Study on Prediction of Burst Hazard Associated with Advancing a Tunnel through Goaf

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Abstract: To prevent gas burst disasters while advancing a tunnel through the goaf, the technology for predicting burst hazard associated with advancing a tunnel through the goaf is presented in this paper. First, the safety control distance of prediction holes in each zone before the tunnel is advanced through the goaf is established via numerical simulation to further determine the number and arrangement of prediction holes. Then, burst prediction indicators are determined and prediction results are obtained through analysis. Prediction of burst hazard associated with advancing the left tube of Huayan Tunnel of Chengdu-Chongqing Motorway through the goaf of coal seam K₁ of South Zhongliangshan Mine at ZK3+130 was performed and it was found that none of the prediction indicators exceeded critical values, thus concluding there was no burst hazard. With more pre-support measures put in place, the proposed technology ensured the safety in advancing the tunnel through the goaf of coal seam K₁.

1. Introduction
Engineering geological conditions are relatively complex in coal measure strata. The goafs left after these strata are mined out are often distributed in a complex and irregular manner⁴,⁵ and there would be coal pillar areas left in the goafs. When a tunnel is advanced through the goaf, not only the stability of surrounding rock is affected, but also there is the potential for coal and gas bursts due to the presence of the coal pillar areas left and disturbances by tunnel excavation⁶.

However, existing researches on advancing a tunnel through goaf concentrate on tunnel stability control and goaf detection⁷, with a lack of systematic investigation into burst hazard prediction associated with advancing a tunnel through goaf. In response, the technology of prediction of burst hazard before a tunnel is advanced through a goaf is presented in this paper and burst hazard prediction before a tunnel is advanced through a goaf is carried out by taking Huayan Tunnel of Chengdu-Chongqing Motorway in Chongqing as an example.

2. Project Overview
Huayan Tunnel is part of the Chengdu-Chongqing Motorway Expansion Project. Its left tube is 4962 m long and its right tube 4974 m long. It is a super long tunnel of the highway passing through Mount Zhongliang. Data on coal seam mining in South Zhongliangshan Mine where Huayan Tunnel is located show that many goafs and coal pillars are present above +280m level after years of mining. Based on design data and mining conditions of South Zhongliangshan Mine, goaf of coal seam K₁ is...
identified at ZK3+130 of the left tube of Huayan Tunnel in Permian Longtan Formation strata. There are coal pillar areas left in the goaf. When the tunnel is advanced through the edge of the goaf, it is difficult for the fractured, loosened surrounding rocks to withstand high stresses. If the coal pillar areas are prone to burst, coal and gas bursts are likely to result from the combined effect of ground stress and gas pressure.

3. Prediction of Burst Hazard Associated with Advancing a Tunnel through Goaf Area
Tunnel excavation will induce changes in coal mass and gas occurrence state within the disturbance zone, whereas beyond this zone the coal mass and gas occurrence state remain in the original state. To predict the burst hazard in coal masses near the coal pillar area, prediction holes should be arranged both inside and outside the disturbance zone [8]. In predicting burst hazard associated with advancing a tunnel through the goaf, an adequate safety control distance should be ensured between prediction hole control points and tunnel contour line.

3.1. Safety control distance of prediction holes
Coal pillars on the edge of the goaf carry pre-support load. Tunnel excavation induced disturbance causes redistribution of the state of stresses within some area around the coal pillars and changes in gas occurrence state. This may increase the risks of gas burst. Consequently, to accurately predict gas burst hazard, we must have an accurate knowledge of the gas occurrence state both inside and outside the stress disturbance zone.

The safety control distance (sum of stress disturbance ranges for the tunnel and goaf) is defined as the distance from coal pillar support pressure boundary to tunnel contour line when the coal pillar edge line coincides with tunnel stress disturbance boundary. To predict the burst hazard in coal masses near the coal pillar area, prediction holes should be arranged both inside and outside the disturbance zone. Numerical modeling analysis was performed for the distribution of stress field in coal mass around the goaf during tunnel excavation to define the range of stress disturbance in the goaf. The safety control distance for advancing the tunnel through the goaf was obtained in combination with the stress disturbance range for the tunnel.

According to actual field conditions, a physical model as shown in Fig. 1 was built and stress monitoring points are arranged as shown in Fig. 2.

![Fig. 1 Physical model for advancing the tunnel through goaf](image-url)
From numerical modeling the distribution of stresses at monitoring points in vertical and horizontal directions is derived as shown in Fig. 3 and 4.

