Geomechanics '96, Rakowski (ed.) © 1996 Balkema, Rotterdam, ISBN 905410....

Effect of Faults on Rockbursts Hazard

A. Tajduś, T. Majcherczyk & M. Cała
University of Mining and Metallurgy, Kraków, Poland

ABSTRACT: At present time in Polish underground coal mining most of the mines excavates burst-prone coal seams. Especially high rockburst hazard occurs in the vicinity of the faults. This paper presents theoretical considerations about stress field around several types of faults (normal and reverse faults). Two cases of coal seam excavation around a fault are described. For both of them numerical calculations of stress field (utilising Finite Elements Method) were done. Case I shows excavation of thick coal seam on three layers with crossing through the fault system. Case II shows excavation of several coal seams on both sides of the fault. In both cases different seismic activity, connected with the geological profile of the rock mass and fault occurrence, was noticed. Finally several conclusions about minimising rockburst hazard in the vicinity of fault, basing on numerical and analytical calculations were formulated.

INTRODUCTION

About 60% of polish underground coal mines excavates burst-prone coal seams. Great part of observed bursts and tremors is connected with faults occurrence. Several investigations considering influence of faults on rockburst hazard has been carried out all over the world (Filcek *et al.* 1984, Kaiser 1993, Stacey & Ortlepp 1994, Wong 1992, Morrison & MacDonald 1990, Goszcz 1996). One can also find several case histories about seismic activity of rock mass around faults - Tajduś *et al.* 1995, Brauner 1994, Konecny 1995. Except macroscopic investigations of this phenomenon some laboratory trials utilising AE techniques were also done (Dai *et al.* 1995). All above presented scientific works only partly explain effects of faults on coal bursts hazard and there are still many questions without answers.

This paper shows simple procedure for estimation of principal, normal and tangential stresses in the vicinity of the faults basing on Coulomb-Mohr failure criterion (Filcek *et al.* 1994).

ANALYSIS OF BURSTS AND TREMOR HAZARD AROUND FAULTS

For proper evaluation of fault influence on rockburst hazard it's necessary to collect some basic data:

- fault geometry (throw, inclination, fault type - normal or inverse, *etc.*),
- rock mass geology around fault (with special care to hard rock layers able do accumulate considerable amounts of elastic energy,
- *in situ* stress measurements,
- strength and strain properties of rock mass,
- occurrence of auxiliary faults,
- detailed fault fissure description (aperture width, gouge type, joint roughness - for example width of K^{3}odnicki fault fissure - Upper Silesia, Poland - ranges to 26m filled with gouge consisted of crushed breccia),
- water inflow or outflow,
- geophysical data of the rock mass seismic activity.

It's well known fact that creation of the fault was accompanied with high tectonic stresses. Some millions years passed from fault creation so probably tectonic stresses had decreased to zero due to relaxation. That's why, in the vicinity of the faults we may assume creation of secondary critical equilibrium state. Vertical stresses are close to initial and horizontal ones depend on critical equilibrium state. Let's assume that before fault creation vertical stress component is close to gravitational. That is for not inclined layers components of initial stresses are equal:

$p_{zt}=$ ❁ $\cdot h$ (1)

$$p_{xt}=\frac{\nu}{1-\nu}\cdot p_{zt} \qquad (2)$$

where: ❁ - average rock mass density

H- mining depth

● - Poisson coefficient

and for inclined layers:

$$p_{zt}=-\gamma\cdot h\cdot\left(cos^2\alpha+\frac{\nu}{1-\nu}sin^2\alpha\right) \qquad (3)$$

$$p_{xt}=-\gamma\cdot h\cdot\left(sin^2\alpha+\frac{\nu}{1-\nu}cos^2\alpha\right) \qquad (4)$$

where: ♀ - layers inclination angle.

