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RESEARCH OF CORRELATION BETWEEN TEMPERATURE ROCK MASS AND ENERGY OF TREMOR

3.1 INTRODUCTION

The observations carried out in the coal mine „Jas-Mos” showed that tremor mining may increase the temperature of the rock mass [1]. This increase in temperature is to be made directly after tremor mining. This was only the area closest to the hypocenter of the mining tremor within a radius of not more than 30 m. Increased temperature remained from 40 minutes to 6 hours [1].

Mining tremor is the being subjected of external loads rocks, which leads to its dynamic cracks. An increase in temperature can be explained based on energy balance related to the destruction of the structure of the rock. General energy balance equation is of the form [3]

$$W + Q_0 = U + E_s + S = Q_1, \quad (3.1)$$

where:

W – work done by external forces,

Q₀ – thermal energy passing through the resort,

U – energy of the elastic deformation,

E_s – the kinetic energy associated with the process of destruction, corresponding to the seismic energy,

S – energy irreversibly dissipated in the process of destruction,

Q₁ – thermal energy accumulated in the rock mass.

In equation (1) occurs the thermal energy Q₁ which means that the effect of mining tremor will also increase the temperature at the rock. The emergence of seismic energy is easily discoverable, regardless of the distance of an outbreak of tremor from mining workings. Temperature rise of rock mass may be detectable only in the case of short distance outbreaks tremors from the excavation due to low ventilation heat rocks [1].

„Jas-Mos” belongs to the mines, where there is a lot of upheaval, but with low energy. This is illustrated in the Table 3.1.

Table 3.1 Tremor in the mine „Jas-Mos”

Year	10 ³ J	10 ⁴ J	10 ⁵ J	10 ⁶ J
1997	6869	568	2	0
1998	8981	228	6	0
1999	8213	162	3	0
2000	8850	192	19	0
2001	2673	131	9	0
2002	304	267	12	0

Source: [1]

In this work there is designated the correlation between temperature and the tremor. The choice was between the temperature of the rock mass before tremor and after tremor and the calculated coefficients of multiple correlation for these quantities.

3.2 CALCULATION OF CORRELATION

To assess the relationship between the two values is used the correlation coefficient ρ_{kl} the specified formula [2]

$$\rho_{kl} = \frac{\text{cov}(x_k, x_l)}{\sigma_k \sigma_l}, \quad (3.2)$$

where:

$\text{cov}(x_k, x_l)$ – means the covariance between the k and l-the value,

σ_k – the standard deviation of k-this value,

σ_l – the standard deviation of l-this value.

Consistent estimator of correlation coefficient ρ_{kl} is from the sample correlation coefficient, which is usually denoted as r_{kl} . This factor is calculated by the formula

$$r_{kl} = \frac{\sum_{j=1}^n (x_{kj} - \bar{x}_k)(x_{lj} - \bar{x}_l)}{\sqrt{\sum_{j=1}^n (x_{kj} - \bar{x}_k)^2 \cdot \sum_{j=1}^n (x_{lj} - \bar{x}_l)^2}}. \quad (3.3)$$

In the formula this value \bar{x}_k and \bar{x}_l means the arithmetic means k-and l-this values. Formula (3.3) can be represented in any other form of better placed for numerical computations [2]

$$r_{kl} = \frac{\sum_{j=1}^n x_{kj} x_{lj} - \frac{1}{n} \sum_{j=1}^n x_{kj} \sum_{j=1}^n x_{lj}}{\sqrt{\left[\sum_{j=1}^n x_{kj}^2 - \frac{1}{n} \left(\sum_{j=1}^n x_{kj} \right)^2 \right] \left[\sum_{j=1}^n x_{lj}^2 - \frac{1}{n} \left(\sum_{j=1}^n x_{lj} \right)^2 \right]}}. \quad (3.4)$$

The correlation coefficient is an normed measure of correlation and range [-1, + 1].

