Focal Mechanisms of Mining Induced Seismic Events: Reliability of the Solutions

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Abstract
Focal mechanisms of 168 mining induced seismic events that occurred in the Halemba coal mine area (Upper Silesian Coal Basin, Poland) were determined using the seismic moment inversion method. 38 seismic events were studied in detail. For 12 tremors, non-double couple components were dominant in seismic moment tensor. Focal mechanisms of 38 tremors were repeatedly recalculated for gradually changing vertical Z coordinate values to obtain the maximum double couple seismic moment tensor component. The high value of non-shearing components in seismic moment tensor is probably a result of inaccurate localization. The non-double couple mining induced seismic events are not so common in the USCB as previous studies suggested.

1. Introduction
Focal mechanisms of underground mining induced seismic events are mostly related to shearing process and double-couple (DC) seismic moment tensor component. However, there are many publications reporting that other focal mechanisms are possible (Feignier and Young 1992, Stickey and Sprenke 1993). They are related to cavity collapse, pillar burst or tensial fault (Haseqawa et al. 1989) and their common feature is the high value of isotropic (I) or compensated linear vector dipole (CLVD) components.

The high value of non-double couple components can also be a result of improper distribution of seismic network. If seismometers are not distributed around the focal source (poor coverage of focal sphere), it is possible that not all of the components of force acting in the source are recognized (Dubiel 1996).
Furthermore, inaccurate localization of the source may influence the quality of focal mechanism estimation. This concerns particularly the vertical coordinate $Z$ of seismic source (Dubiel 2003).

For seismicity observed in Upper Silesian Coal Basin (USCB) the number of seismic events with non-double couple focal mechanisms exceeds 30% (Sagan and Dubiel 1996). Considering the longwall opening exploitation system applied in the USCB mines, so large number of non-shearing seismic events seems to be difficult to explain.

The goal of the present study was to determine the reliability of focal mechanisms solutions and to estimate the relation between the value of vertical coordinate $Z$ and the percentage share of DC component of seismic moment tensor.

2. The results

The series of 168 seismic events induced in the Halemba coal mine (USCB) was studied. The energy range of the events was $1\div700$ kJ. All the events were recorded by local, underground seismic network consisting of 16 vertical seismometers. The localizations of the seismic events were determined by mine seismological staff with standard procedure.

Focal mechanisms of all the seismic events were calculated using the seismic moment tensor inversion method. The inversion was executed for P-wave first motion, in time domain, according to linear L1 and square L2 norms.

![Fig. 1. Spatial distribution of 38 studied seismic events in relation to seismic network.](image)

To obtain the most reliable focal mechanism solutions, the following seismic events were excluded:
− events with the low-quality records,
− events which differed in focal mechanism solutions according to L1 and L2 norms,
− events whose sources were localised outside the seismic network area.

The consequence of the selection was the rejection of 130 tremors. For 26 of the remaining 38 tremors, the dominant double couple component was observed. The average share of DC component was 55%. The spatial distribution of 38 studied seismic events in relation to seismic network is presented in Fig. 1.

Next, the focal mechanisms of all 38 seismic events were recalculated repeatedly for various $Z$-coordinate values. The value of vertical coordinate $Z$ had been increased and decreased by 5 m in consecutive calculations until the maximum value of double couple component was achieved. The total number of calculations was 833. The example of recalculations for one seismic event is presented in Table 1. The table shows that the initial value of the percentage share of DC component increased from 32.2 to 97.7%

<table>
<thead>
<tr>
<th>Z coordinate [m]</th>
<th>Isotropic component [%]</th>
<th>CLVD component [%]</th>
<th>DC component [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>−498</td>
<td>13.4</td>
<td>54.4</td>
<td>32.2</td>
</tr>
<tr>
<td>−508</td>
<td>11.08</td>
<td>50.2</td>
<td>38.1</td>
</tr>
<tr>
<td>−533</td>
<td>12.9</td>
<td>48.4</td>
<td>38.8</td>
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<tr>
<td>−558</td>
<td>5.1</td>
<td>26.4</td>
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<tr>
<td>−583</td>
<td>2.6</td>
<td>3.6</td>
<td>93.8</td>
</tr>
<tr>
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<td>0.6</td>
<td>2.6</td>
<td>96.8</td>
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<tr>
<td>−598</td>
<td>0.3</td>
<td>2.1</td>
<td>97.7</td>
</tr>
<tr>
<td>−603</td>
<td>1.6</td>
<td>0.8</td>
<td>97.5</td>
</tr>
</tbody>
</table>

For all 38 studied seismic events, the value of DC component significantly increased and exceeded 50%. Its average value was 79%. For most seismic events the maximum percentage share of DC component was achieved in the range ±100 m but the maximum change of $Z$ coordinate value was 300 m.

The spatial orientations of nodal planes for optimized focal mechanisms are presented in the Fig. 2. The orientations are closely related to N-S, NE-SW and NW-SE fracture orientations previously observed and measured in the rock mass.

The study revealed that the mining seismic events are induced in various and instantaneously changing stress conditions. Variation of state of stress manifests itself
by inducing the tremors related to various faulting processes. 21 studied seismic events were relevant to normal, 15 to reverse and 2 to strike-slip faulting (Fig. 3). The seismic events of various focal mechanisms were induced close each other in time and space alike.

Fig. 2. Spatial orientations of nodal planes for optimized focal mechanisms solutions: (a) A-nodal plane, (b) B-nodal plane.

Fig. 3. Focal mechanisms of studied seismic events in relation to mining and geological conditions.
3. Conclusions
1. The non-double couple mining induced seismic events are not so common in the USCB as previous studies suggested.
2. The high value of non-shearing components in seismic moment tensor is probably a result of inaccurate localization, especially of the vertical coordinate Z.
3. The seismic events related to normal, reverse and strike slip faults were observed. These seismic events occur close to each other.
4. The spatial orientation of nodal planes is closely related to spatial orientation of fractures in the rock mass.
5. Assuming that the shearing process is the most reliable focal mechanism for seismicity in the USCB, the percentage share of non-double couple components can be applied for estimation of the accuracy of vertical localization of seismic events foci. Thus, the high value of non-double couple component may indicate inaccuracy of vertical localization.

References
Dubiel, R., 2003, Non-double couple induced seismic events, Sbornik vedeckich praci, Technical University Ostrava 2, 61-66.

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