In case of reverse fault horizontal stresses p_{xt} are compressive and lower from initial horizontal and vertical stresses (fig.1). In case of normal fault horizontal stresses p_{xt} are higher than initial and depending on rock mass strength may be compressive or tensile (fig.1).

Nomenclature for fig.1:

p_{zt}^{n}, p_{xt}^{n} - horizontal and vertical stresses around normal fault,

p_{zt}^{r}, p_{xt}^{r} - horizontal and vertical stresses around reversed fault.

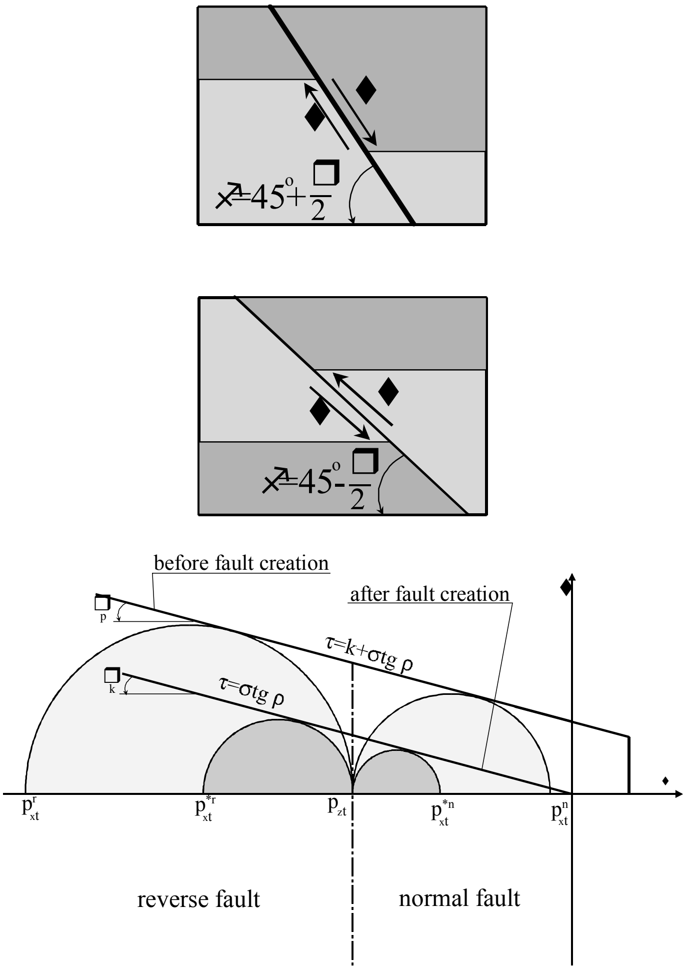

Fig.1 Stress field during formation of normal and reversed faults.

The reason of fault formulating is occurrence of tangential stresses (higher than rock mass shear strength) along fault plane. Rock mass shear on fault plane happens because of acting of principal stresses:

- for normal fault

$$p_{xt}^{n}=p_z\cdot\left[tg^2\left(45^o-\frac{\rho}{2}\right)-\frac{2k_u}{p_z}\cdot tg\left(45^o-\frac{\rho}{2}\right)\right] \qquad (5)$$

- for reverse fault

$$p_{xt}^{r}=p_z\cdot\left[tg^2\left(45^o+\frac{\rho}{2}\right)-\frac{2k_u}{p_z}\cdot tg\left(45^o+\frac{\rho}{2}\right)\right] \qquad (6)$$

