whereof rockmass has been built have rheological properties, which, in practice, ought to have resulted over time in the decrease of intensity of the influence of completed excavation. Hence, it seams to be reasonable to develop the dependency (3) by introducing an additional equation characterizing this process. Thus, we suggest calculating as well certain substitute vertical strain ε_{zr} at the height of deposited, investigated rock layer, whereof decrease will be running in a similar way as the decrease of vertical stress effected by relaxation:

$$\varepsilon_{zr} 9x, y, t) = \int_0^t \frac{d\varepsilon_z}{dt} e^{-\frac{t-\tau}{t_z}} d\tau , \tag{4}$$

where:
t_z – coefficient defining the decrease pace of completed mining influence.

As a consequence of such modification of dependency (3), it will be broadened by additional components A_7X_7, A_8X_8 (which will characterize the influence of rheological factor on the level of induced seismicity) and will have the following form:

$$E_\varphi(x, y, z = \text{const.}, t_1, t_2) = A_1X_1 + A_2X_2 + \cdots + A_8X_8 . \tag{5}$$

Correlation coefficients between determined in this way predicted values E_φ, obtained as a result of the application of dependency (5), and observed ones E_w of energy density [J/m^2] of all recorded tremors have the following values: $r = 0.52$ for the area of coal mine Bobrek and Miechowice, and $r = 0.58$ for the area of walls 7a, 4 and 5 of coal mine Bobrek (Fig. 5).

If we ignore selected tremors from group I (Section 2), then, using the dependency (5) after specifying 8 parameters A_i, we obtain substantially better results of prognostic calculations. In such a case, correlation coefficients between predicted values E_φ and observed ones E_w of seismic energy density [J/m^2] have the following values: $r = 0.65$ for the area of coal mines Bobrek and Miechowice, and $r = 0.76$ for the area of walls 7a, 4 and 5 (Fig. 6).

The above dependencies – models describing tremor energy release taking place in the discussed area of rockmass and within relevant time period – may be used to predict the degree of seismic hazards, only in areas where substantial majority

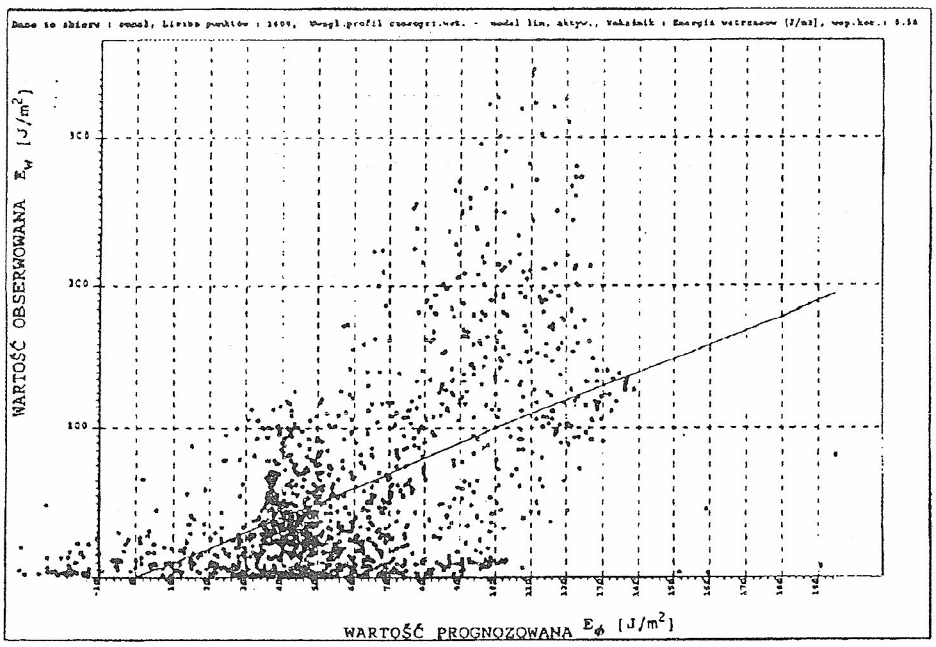

FIG. 5. Dependency between observed values E_w and predicted ones E_φ of energy release of all tremors induced in the area of wall fields 7a, 4 and 5.

