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STRESS TENSOR ANALYSIS FROM THE FOCAL MECHANISM OF MINING TREMORS IN THE UPPER SILESIA COAL BASIN.

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Abstract: About 200 shocks were analyzed using fault plane solution method, to obtain fault plane orientation as well as sliding vector direction for focal mechanisms of every shock. The results of fault plane solution method were divided into three groups according to different orientation of nodal planes. As one can assumed, they represent three types of the movement in the source.

The orientation of the rupture plane and the direction of the sliding vector were used to calculate stress tensors for the above mentioned three groups of tremors. The knowledge of tensor components give opportunity to determine the origin of the stress field affecting the tremors occurrence.

Key words: mining induced seismicity fault plane solution, stress tensor inversion

1. INTRODUCTION

The determination of the stress state previous to the sudden energy release is one of the most important problem in mining seismology. The stress tensor analysis is useful for the determination of stress state in the past (Anglier, 1979; Malek et al, 1989,) basing on the field angular measurement of striations and fault fissure orientation as well as on focal mechanism data received from the seismological research.(Yeh et al, 1991) One can also assume that the only specific state of stress cause the fact of sliding on the fault plane. That condition seems to be satisfied during the tremor, when the sudden slip occur in the very short time.

The determination of stress state causing the mining tremors let us suppose the possible mechanism of each event and probably determine the cause of these events. The application of this method in the daily mining activities could increase the safety of mining works, if the standard procedures would be applied on mines.

2. FAULT PLANE SOLUTION FOR MINING TREMORS.

The mechanism of analyzed tremors was determined by Sagan and Zuberek (1991) as a part of greater number of seismic events in the Upper Silesian Coal Basin (USCB) area. The determined focal mechanism can be divided into three groups according to different orientations of nodal planes:

a) both planes have got a vertical orientation (type 1);

b) one plane is almost horizontal and the second one is close to vertical (type 2)

c) both planes are oriented diagonally with a middle dip angle (type 3).

The above distinguished results was used as an original data for the stress tensor analysis.

The planes oriented close to W-E direction from the first type of tremors was chosen. This type of tremors was determined as a type, which could be connected with the tectonic movements on the W-E discontinuities widely represented on the research area, and being active during the last phases of Alpine orogeny. The vertical W-E planes could be the fault planes of the major latitudinal fault zones. These planes with the slip direction on them consist the first set of original data.

The second type of focal mechanism (if one assume the vertical plane as a fault plane) can be interpreted as the events closely connected to mining due to big dispersion of the strike angle. The determined orientations of these planes aren't parallel to the existing fault directions and have got rather a random distribution.

On the other hand, if one assume the horizontal planes as a rupture plane, it is difficult to imagine the mining mechanism of such kind of shearing process. The slip on the horizontal planes is well known in tectonics as a result of the strike-slip movement in the deep basement, which cause the interlayer slip in the overlayed rock mass. Both kinds of the result (vertical and horizontal planes with the slip vector orientation) were used as a second and a third set of original data.

The tremors of the third type have both diagonal nodal planes, that means the rupture occurs on the planes with dip angle 40-60°. There is not a sharp boundary between the second and third type mechanism. The second type was distinguished if one of the planes has dip angle less then 30°. The fourth set of original data was determined on the basis of third type nodal plane orientation, taking into account only the planes parallel to latitude (W-E direction).

3. DETERMINATION OF STRESS TENSOR FOR THE GROUP OF TREMORS

The data obtained from the first motion of P-waves analysis and grouped due to focal mechanism similarity were used for obtaining mean stress tensors. The single stress tensor determine the direction and the sense of the movement in the focal area. We assumed following that for different tremors of the similar focal mechanism stress tensors differ not so much. Thus, for groups of tremors occurring in the limited area the mean stress tensor exist (Yeh et al, 1991). The basic concept of the method used for accounting of this tensor was minimizing the difference between the actual slip vector and the computed shear stress.

Because the direction and the sense of shear stress are not affecting by absolute values of stress components, and also by isotropic stress, the number of independent stress components can be reduced to four (Anglier, 1979). The slip mechanism needs the stress components not have in the same signs. It is expedient to select from all the tensor these fulfilling the condition:

$$T_{11} + T_{22} + T_{33} = 0 \qquad (1)$$

and normalizing condition:

$$T_{11}^2 + T_{22}^2 + T_{33}^2 = 3/2 \qquad (2)$$

According to these conditions the following parameterization of the stress tensor is possible (Malek et al, 1991):

$$T = \begin{bmatrix} \cos\psi & \alpha & \beta \\ \alpha & \cos(\psi+2\pi/3) & \gamma \\ \beta & \gamma & \cos(\psi+4\pi/3) \end{bmatrix} \qquad (3)$$

The fault plane is characterized by the unit vector **n** normal to it. The unit displacement vector **u** on the fault plane is perpendicular to the auxiliary plane and make with the horizontal line the angle λ. The unit **n** is oriented toward the fault plane dip and λ is measured opposite clockwise.