In order appoint the multiple correlation we create the matrix K of correlation factors r_{kl} for all values. We use the patterns (3.3) or (3.4)

$$K = \begin{bmatrix} 1 & r_{12} & \dots & r_{1m} \\ r_{21} & 1 & \dots & r_{2m} \\ \vdots & \vdots & & \vdots \\ r_{m1} & r_{m2} & \dots & 1 \end{bmatrix}. \quad (3.5)$$

Correlation matrix K is symmetric matrix with on the main diagonal of the only ones. Next, we compute the coefficients of correlation multiple for each test the values

$$R_{i(i-1, i+1, \dots, m)} = \sqrt{1 - \Delta / \Delta_{ii}}, \quad (3.6)$$

where:

Δ is the determinant of a matrix K,

Δ_{ii} is minor after removal the i-th row and i-th column of the matrix K.

Multiple correlation coefficient determines the degree of correlate i-th values from the other.

In this paper we approached three value: temperature before tremor, temperature after tremor and energy tremor. List of associated mining tremors temperature increments in the mine „Jas-Mos” is presented in table 3.2.

Table 3.2 List of associated mining tremors temperature increments

Lp.	Deck	Energy of tremor [J]	Temp. of rock mass before tremor [°C]	Temp. of rock mass after tremor [°C]	Lp.	Deck	Energy of tremor [J]	Temp. of rock mass before tremor [°C]	Temp. of rock mass after tremor [°C]
1	415/1-2	1,3E+03	30	35	22	417/1	1,4E+03	30	38
2	415/1-2	2,7E+03	30	38	23	417/1	2,3E+03	27	38
3	415/1-2	2,3E+03	30	35	24	417/1	2,2E+03	29	38
4	415/1-2	3,4E+03	30	35	25	417/1	1,2E+03	29	38
5	415/1-2	2,7E+03	30	38	26	417/1	3,1E+03	29	38
6	415/1-2	2,2E+03	30	35	27	417/1	2,0E+03	29	38
7	415/1-2	3,2E+03	30	33	28	417/1	2,6E+03	30	38
8	415/1-2	2,8E+03	30	38	29	417/1	4,5E+03	29	38
9	415/1-2	2,5E+03	30	38	30	417/1	1,9E+03	29	38
10	415/1-2	2,3E+03	30	35	31	417/1	7,5E+03	29	38
11	415/1-2	2,0E+03	30	38	32	417/1	1,9E+03	29	38
12	415/1-2	1,2E+03	30	38	33	417/1	9,2E+03	31	38
13	417/1	2,9E+03	31	38	34	417/1	1,3E+03	29	38
14	417/1	1,4E+03	29	35	35	417/1	3,0E+03	29	38
15	417/1	1,9E+03	29	38	36	417/1	1,9E+03	29	38
16	417/1	2,2E+03	30	38	37	417/1	2,1E+03	29	38
17	417/1	1,7E+03	29	38	38	417/1	3,4E+03	29	38
18	417/1	1,5E+03	29	38	39	417/1	5,3E+03	31	38
19	417/1	2,3E+03	29	41	40	417/1	1,1E+03	29	38
20	417/1	7,2E+03	29	38	41	417/1	1,E+03	29	38
21	417/1	1,8E+03	31	38	42	417/1	2,8E+03	29	38

Source: [1]

To the convenience of writing introduced numbered value:

1 – temperature of rock mass before tremor,

2 – temperature of rock mass after tremor,

3 – energy of tremor.

Temperature of rock mass before tremor and after tremor illustrated in Figure 3.1.