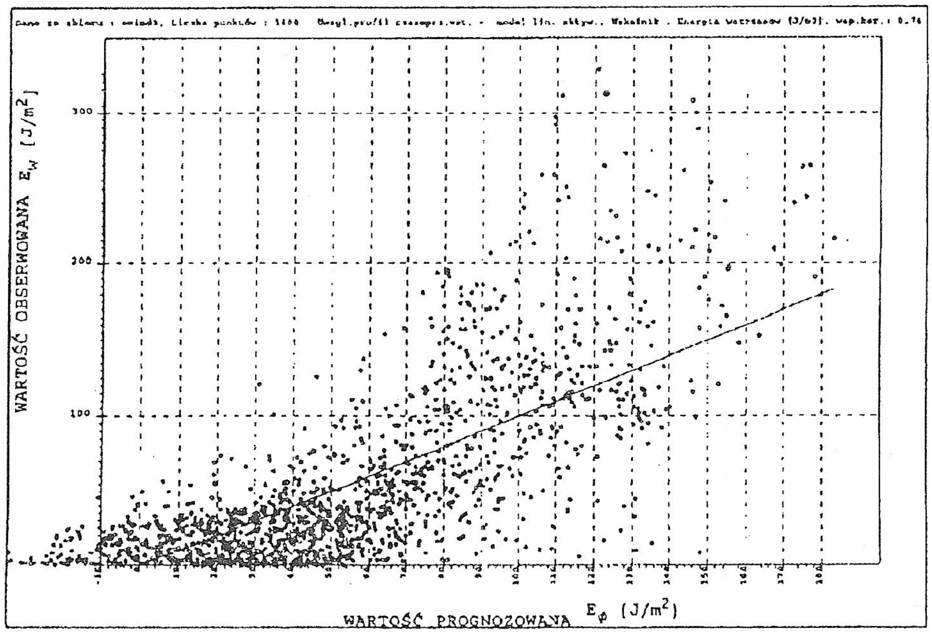

FIG. 6. Dependency between observed values E_w and predicted E_φ of tremor energy release from group II, induced in the area of wall fields 7a, 4 and 5.

of mining induced tremors have their focal points in a definite, single rock layer. It is very difficult to select such a layer due to insufficient data concerning the height coordinate (z) of the focal points of the recorded tremors. The difficulties increase if there is a number of stronger rock layers within the area of intensified mining influence, whereof each may be responsible for the recorded events. In such cases, to avoid integration along coordinate (z) of values defined by dependency (5), which is in practice time consuming, we suggest broadening the discussed model onto all stronger rock layers, which, being deposited above and below mined beds, are subjected to the influence of discussed mining.

Applying formula (5) for a single layer – we suggest expressing the summary energy of tremors released per area unit of the area of all investigated m–layers by the following dependency:

$$E_{\varphi}(x, y, t_1, t_2) = \sum_{n=1}^{m} A_{1n}X_{1n} + \cdots + A_{8n}X_{8n} \tag{8}$$

with the calculation process running as follows:

- for each of the points $P(x, y, z)$ of the calculation network, multi–element tables of subsidence $W_{(tj)}$, inclinations $Tx_{(tj)}$ and strain $\varepsilon z_{(tj)}$ changing in time and with each successive rock layer are created,
- using the tables with values $W_{(tj)}$, $Tx_{(tj)}$, $Ty_{(tj)}$, $\varepsilon z_{(tj)}$, we determine values X_{in} being an $m \cdot 8$–element matrix X of independent variables.

Having the matrix of independent variables X and observation vector E (values of energy released by recorded tremors [J/m^2]), coefficients of multiple regression A_{in} defined by formula (6) are determined using the least square method. When we investigate m–layers of rock, $m \cdot 8$ coefficients are determined. To reduce the number of coefficients to be determined, a simplification of the above model seems to be possible. We assume that coefficients specified for each particular rock layer (8 coefficients for one layer) vary from one another only with a multiplier, constant for a given layer.

Determining flat distribution (contour map) of energy release of mining tremors induced in analyzed area of Bytom Basin on the basis of dependency (6), and assuming that the level of seismic activity in this area is dependent on stress and deformation processes going on in all strong rock layers affected by greater deformation, i.e. in four layers of sandstone (1 layer below mining level), further, significant improvement of results of comparative prognosis has been achieved.

Correlation coefficient between predicted values E_{φ} and observed ones E_w of summary energy release of tremors from group II (Section 2) for the investigated above area of walls 7a, 4 and 5 of coal mine Bobrek equals in this case $r = 0.81$ (Fig. 7). The distribution of real values of energy release E_w [J/m^2] recorded in the area of walls 7a, 4 and 5 of tremors from group II is presented in Fig. 7.

The distribution (contour plan) of real values of energy release E_w [J/m^2] recorded in the area of walls 7a, 4 and 5 of tremors from the separated group II is presented in Fig. 8.