The resultant stress vector acting on the fault plane is σ=Tn. Its normal and tangential component are equal:

$$\sigma_n = \left[n(Tn)\right]n \qquad \sigma_t = \left[s(Tn)\right]s \qquad (4)$$

where s is the unit vector parallel to the fault plane. The stress components σ_n and σ_t hold following relation:

$$\sigma = \sigma_n + \sigma_t \qquad (5)$$

and further:

$$(sTn)s = Tn - (nTn)n \qquad (6)$$

The tangential stress unit s should be in agreement with the displacement unit u thus the right side of eq. 6 can be theoretical value of σ_t and the left side is the empirical one. For the group of fault planes we defined the residual vector f:

$$f_{3(k-1)+i} = (nTn)s_i^{(k)} - \left[(Tn)_i - (nTn)n_i^{(k)}\right] \quad (7)$$

where $n_i^{(k)}$, $s_i^{(k)}$ are the directional cosines of n_k and s_k for the k-th fault plane respectively. This vector depend on parameters α, β, γ and ψ. to optymalize this parameters the merit function

$$\Phi = f\ f \quad (8)$$

was minimalized using the least square method. To improve the convergence of the iterative steps this method was modified according to Meiron (1965). The iterative procedure was proceeded due to the formulae:

$$t^{(h+i)} = t^{(h)} - (A^T A - pQ) A^T f \quad (9)$$

where: t - is the vector of parameters $\alpha, \beta, \gamma, \psi$

A - the matrix of the partial derivatives $\partial f/\partial t$

Q - the damping matrix

p - the damping coefficient.

The calculations had been continued until the given accuracy was achieved. The starting values for iterative process were obtained from matrix equation:

$$T^{(O)} = YX^T(XX^T)^{-1} \quad (10)$$

where X, Y are the matrix of column vector n_k and s_k.

As we proved it, $T^{(O)}$ were the best starting value for the iterative process.

The best approximated stress tensor was transformed to the diagonal one and its eigenvalues as well as eigenvectors were calculated numerically (Potter, 1982). All the calculation described above were done using the program STAMIT made by authors for the computer IMB PC.

4. RESULTS AND CONCLUSIONS.

The above described method was used for calculating the four parameters of the stress tensor as well as for determining the eigenvalue of computed tensor. The four sets of original data presented in chapter no. 2 was used. The results of the calculations are presented on Figures 1,2 3, and 4, the estimated values of tensor parameters in the Table 1.

Table I. Results of an analysis of 4 investigated sets.

	α	β	γ	ψ
1-st set	-0.4167	0.1694	-0.4650	-2.1150
2-nd set	-0.0268	-0.0398	0.0399	2.1391
3-rd set	0.0215	0.0405	-0.0882	0.6957
4-th set	0.2326	-0.0351	-0.1330	1.4089

The first set of data represent the focal mechanism consisting of two vertical planes, which shows that the slip in the focus is oriented horizontally. The greatest stress component is extensional and oriented close to horizontal plane on the W-E direction. Both others components are compressional and oriented diagonally (see Fig 1). This kind of stress components pattern is hard to explain by the pure or mining stress. Such type of stress ellipsoid is instead well known in global tectonics in some theories of expansions of the Earth. In this case the orientation of the both others axis is not important because of their small values.

The second set of data represents the slip on the close to vertical planes in the second type of tremors. The greatest stress component is extensional and oriented almost vertically, and the

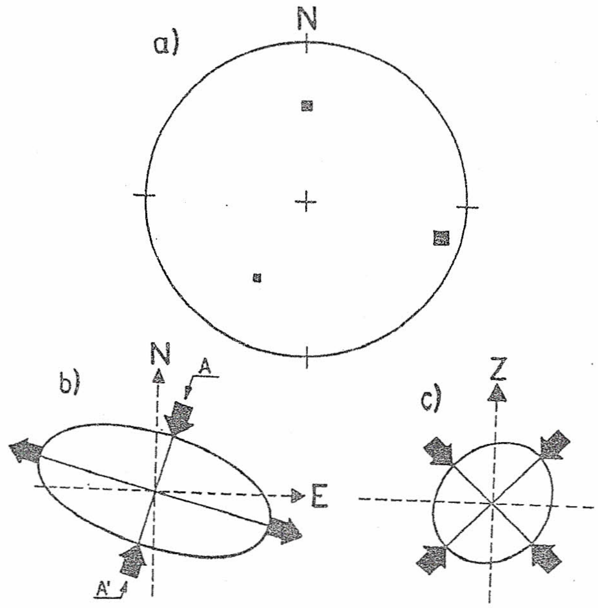

Fig.1. Results of the stress tensor analysis for the first set of data: a) computed tensor components in the equal area Schmidt projection on the upper hemisphere (the largest, intermediate and smallest squares are the axis of maximum, intermediate and minimum stress); b) the horizontal section of stress ellipsoid; c) the vertical section of stress ellipsoid along the A-A' line.