As shown in Fig. 3 and 4, stresses are relatively low near the goaf boundaries and increase toward coal pillars where stress concentration occurs; as the distance increases, stresses decrease gradually to the original stress level. As shown in Fig. 3, the stress disturbance zone for goaf in vertical direction is in the range of -50m≤z≤50m while upper and lower boundaries of the goaf are z_{upper}=40m and z_{lower}=-40m respectively. Thus the range of pre-support pressure on coal pillar is 10m for S_{upper} and S_{lower}; the safety control distance in vertical direction is 22m for S_{upper} and 18m for S_{lower}. As shown in Fig. 4, the stress disturbance zone in goaf in horizontal direction is in the range of -50m≤x≤50m while its left and right boundaries are x_{left}=-40m and x_{right}=40m respectively. Thus the range of pre-support pressure on coal pillar is 10m for S_{left} and S_{right}; the safety control distance in horizontal direction is 17m for S_{left} and S_{right} [9].

Therefore, values of safety control distance of prediction holes for advancing the tunnel through goaf are determined as shown in Table 1.
Table 1 Values of safety control distance of prediction holes for advancing the tunnel through goaf

| Safety control distance (m) | $S_{upper}$ | $S_{lower}$ | $S_{left}$ | $S_{right}$ |
|---------------------------|-------------|-------------|------------|-------------|
|                           | 22          | 18          | 17         | 17          |

3.2. Number and arrangement of prediction holes

Once the coal pillar area enters the tunnel excavation induced disturbance zone, the burst hazard prediction should be performed before the tunnel is 14m (prediction distance) from the goaf. The arrangement of boreholes is as follows:

Drill at least 4 prediction holes toward coal pillar area, with holes located on four sides of the coal pillar area and at least 1 hole reaching beyond the safety control distance $S$ (22m in vertical distance above the contour line, 18m in vertical distance below the contour line and 17m in horizontal distance on the left and right sides). If the geological conditions are complex, the number of prediction holes should be increased as appropriate to ensure the reliability and accuracy of prediction results. The arrangement of prediction holes is illustrated in Fig. 5.

![Fig. 5 Schematic arrangement of prediction holes](image)

3.3. Burst prediction approach and method for advancing the tunnel through goaf

(1) Once the coal pillar area enters the tunnel excavation induced disturbance zone, the burst hazard prediction should be performed before the tunnel is 14m (prediction distance) from the goaf.

(2) Holes for burst hazard prediction are arranged as follows: Drill at least 4 prediction holes toward coal pillar area, with holes located on four sides of the coal pillar area and at least 1 hole reaching beyond the safety control distance (22m in vertical distance above the contour line, 18m in vertical distance below the contour line and 17m in horizontal distance on the left and right sides). If the geological conditions are complex, the number of prediction holes should be increased as appropriate to ensure the reliability and accuracy of prediction results.

(3) Measure burst prediction indicators and obtain prediction result:
   a. If gas content $W < 8m^3/t$, then there is no burst hazard;
   b. If gas content $W \geq 8m^3/t$, then there is burst hazard;
   c. If gas dynamics such as burst, jamming, jacking and sound due to sudden pressure release occur in prediction holes, then the presence of burst hazard should be determined directly.

4. Field Application of Burst Hazard Prediction Technology

Prediction of burst hazard was performed for the coal pillars within 22m above the tunnel. The measured maximum gas content in the coal pillar area is 3.31$m^3/t$. This value is less than the critical value of 8 $m^3/t$. To ensure the accuracy of prediction result, cuttings gas desorption indicator was also
determined and it was found that the maximum cutting gas desorption indicator was 0.10 ml/g•min$^{1/2}$. This value is less than the critical value of 0.5 ml/g•min$^{1/2}$ [10]. There were no gas anomalies such as burst, jamming and jacking during drilling operation. It is thus determined that there is no burst hazard. With more pre-support measures put in place, the tunnel was safely and smoothly advanced through goaf of coal seam K1.

5. Conclusions
(1) The law of distribution and change of stress in coal mass around the goaf during tunnel excavation was numerically modeled and analyzed, and the safety control distance of prediction holes for advancing the tunnel through the goaf was established.

(2) The technology to predict burst hazard associated with advancing a tunnel through goaf, including determining the safety control distance of prediction holes, the number and arrangement of prediction holes, measuring burst prediction indicators and drawing prediction result through comprehensive analysis, was presented.

(3) By predicting the burst hazard associated with the left tube of Huayan Tunnel passing through the goaf of coal seam K1 in South Zhongliangshan Mine at ZK3+130, it was found that none of the burst hazard prediction indicators including gas content and cutting gas desorption indicator exceeded critical value. Thus it is determined that there is no burst hazard. With more pre-support measures put in place, the proposed technology ensured the safety in advancing the tunnel through goaf of coal seam K1.

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