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ESTIMATION OF THE LOCAL STRESS FIELD USING SEISMOLOGICAL DATA

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ABSTRACT
Focal mechanisms of 400 mining induced seismic events were determined using seismic moment tensor inversion method. The seismic moment tensors were calculated in time domain for P-wave first arrivals. All the seismic events were induced in the vicinity of one longwall opening localised in the Halemba coal mine area (Upper Silesian Coal Basin, Poland). Assuming that the tremors occurring in the same area in short time intervals are generated by similar stress conditions, mean local stress tensors for sets of seismic events were calculated. Only shearing focal mechanism seismic events were taken into account. The stress tensors were calculated for ten succeeding seismic events. The study showed that the state of stress was very unstable in the investigated area. Variation of the local stress field manifested itself by instantaneous interchanging of the positions of main stress axes. Variations of the state of stress were probably the result of mutual interaction of lithostatic, mining and tectonic stresses.

KEYWORDS: mining induced seismicity, mean local stress tensor, focal mechanism

INTRODUCTION

Seismic activity has been observed in the Upper Silesian Coal Basin (USCB) for many years. Mining induced seismic events cause considerable damages on the Earth's surface and in the underground openings. They are also a danger to miners' life. The origin of seismic activity in the USCB has not been explained in all respects up to the present. Numerous, previous research revealed various focal mechanism of mining induced seismic events, for example related to normal, reverse and strike-slip faults (Wiejacz and Ługowski, 1997; Gibowicz and Lasocki, 2001). One also observed non-shearing source mechanisms. Estimation the state of stress in the rock mass subjected to mining may be useful for recognition the origin of the seismic activity (Dubiński and Stec, 1996). The solutions of tremors' focal mechanisms provide the data for calculation the mean local stress tensor and recognition the state of stress inducing the seismic events (Dubiel, 1999, 2002).

RESULTS

The investigation area was the Halemba coal mine situated in the central part of Upper Silesian Coal Basin. One longwall opening with high seismic activity was selected for study. The longwall opening was situated in the coal seam number 506. Four hundred seismic events were induced in investigated area. The energy range of the seismic events was $10^3 \div 10^6$ J. The seismic events were recorded by local seismic network consisting of sixteen vertical seismometers.

First, the focal mechanisms of all recorded events were estimated using seismic moment tensor inversion method in time domain for P-wave first arrivals (Wiejacz, 1991). One obtained percentage share of particular seismic moment tensor components, spatial orientation of nodal planes and rake angle. Only seismic events with dominant double couple component (DC > 50%) were taken into further calculation. Thus, the number of studied seismic events decreased to 240 events.

The solution of seismic event focal mechanism provides two nodal planes. For each seismic event one of two nodal planes was fixed as a fault plane according to:

- spatial orientation of fractures in the rock mass (45^o – 85^o; 125^o – 185^o) and Coulomb – Mohr criterion

  or

- azimuth of longwall opening (30^o – 40^o) and Coulomb – Mohr criterion

Some of the seismic events have not fullfilled the above conditions. These tremors have also been excluded from the further calculations.

Assuming that the seismic events induced in the same area in short time intervals were caused by