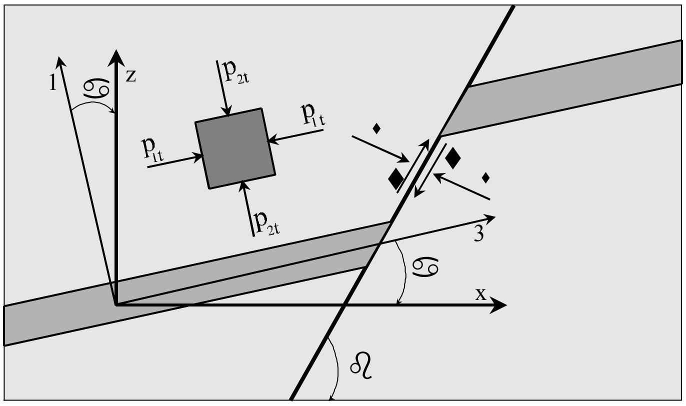

Fig.2 Stress field during normal fault formulation

Utilising Coulomb-Mohr strength criterion we may obtain principal stresses before fault creation:

$$p_{1t}=p_{2t}\cdot tg^2\left(45^o-\frac{\rho}{2}\right)-2k_u(1-cos2\alpha)\cdot tg\left(45^o-\frac{\rho}{2}\right) \qquad (7)$$

$$p_{2t}=\frac{2\left\{p_{zt}+k_u(1-cos2\alpha)\right\}\cdot tg\left(45^o-\frac{\rho}{2}\right)}{(1+cos2\alpha)+(1-cos2\alpha)\cdot tg^2\left(45^o-\frac{\rho}{2}\right)} \qquad (8)$$

$$p_{3t}=\nu\cdot\left(p_{1t}+p_{2t}\right) \qquad (9)$$

where: p_{1t}, p_{2t}, p_{3t} - principal stresses around fault, (p_{2t} ● p_{3t} ● p_{1t})

k_u - cohesion of rock mass around fault

● - internal friction angle of the rock mass around fault.

After fault formulation horizontal stresses decrease occurred due to lack of cohesion along fault plane. Assuming k_u=0 one can obtain values of principal stresses after fault formulation (p_{1t}^{*}, p_{2t}^{*}, p_{3t}^{*}) from equations (7), (8), (9). Knowing values of principal stresses we can easily calculate normal and tangential stresses on fault plane:

$$\sigma=\frac{p_{1t}^{*}+p_{2t}}{2}-\frac{p_{1t}^{*}-p_2}{2}cos2\left[\alpha-\left(45^o-\frac{\rho}{2}\right)\right] \qquad (10)$$

$$\tau=\sigma\cdot tg\rho \qquad (11)$$

It may be easily calculated that value of fault inclination and also layer inclination strongly influences both normal and tangential stresses on fault plane. Fig.3 shows normal stresses on fault plane versus layer and fault inclination angles (example data).

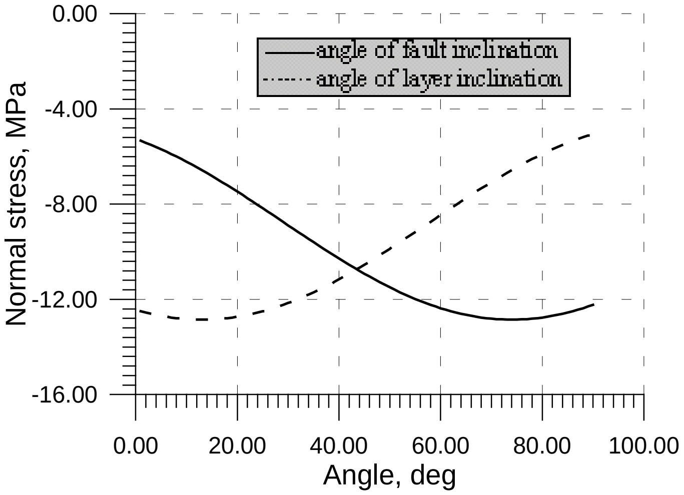

Fig.3 Normal stresses on fault plane versus layer and fault inclination angles

EXAMPLES OF STRESS FIELD ANALYSIS AROUND FAULTS

Two examples of mining in the vicinity of the fault are investigated below.

Case I shows mining of thick coal seam (three layers) with backfill close to fault (fig.4,5).