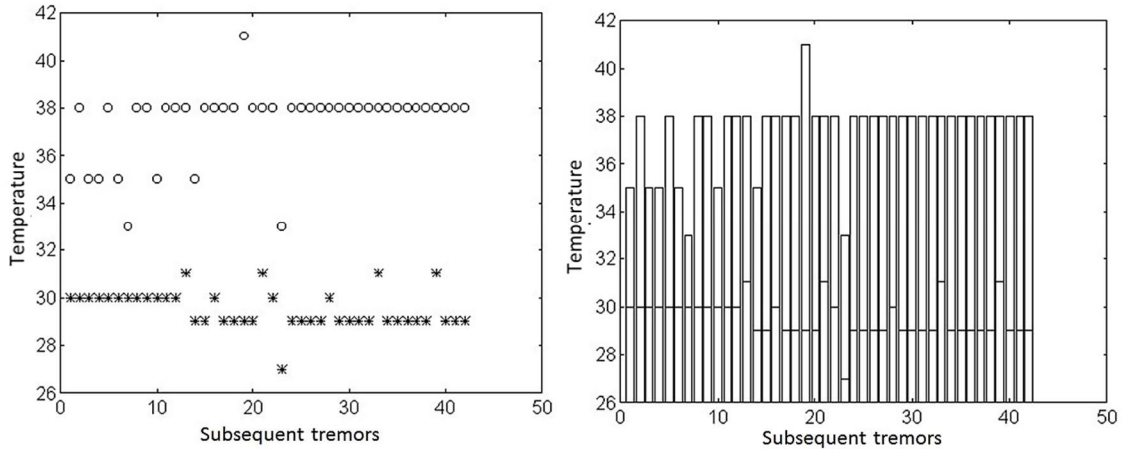


Fig. 3.1 Temperature of subsequent tremors

(* - temp. before tremor, o - temp. after tremor)

Figure 3.2 shows the energy for the next tremors.

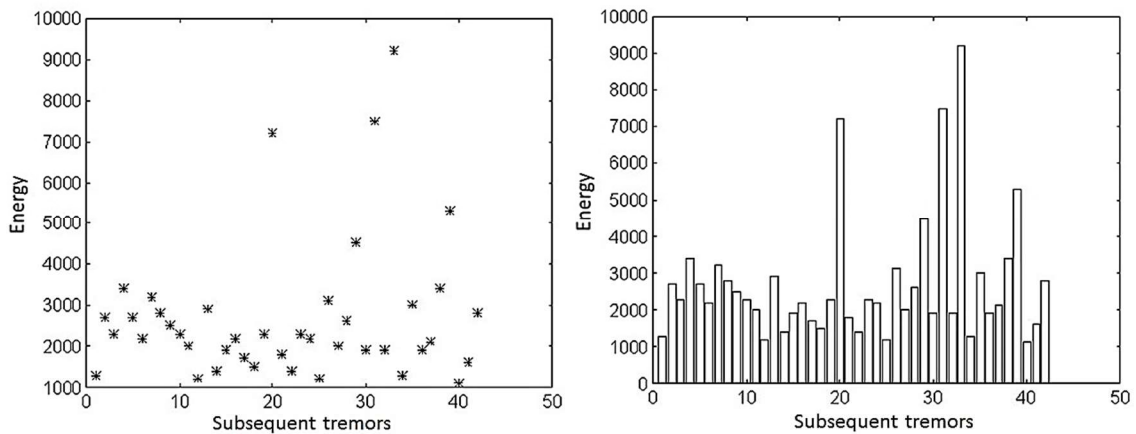


Fig. 3.2 Energy of subsequent tremors

Figures 3.1, 3.2 and 3.3 are presented in two forms in order to better illustration analysed issues. Figure 3.3 shows the temperature difference for successive tremors.

Based on the models (3.3) or (3.4) the calculated correlation coefficients between these values (corresponding columns of Table 3.1). They are respectively:

$$r_{12} = 0.0510, \quad r_{13} = 0.2147, \quad r_{23} = 0.0774.$$

In order to determine the coefficients of multiple correlation, correlation matrix was created. The correlation matrix is symmetric, so $r_{ij} = r_{ji}$. It has the following form:

$$K = \begin{bmatrix} 1 & 0.0510 & 0.2147 \\ 0.0510 & 1 & 0.0774 \\ 0.2147 & 0.0774 & 1 \end{bmatrix}.$$