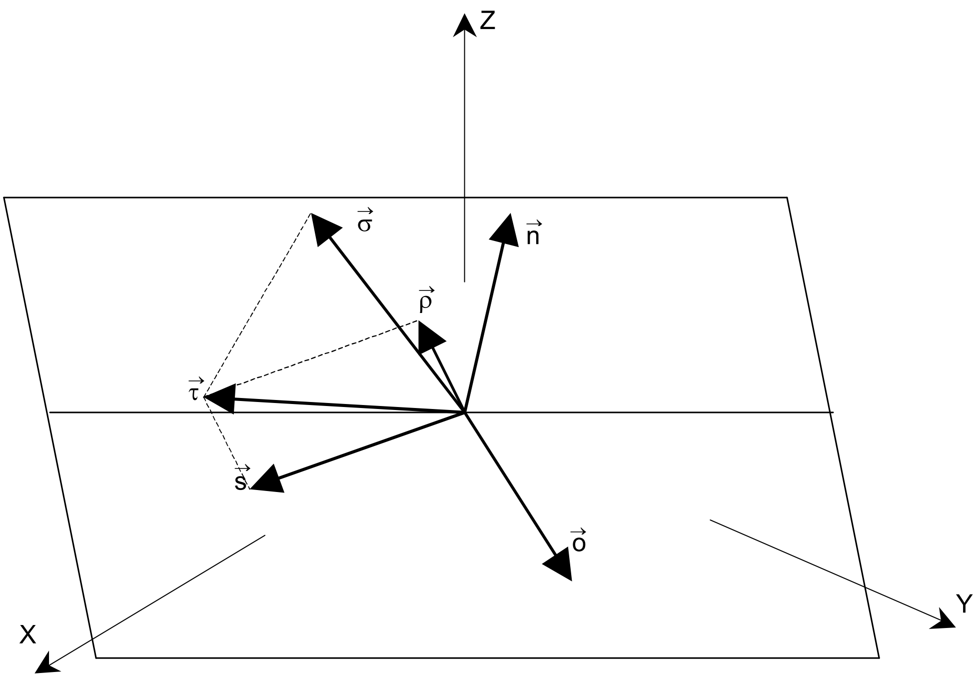

Fig. 1 Geometry of fault plane (Angelier, 1979)
$\vec{n}$ - unit normal vector of fault plane
$\vec{s}$ - unit slickenslide vector
$\vec{\sigma}$ - stress vector
$\vec{\rho}$ - tangential component of stress vector acting on fault plane

similar stress conditions, the state of stress can be described by the one mean local stress tensor. Stress tensors were calculated for sets of 10 succeeding tremors and time interval between succeeding sesmic events did not exceed two weeks .

Angelier's method (1979) was applied into calculation. The method is based on a least squares minimisation of the component of tangential stress perpendicular to the slickenslide (Fig. 1):

$$F = \sum_{k=1}^{n} \rho_k^2$$

One obtained spatial orientation of main stress axes σ_1, σ_2, σ_3, and coefficient R defined as:

$$R = \frac{\sigma_2 - \sigma_1}{\sigma_3 - \sigma_1}$$

The calculation interval of the stress tensors was three tremors. Thus 70% of data were the same for succeeding stress tensors. This way, the continuous observation of stress field was possible. The solutions 4 and 5, 5 and 6, 12 and 13, 13 and 14 are exceptions. These solution are separate because of long time interval between succeeding tremors. The results of stress tensors calculation are presented in table 1 and in fig. 2.

DISCUSSION

Calculated mean local stress tensors allow for almost continuous observation the variations of the stress field in the rock mass subjected to mining during 15 months. The state of stress was very unstable in the studied area. One observed vertical orientation of maximum stress axis related to lithostatic stress conditions or vertical orientation of intermediate or minimum stress axes related to tectonic stress conditions alike (Fig. 2). The transitional state of stress are observed occasionally. Instantaneous interchanging of the position of main stress axes are the common feature of the studied stress conditions. Coefficient R values vary from 0,0174 (value of intermediate stress is close minimum stress) up to 0,9463 (value of intermediate stress is close maximum stress). It reveals that relation among main stress values are also very variable.

Table 1 Spatial orientations of main stress axes and coefficient R values for succeeding stress tensor solutions

SOLUTION	Time period	σ_1 azimuth/dip	σ_2 azimuth/dip	σ_3 azimuth/dip	coefficient R
1	1993-08-04 - 1993-09-03	350/5	224/81	80/7	0.6979
2	1993-08-16 - 1993-09-06	221/47	36/43	128/3	0.9463
3	1993-08-31 - 1993-09-10	237/79	46/11	136/2	0.9210
4	1993-09-02 - 1993-09-21	140/1	50/2	261/88	0.1184
5	1994-01-21 - 1994-02-21	65/5	158/32	328/57	0.1327
6	1994-03-02 - 1994-03-18	85/8	347/44	183/45	0.1215
7	1994-03-08 - 1994-03-25	153/3	55/67	245/22	0.1517
8	1994-03-15 - 1994-04-05	163/10	331/80	72/2	0.5060
9	1994-03-18 - 1994-04-12	157/7	325/82	67/2	0.3118
10	1994-03-25 - 1994-04-16	312/5	219/32	50/58	0.2221
11	1994-04-05 - 1994-04-20	145/0	54/83	235/7	0.0806
12	1994-04-12 - 1994-04-26	173/4	264/14	69/76	0.4369
13	1994-05-18 - 1994-05-30	87/11	333/66	182/22	0.2063
14	1994-08-03 - 1994-09-12	178/2	271/51	86/39	0.4009
15	1994-08-19 - 1994-09-21	245/11	336/2	76/78	0.4744
16	1994-08-29 - 1994-10-11	184/6	274/1	13/84	0.0916
17	1994-09-12 - 1994-10-21	218/80	10/9	101/5	0.8116
18	1994-09-21 - 1994-10-24	135/1	225/4	27/86	0.0174

The investigation showed that the mining activity put the rock mass in the state of instability manifesting itself by inducing the seismic events. Mining stresses may probably trigger the horizontal tectonic stresses. Geological position of the Upper Silesian Coal Basin, especially the nearness of Carpatian arc, suggests the possible existence of the horizontal tectonic stresses N-S directed. The study revealed that these stresses become active by mining exploitation and, in some extent, increase seismic activity in mining areas. Horizontal maximum stress axis σ_1 is mostly N-S oriented (Fig. 2 – solutions: 1, 7, 8, 9, 12, 14, 16). Moreover, the existence of tectonic component in inducing the seismic events may be also confirmed by the state of stress with vertically oriented σ_2 axis and horizontally oriented σ_1 and σ_3 axes (Fig. 2 solutions 1, 7, 8, 9, 11, 13). This state of stress is typical for originating strike-slip faults in active tectonic zones.