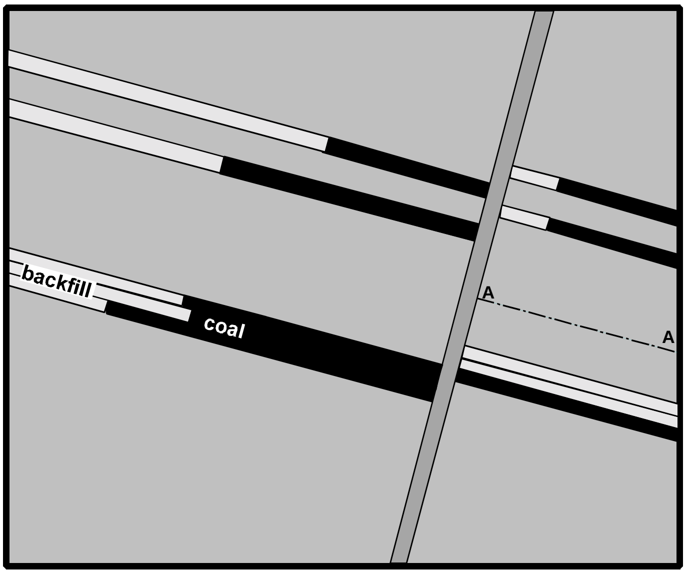

Fig. 4 Case I, situation before mining through the fault

Fault fissure is very wide and filled with low strength gouge. For estimating stress field around fault Finite Element Method (FEM) was utilised. Calculations were performed for two flat models: situation before mining through the fault (fig.4) and situation after mining through the fault (fig.5)

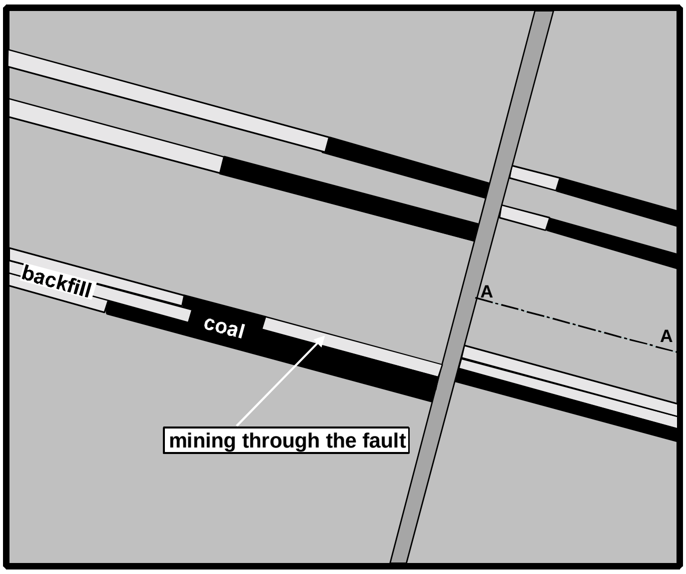

Fig.5 Case I, situation after mining through the fault

Fig.6 and fig.7 show respectively vertical and effective (Von Mises) stresses for intersection (A-A) chosen in hard layer placed above coal seam. This hard, sandstone layer is able to accumulate elastic energy (which might be emitted in case of burst or tremor).