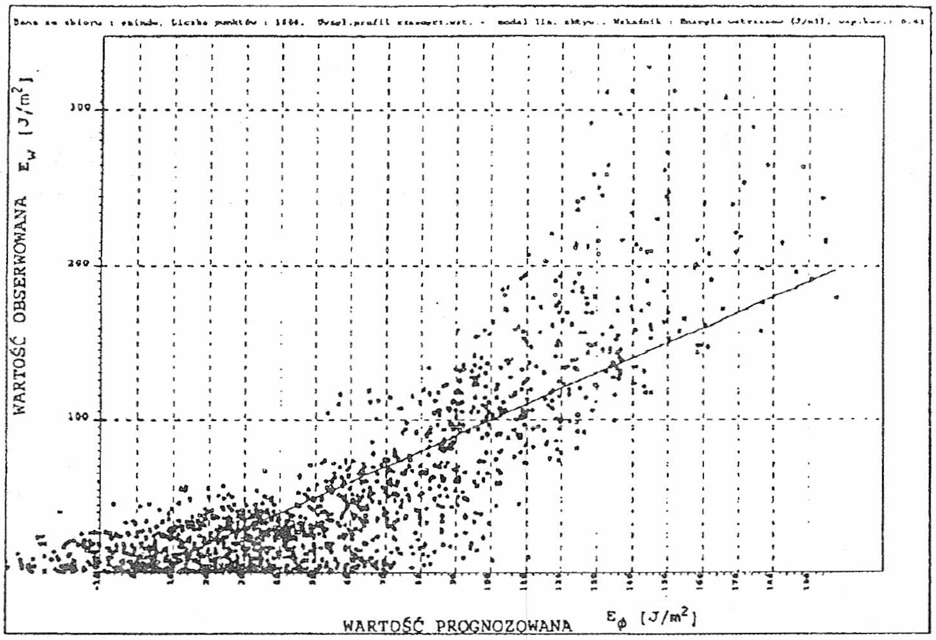

FIG. 7. Dependency between observed values E_w and predicted by means of formula (6) values E_φ of energy release of all tremors recorded in the area of wall fields 7a, 4 and 5.

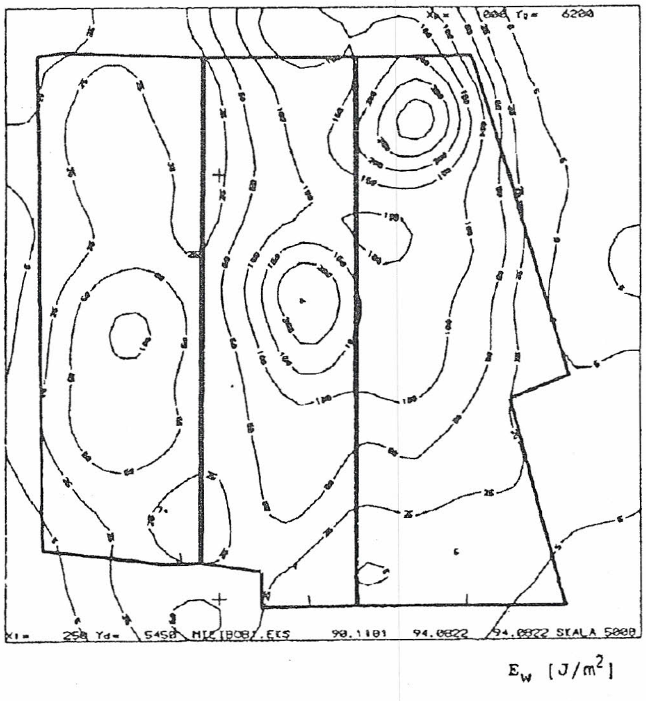

FIG. 8. Distribution of observed values E_w [J/m^2] of energy release of tremors from group II induced in the area of walls 7a, 4 and 5 within the period 90.10.01 – 94.10.01.

Distribution (contour plan) of predicted through comparison and on the basis of formula (6) values of energy release E_φ [J/m^2] of discussed tremors from the separated group II is presented in Fig. 9.

E_ϕ [J/m^2]

FIG. 9. Distribution of predicted by means of formula (6) values E_φ [J/m^2] of tremors from group II induced in the area of walls 7a, 4 and 5 within 90.10.01 – 94.10.01.

Great concurrence of results (correlation coefficient $r = 0.81$) between observed values E_w and predicted ones E_φ entitles us to undertake the attempt to carry out a prognosis predicting the distribution of energy release and also the number of tremors for successive excavations in the discussed mining area.

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