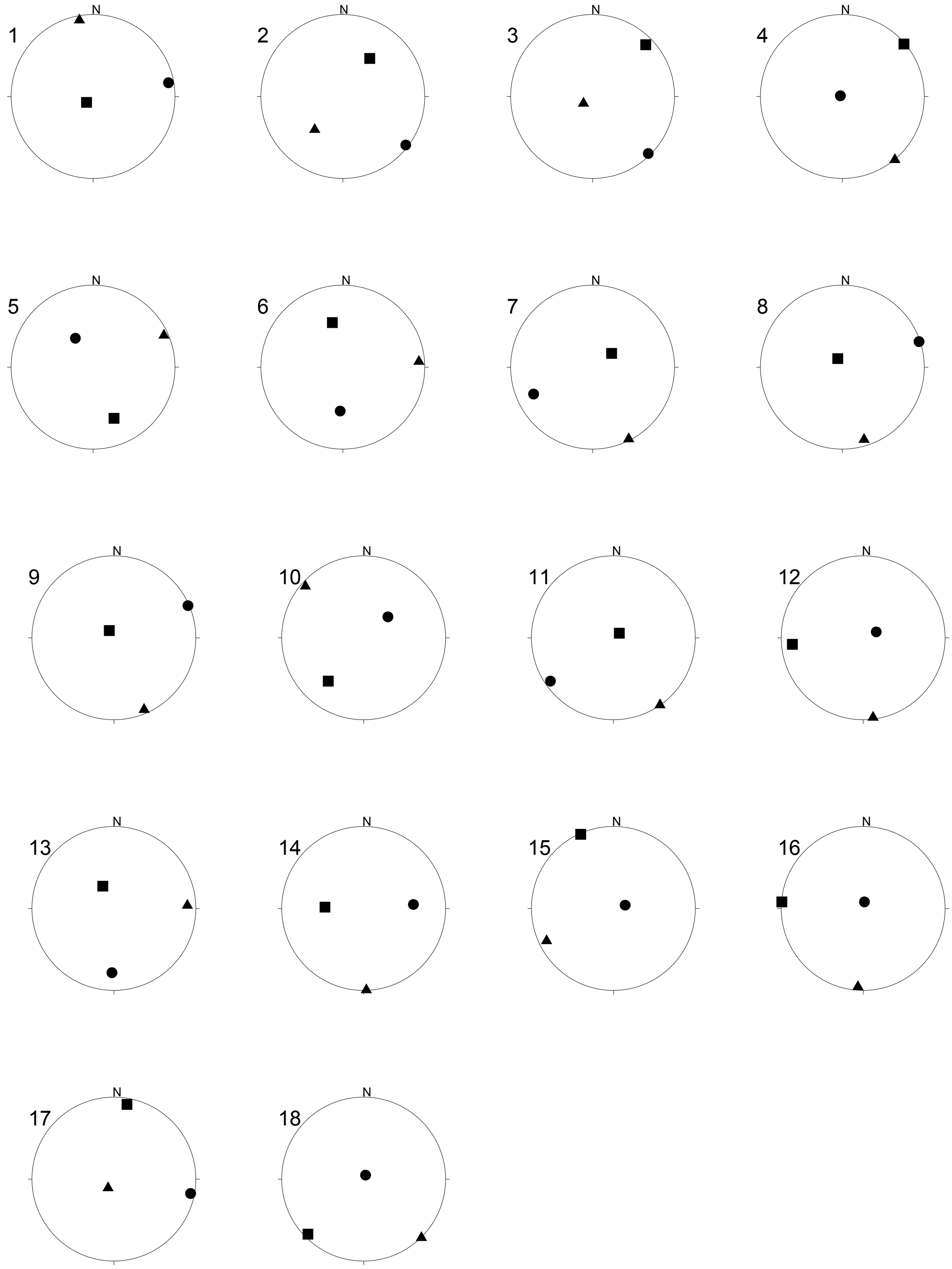

Fig. 2 Spatial orientations of main stress axes

▲ - σ_1, ■ - σ_2, ● - σ_3
1, 2, 3… number of stress tensor solution

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