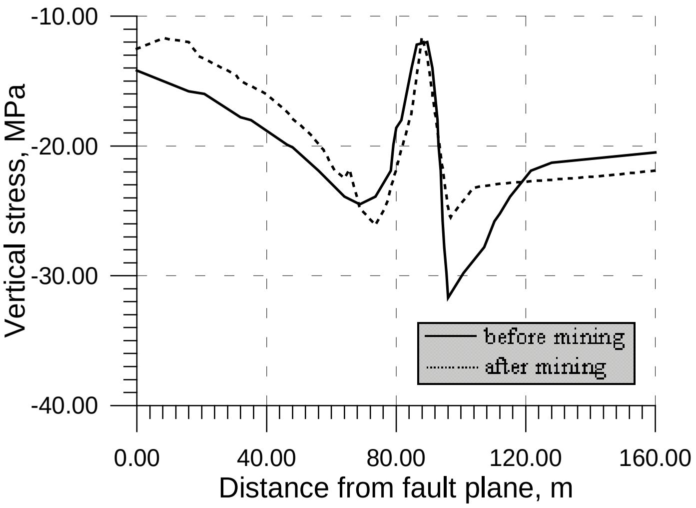

Fig.6. Vertical stresses for intersection A-A (case I)

For both analysed models considerable stress concentrations ranging about 15m from fault zone can be observed. Taking this under consideration one may suppose that tremor mechanism is connected with hard sandstone layer placed above coal seam. Due to low strength properties of fault gouge dynamic fault slip should not take place. But during mining several roof falls in fault region were noted, what implicates that quasi-static displacement on fault plane had occurred. Effective stress values are higher than tensile and bending strength of sandstone and may lead to its failure. This hypothesis is confirmed by observed seismic activity of the rock mass: a lot of low-energy tremors.

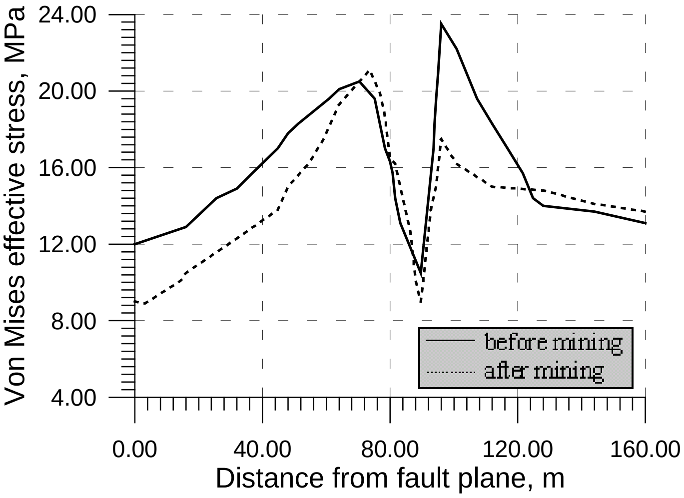

Fig.7 Effective stresses for intersection A-A (case I)

Case I showed mining of thick coal seam in the vicinity of fault with wide fissure filled with low-strength gouge. Case II presents mining of three thin coal seams around normal fault with thin fissure. Numerical calculations (utilising FEM) were also performed for case II - fig. 8 shows a flat model of mining situation.

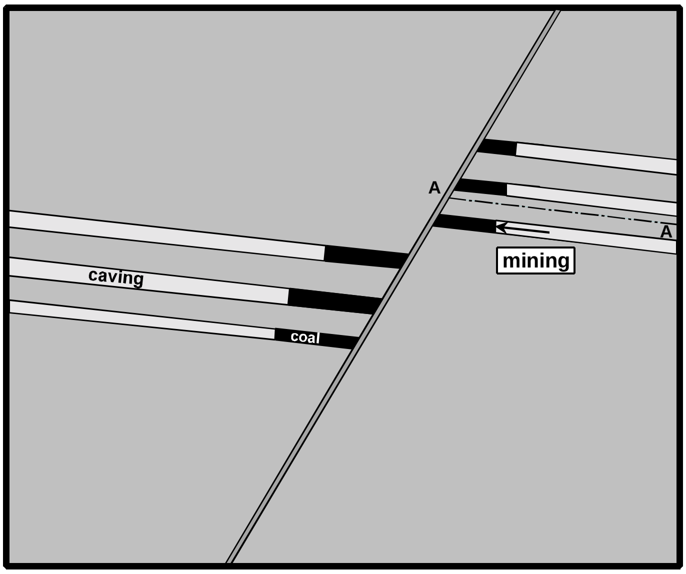

Fig.8 Case II - mining situation

Fig.9 and fig.10 show respectively vertical and effective (Von Mises) stresses for intersection (A-A) chosen in hard layer placed above coal seam. Several tremors were occasionally noted at excavation time. Calculation's results shows vertical and effective stress concentrations above seam's edges (similarly as for the case I) but the values are much lower than in the case I. Differences in rock mass seismic activity can also be preliminary predicted utilising analytical calculations - equation (1)-(11). Table 1 shows calculation's result for both cases.