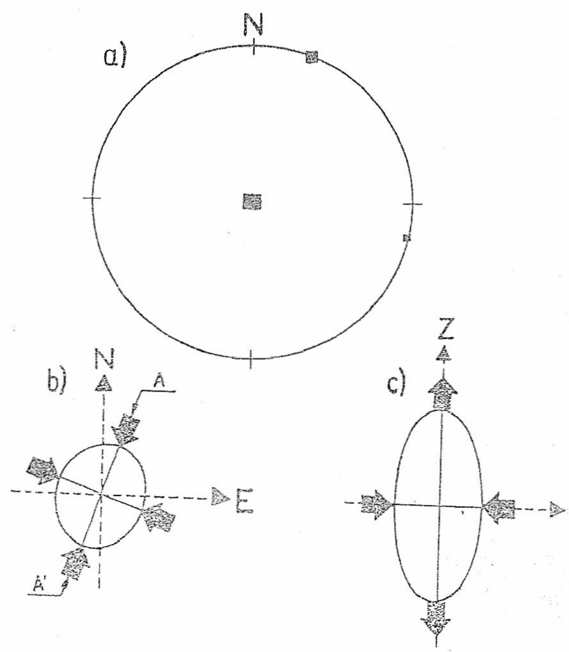

Fig.2. Results of the stress tensor analysis for the second set of data (others symbols as in Fig.1)

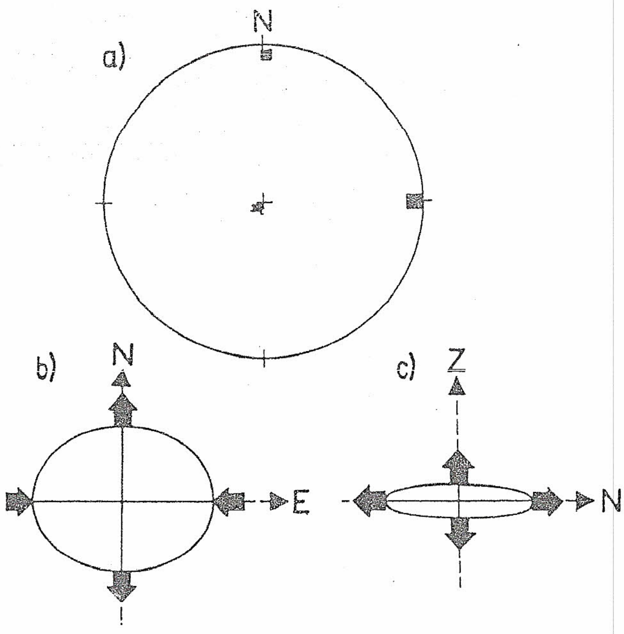

Fig. 3. Results of the stress tensor analysis for the third set of data (others symbols as in Fig.1)

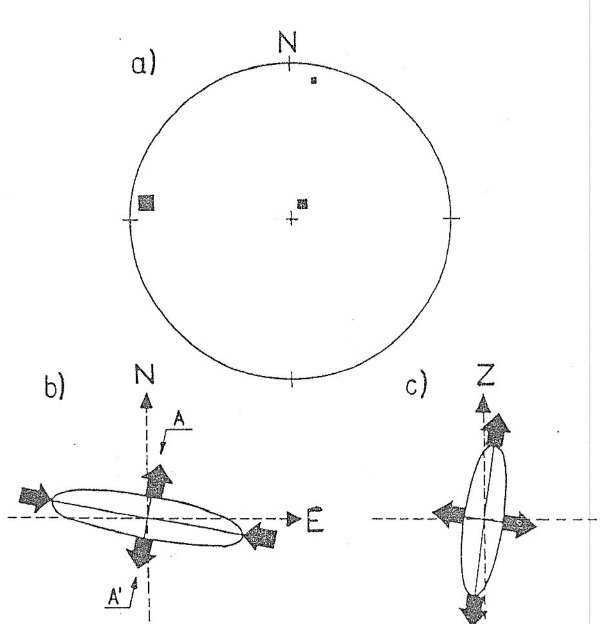

Fig. 4. Results of the stress tensor analysis for the fourth set of data (others symbols as in Fig.1)

medium and smallest components are compressional and oriented almost horizontally (as on Fig. 2). This orientations could be interpreted as a kind of roof collapse with the stable state of horizontal components of stress. There is not a natural tectonic state of stress similar to the detected one, so that kind of tremors seems to be closely related to mining works.

The third and fourth sets of data give the stress components pattern with the biggest compressional component oriented almost horizontally with strike azimuth parallel to W-E direction (Fig 3 and 4). The second and third components are almost equal and oriented vertically and horizontally to the N-S direction. The same stress state seems to affect on the occurrence of this two type of tremors. The W-E direction is one of the most important tectonic direction in the USCB area connected with the strike-slip movement along the W-E faults caused by Alpine rotation of Carpathian massif or in the other opinion of the movement on the so called "50°" North fracture zone. One can be sure that it hard to explain this kind of stress pattern by the simple mining activity. The more exact explanation of these stress states require the wider tectonic studies as well as the direct investigations of stress state surrounding the mine excavation.

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