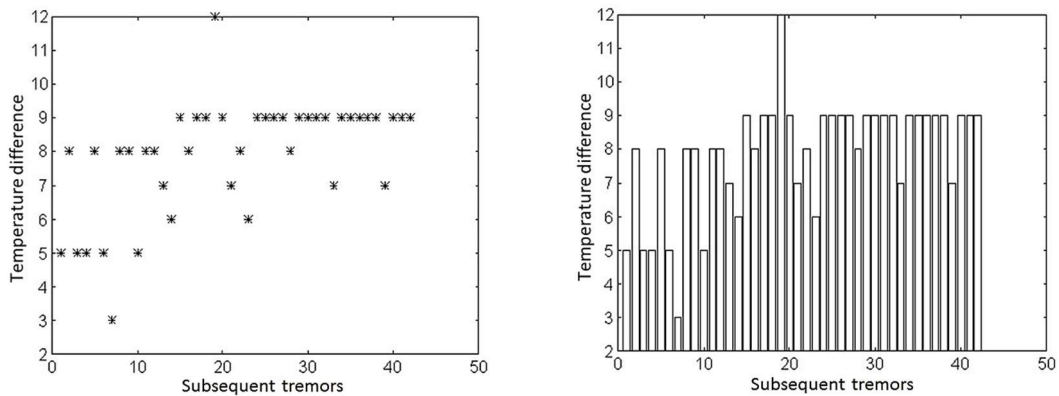


Fig. 3.3 Temperature difference for successive tremors

Coefficients of multiple correlation, calculated on the basis of the formula (3.6) shall be:

$$R_{1(2,3)} = 0.2174, \quad R_{2(1,3)} = 0.0850, \quad R_{3(1,2)} = 0.22747.$$

Were counted also correlation between temperature difference and energy. The correlation is

$$r_{et} = -0.0273.$$

An illustration of the graphics for the size occurring in determining the correlation coefficients r_{12} , r_{13} , r_{23} and r_{et} show Figures 3.4, 3.5, 3.6 end 3.7.