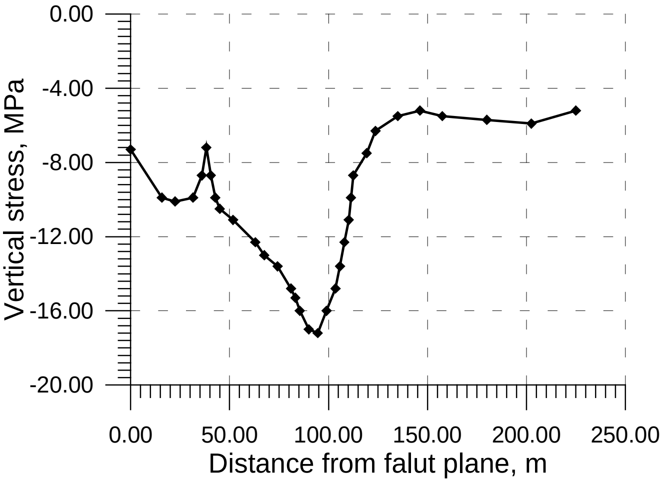

Fig.9 Vertical stresses for intersection A-A (case II)

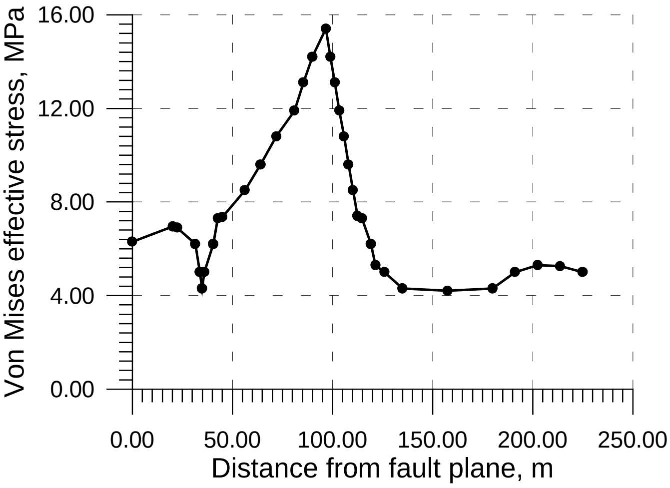

Fig.10 Effect. stresses for intersection A-A (case II)

Table 1. Comparison of analytical calculation's result for case I and case II

stress, MPa	case I	case II
p_z	-12.34	-14.91
p_x	-9.53	-11.34
p_{t1}	-6.76	-12.65
p_{t2}	-15.44	-15.06
p_{t3}	-6.66	-8.31
p_{t1}^*	-5.57	-5.44
p_{t2}^*	-15.5	-15.24
p_{t3}^*	-6.32	-6.2
•	-7.9	-8.76
•	-4.2	-4.66

Table 1 shows that due to fault creation values of vertical stresses increased of about 25% for case I and 2% for case II. This simple procedure lets estimate the scale of predicted rock mass seismic activity.

REDUCING ROCKBURST HAZARD IN GALLERIES MINED IN FALUT REGION

Several active methods of rock burst prevention can be utilised for to change stress field around the faults. This methods may be separated into two groups. First group includes all activities for discharge stress concentration in high-strength layers placed above coal seams. That may be for example destressing or torpedo blasting, water injections or proper order of mining around the fault (Tajduœ *et al.* 1995)

Second group covers the activities for eliminating possibility of sudden slip on the fault plane using for example liquid injections (Logan 1992, Board *et al.* 1992).

