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Evaluation of Stress Concentration in a Coal Mine Panel Using Seismic Data

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Abstract Since P and S-velocities in rocks are often stress sensitive, we inverted P and S-velocities of coal bed roof to evaluate stress concentrations in a coal mine panel. Because P and S-wave in this panel have almost the same detectability, we normalized velocities and used a two-category classification to evaluate stress-concentration zones. By comparing with monitoring results of microseisms, two zones were proven plausible, and another one was confirmed as a reasonable conclusion. By spatial Monte Carlo simulations and statistics, we found spatial associations between faults and stress concentrations, and estimated correlation radius between faults and stress-concentration zones.
Keywords seismic refraction, tomography, stress evaluation, simulation, spatial statistics

Introduction

Stress concentration near underground panel of coal mine has direct association with water inrush. Although coal industry had adopted some methods, such as geomechanical analysis of regional stress, on-line stress monitoring, electromagnetic radiation monitoring, and micro seismic monitoring, to predict stress distributions, it is not sufficient to fully understand underground stress concentration (Xue et al. 2010, Dou et al. 2012).

Since seismic velocities are positively correlated with underground stress, velocity tomography of P-wave has been applied for prediction of pillar stress in gold mine (Scott et al. 2004) and stress in coal mine panel (Dou et al. 2012). On the other hand, seismic refraction tomography is a useful tool to build near-panel velocity model. We can use refraction tomography to invert velocity distribution of coal mine panel and to estimate stress concentration.

In this work, we used P and S-wave tomography to rebuild roof velocities of a coal mine panel respectively and to evaluate stress concentration simultaneously. We also researched the association between stress concentration and nearby faults by spatial Monte Carlo simulations and statistics.

Study underground panel

163L02C is a production panel of Jisan coal mine, Shandong province, China. This panel is 755 m long and 135 m wide (fig. 1). In the middle of this panel, a parallel middle roadway separates whole panel into two parts―the larger (78 m) western section and the smaller (57 m) eastern one. Nine small-throw faults are scattered around this panel (fig. 1). All faults found in this panel are normal fault and their throw is less than 1.5 m. As for coal bed, its dip angle is smaller than 6 degree, its average depth is 677 m, and its thickness is between 2.3 m and 6.4 m. In sum, geological structures in this panel are relatively simple.

Methodology

Field observation and tomography

In the process of observation, we arranged seismic sources in the middle roadway with a spacing of 16 m and deployed receivers in head entry and belt entry with a spacing of 8 m. After carried out survey by a 54 channels observation system, we gathered 105 original shot records. Because coal bed roof (medium grained sandstone) is stiffest and has largest velocity in coal-bearing strata, first breaks of seismic records are roof refraction. Among gathers, we interactively picked their first breaks of refracted P and S-wave respectively. Then, we used Simultaneous Iterative Reconstruction Technique (Gilbert 1972) to invert for velocity images of P and S-wave first breaks. After several iterations, we achieved final velocity distributions of panel's roof, and used them as input to evaluate stress concentration.

Evaluation of stress concentration

In this panel, deposition condition is relatively stable and homogeneous, vertical stress is two times horizontal stress, and confining stresses have small difference (Kang and Zhang 2010). We assume vertical stress as the only factor which can affect seismic velocity. Since P-wave and S-wave have the same detectability (product of stress sensitivity and spatial resolution) on stress in this panel, we normalized velocities and classified them with two category classification. After classification, we achieved three stress-concentration zones and marked them with A, B and C (fig. 2); meanwhile, we used an indirect method of microseisms to verify the plausibility of evaluation. Since high-energy microseisms often happen in the location of maximum stress gradient (Maxwell and Yang 1995, He and Dou 2012), we found microseisms and zone C are consistent with each other. Meanwhile, high-energy microseisms are easily being triggered at weak structures such as in-seam faults and roadways (zone B) and unlikely being triggered at strong structure (zone A, where surrounding rocks were reinforced by bolt and other methods).

Discussion

Traditionally, faults were treated as an important factor which can affect stress concentration in coal mine panel. In this in situ example, area around zone B contains some small-throw faults. Are those faults directly connected with stress concentrations? In order to confirm this issue, we used spatial Monte Carlo simulations and spatial statistics to explore it.

This method evaluates the spatial correlation of a given pattern of fault traces and stress-concentration zones by computing the percentage of included faults (PIF) and percentage of extended concentration areas (PECA) as the stress concentration areas are increasingly dilated and expanded out from the original centers. In the process of simulation, fault traces are random generated in panel and stress-concentration areas are spatial correlation with them within a given radius (10 m, 20 m, 30 m, 40m or 50 m). To every radius, we carried out 20 simulations. After spatial statistics, we cross plot their PECA and PIF in fig. 3(a). If correlation radius is small, points will be close to top left corner; if correlation radius is big, points will be close to diagonal. In order to clarify this relationship, we fit every cloud with an exponential model and show the results in fig. 3(b). With correlation radius increasing from 10 m to 50 m, fitted curves move from top left corner to the diagonal. The farther the curve is away from the diagonal, the higher the spatial correlation exists between stress concentration centers and faults.