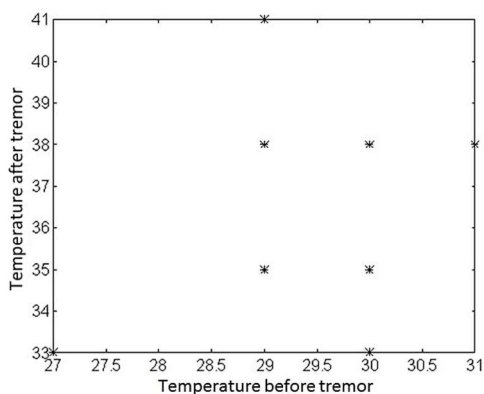


Fig. 3.4 Illustration of the correlation r_{12}

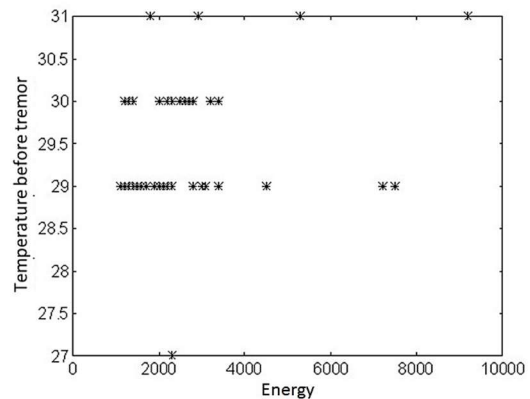


Fig. 3.5 Illustration of the correlation r_{13}

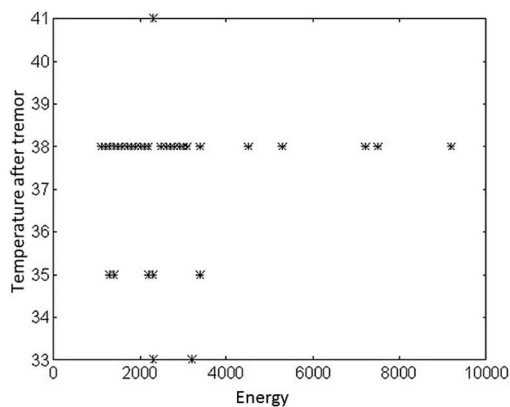


Fig. 3.6 Illustration of the correlation r_{23}

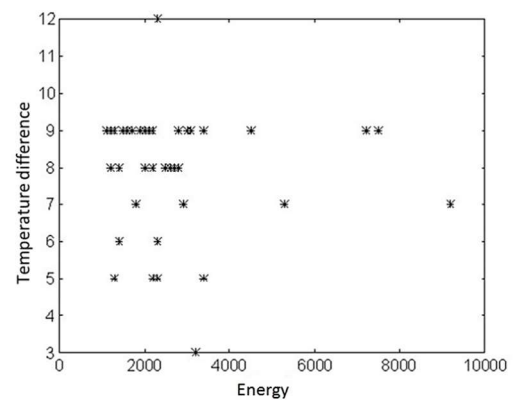


Fig. 3.7 Illustration of the correlation r_{et}

3.3 CONCLUSIONS

With calculations penetrates that all correlation coefficients r_{12} , r_{13} , r_{23} and r_{et} are very small. It also confirms the location of points in figures 4, 5, 6 and 7. Also coefficients of multiple correlation $R_{1(2,3)}$, $R_{2(1,3)}$ and $R_{3(1,2)}$ are very small. So not getting the dependencies between the values. While real and noticeable was the fact that after the tremor of rock mass, the temperature was increased by a few degrees in the immediate vicinity of an outbreak of tremor. The ratio r_{ed} shows that the temperature difference after tremor was independent of the value of the energy tremor. It should be noted that the increase in the temperature of the rock mass was recorded after the fact, i.e. after the onset of tremor. In order to prognosis the occurrence of tremor research should be before tremor and look for symptoms or precursors to indicate an instance of tremor in a short period of time.

REFERENCES

1. P. Chmiel, J. Kutkowski, M. Lubryka and J. Sułkowski. "The occurrence of rock mass temperature increase in these areas the mining tremors observed in the excavation KWK „Jas-Mos”,” in *Proc. The school of the exploitation of the underground 2004. PAN, AGH, Szczyrk 23-27. 02, 2004*, pp. 407-417 (in Polish).
2. J. Greń. *Mathematical statistics. Models and task*. PWN, Warszawa, 1982, pp. 163-169 (in Polish).
3. K. Stec. *The methods of calculating seismic energy - development of methods and status of current. Geophysical surveys in the mines*. Collective work edited by J. Dubiński, Z. Pilecki, W. Zuberek. Publishing IGSM i E PAN, Kraków, 2001, pp. 103-115 (in Polish).

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RESEARCH OF CORRELATION BETWEEN TEMPERATURE ROCK MASS AND ENERGY OF TREMOR

Abstract: In paper results of calculations of correlation between temperature of rock mass in coal mine "Jas-Mos", and energy of tremor are presented. Correlation referred temperatures before tremor and after tremor, temperatures before tremor and energy of tremor and temperatures after tremor and energy of tremor. Also multiple correlation was calculated between the test values. At the correlation between difference of temperatures and energy of tremor was also determined.

Key words: rock mass, tremor, temperature, correlation

BADANIE KORELACJI POMIĘDZY TEMPERATURĄ GÓROTWORU A ENERGIĄ WSTRZĄSU

Streszczenie: W pracy przedstawiono wyniki obliczeń korelacji pomiędzy temperaturą górotworu a energią wstrząsu w kopalni węgla „Jas-Mos”. Określono korelację pomiędzy temperaturą przed wstrząsem i po wstrząsie, temperaturą przed wstrząsem i energią wstrząsu oraz temperaturą po wstrząsie i energią wstrząsu. Obliczono też korelację wieloraką pomiędzy badanymi wielkościami. Określono także korelację między różnicą temperatur i energią wstrząsu.

Słowa kluczowe: górotwór, wstrząs górniczy, temperatura, korelacja