Special support systems should be applied in case of galleries mined in the vicinity of the faults in rockburst hazard. Support system should consist of high-capacity steel arches accompanied with yielding rock bolts - fig.11 (Tajduœ & Ca³a 1996).

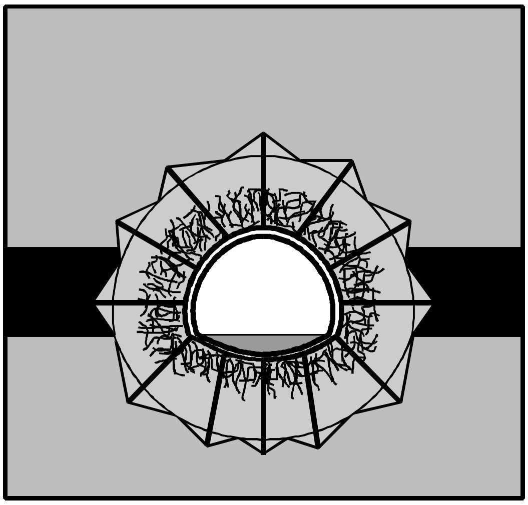

Fig.11. Proposed gallery support in rockburst hazard conditions

Widespread application of rock bolt reinforcement in South Africa (Ortlepp 1993, 1994, Ortlepp & Stacey 1995), cable bolts in Chile (Kvapil *et al.* 1989) and Canada (Kaiser 1993, Brummer *et al.* 1994, Tannant *et al.* 1995) proved its effectiveness in rockburst's hazard conditions. Taking this under consideration such kind of reinforcement should be applied in rockburst hazard conditions, especially in the vicinity of the faults.

CONCLUSIONS

1. The data base, necessary to collect, for proper estimation of rockburst hazard in the vicinity of the faults was presented.
2. Simple analytical procedure for obtaining stress field components around faults basing on Coulomb-Mohr strength criterion is shown. Utilising this procedure one can qualitatively estimate scale of the rock mass seismic activity around faults (what was confirmed by analysing two case histories).
3. Proposition of support system for galleries mined in the vicinity of faults consisted of high-capacity steel arches and yielding rock bolts was formulated.

ACNOWLEDGEMENTS

Versatile help and technical co-operation of Dr. Jerzy Flisiak is gratefully acknowledged.

REFERENCES

Board M., Rorke T., Williams G. & Gay N. 1992. Fluid injection for rockburst control in deep mining. *Proceedings of 33rd U.S. Symposium on Rock Mechanics*. (ed. by Tillerson & Wawersik). A.A.Balkema. Rotterdam. pp. 111-120.

Brauner G. 1994. *Rockburst in coal mines and their prevention.* A.A. Balkema. Rotterdam. pp.119-120.

Brummer R.K., Yi X., Tannant D.D., McDowell G.M. 1994. Rock bolt behaviour under dynamic loading: Field trials and numerical simulation. *Proceedings of the 1st North American Rock Mechanics Symposium Rock Mechanics, Models and Measurements, Challenges from Industry*, ed. by P.P. Nelson and S.E. Lubach. A.A. Balkema. pp. 961-968.

Dai S.T., Labuz J.F. & Shah K.R. 1995. Seismic global measurements of fault slip and energy release from laboratory experiments. *Proceedings of 35th U.S. Symposium on Rock Mechanics* (ed. Daemen & Schultz). A.A. Balkema. Rotterdam. pp. 447-452.

Filcek H., K³eczek Z. & Zorychta A. 1984. Approaches and solutions of rock burst hazard problems in underground coal mines. *Zeszyty*

Naukowe AGH, Górnictwo 123, Kraków, (in polish).