For true faults and stress concentrations around zone B, we also carried out spatial statistics and cross plot its PECA and PIF with red circles in fig. 3(b). We found almost all circles are near dash curve with small deviation (correlation radius = 40 m). Therefore we concluded that faults and stress-concentration areas around zone B are directly correlated and their correlation radius is most likely around 40 m.

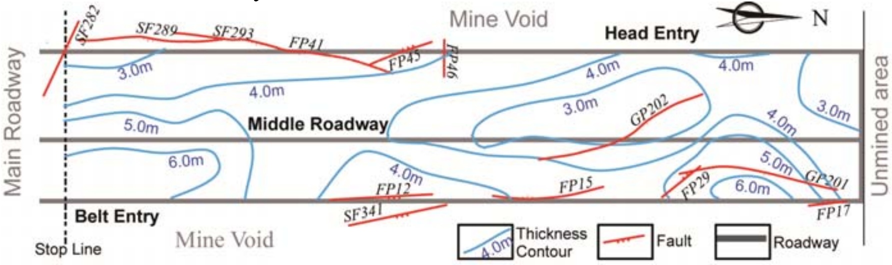

Fig. 1 *Plan view map of 163L02C coal mine panel. Map plots the layout of roadways, the contours of coal bed thickness and true fault traces (fault throw ≤ 1.5 m).*

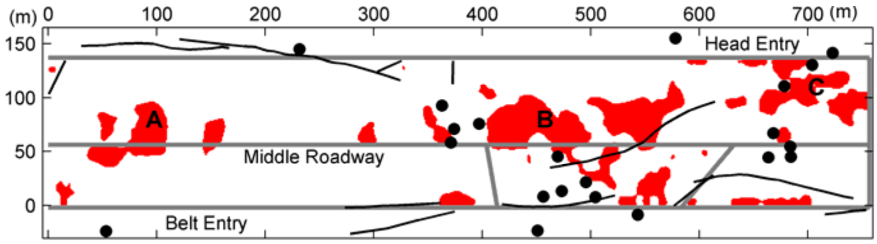

Fig. 2 *Stress-concentration zones (red color) and high-energy microseisms (black point) in 163L02C panel. Black lines are true fault traces as fig.1 shown.*

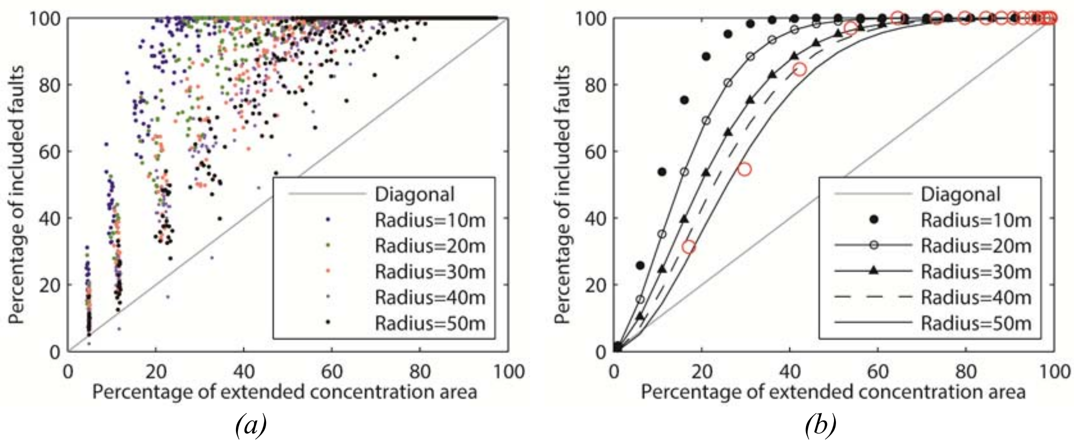

Fig. 3 *Simulated and fitted cross plots of PECA and PIF. (a) Simulated cross plots with different correlation radii; (b) Fitted curves of cross plots with different correlation radii. Red circles are true cross plots around zone B.*

Conclusion

In this in situ example, we presented a seismic tomographic approach for characterizing stress concentration in a coal mine panel and analyzed spatial association between stress concentrations and faults. After analysis, we found: (1) roof refraction tomography is a useful tool to evaluate stress concentration in coal mine panel and the evaluated zones in this panel are plausible, (2) faults have direct spatial association with stress concentration, and (3) correlation radius between faults and stress-concentration zones is around 40 m in this in situ example.

Through tomography of roof refraction, one can obtain stress concentrations of local stress field, which affects the fracture behavior and extent of nearby strata. Furthermore, one can estimate the permeability changes and pore pressure variations of nearby aquifer during the process of coal mining supported by other geological and geomechanic data. In sum, this method can help coal producers to manage underground water or prevent water inrush of underground panel.

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