Filcek H., Majcherczyk T., Tajduœ A. & Ca³a M. 1994. *Analyse of stress concentrations in the vicinity of Brynowskie faults in part of coal deposit under Katowice downtown in the light of coal bumps hazard*. Unpublished materials. Kraków, Dept. of Rock Mechanics, University of Mining & Metallurgy, (in polish).

Goszcz A. 1996. Rockburst hazard in underground coal mines and activities for its restriction. *Proceedings of XIX Winter School of Rock Mechanics*. Ustroñ-Kraków. University of Mining and Metallurgy, pp. 91-106, (in polish).

Kaiser P.K. 1993. Keynote address: Support of tunnels in burst prone ground - Toward a rational design methodology. *Proceedings of International Conference Rockburst and Seismicity in Mines*, ed. by Young. A.A. Balkema. Rotterdam. pp. 13-27.

Konecny P. 1995. The influence of tectonic structures on the stress strain conditions and rock bursts induction in the vicinity of a longwall face. *Proceedings of International Conference Mechanics of Jointed and Faulted Rock*. Ed. by H.P. Rossmanith. A.A.Balkema. Rotterdam. pp. 731-736.

Kvapil R., Baeza L., Rosenthal J., Flores G. 1989. Block caving at El Teniente mine, Chile. *Transactions of the Institutions of Mining & Metallurgy Section A. Mining Industry*. no 98, Jan-April, pp. A43-A56.

Logan J.M. 1992. The influence of fluid flow on the mechanical behaviour of faults. *Proceedings of 33rd U.S. Symposium on Rock Mechanics*. (ed. by Tillerson & Wawersik). A.A.Balkema. Rotterdam. pp. 144-149.

Morrison D.M & MacDonald P. 1990. Rockburst mechanisms at INCO mines. *Proceedings of 2nd International Symposium Rockburst and Seismicity in Mines*. A.A.Balkema. Rotterdam.

Ortlepp W.D. 1993. High ground displacement velocities associated with rockburst damage. *Proceedings of International Conference Rockburst and Seismicity in Mines*, ed. by Young, A.A. Balkema pp. 101-106.

Ortlepp W.D. 1994. Grouted rock-studs as rockbursts support: A simple design approach and an effective test procedure. *Journal of South African Institution of Mining & Metallurgy*, no 2, pp. 47-63.

Ortlepp W.D. , Stacey T.R. 1995. Technical note: Safety and cost implications in the spacing of support. *Journal of South African Institution of Mining & Metallurgy*, no 5-6, pp. 141-146.

Stacey T.R. & Ortlepp W. D. 1994. Rockburst mechanisms and tunnel support in rockburst conditions. *Proceedings of International Conference Geomechanics'93*. ed. by. Z. Rakowski. A.A.Balkema. Rotterdam. pp. 39-46.

Tajduœ A., Majcherczyk T., Ca³a M. 1995. The influence of faults on coal burst hazard in coal seams excavated in its vicinity. *Proceedings of International Conference Mechanics of Jointed and Faulted Rock*. Ed. by H.P. Rossmanith. A.A.Balkema.Rotterdam. pp. 737-742.

Tajduœ A. & Ca³a M. 1996. possibilities of rockbolts application in rockburst hazard condition. *Proceedings of XIX Winter School of Rock Mechanics*. Ustroñ-Kraków. University of Mining and Metallurgy, pp. 197-213, (in polish).

Tannant D.D., Brummer R.K., Yi X. 1995. Rockbolt Behaviour Under Dynamic Loading: Field Tests and Modelling. *Int. J. Rock. Mech. Sci. & Geomech. Abstr*. vol 32, no 6, pp. 537-550.

Wong I.W. 1992. Recent developments in rockburst and mine seismicity research. *Proceedings of 33rd U.S. Symposium on Rock Mechanics*. (ed. by Tillerson & Wawersik). A.A.Balkema. Rotterdam. pp. 1103-1112.