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Height of the mining-induced fractured zone above a coal face

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ABSTRACT

The development height of a gas conducting fracture zone (GFZ) in the gob overlying strata is crucial to the gas drainage and safe production of a coal mine. In order to address the issues of excessive gas concentration and uncertain GFZ height in No. 7435 Face overlying strata of Kongzhuang Coal Mine, China, the caving characteristics of overlying strata were explored using both physical experiments on similar materials and numerical simulations of Particle Flow Code (PFC) software and verified each other. The relationship of cracks development to porosity changing characteristics was introduced to quantitatively determine the height of the local GFZ. The quantified GFZ heights were compared with those measured using the in-situ drilling flow method. The results showed that 1) PFC software could accurately simulate the overlying strata caving behaviors, thus saving manpower, materials and financial resources needed for related physical experiments, and 2) the temporospatial distribution characteristics of porosity could be used to forecast GFZ height, and are of significant importance for determination of GFZ. Overall, the conclusions are of engineering significance for accurate arrangement of boreholes for gas drainage and reduction of mine gas disasters.

1. Introduction

The overlying and underlying strata are affected during mining. Fractures separating strata on the stratum surfaces and crossing strata interconnect to each other, forming a dynamically changing mining-induced fracture zone. Gas adsorbed in the fractures of coal seams gradually desorbs and flows under gas pressure through strata-crossing fractures into the roadway and mining face (Peng, 2006; Jozefowicz, 1997). The mining-induced fracture zone provides passageways for pressure-relief gas flowing from coal seam and its surrounding coal/rock strata as well as spaces for pressure-relief gas storage (Whittles et al., 2007). Therefore, the mining-induced fracture zone together with the caving zone is defined as gas conducting fracture zone (GFZ). Due to its presence, the desorbed gas will rapidly flow upward in the fracture zone and its above separating zone.

To ensure the safety of gas-bearing coalbed excavation and the rational utilization of coal and gas resources, three primary incentives were proposed for recovering coal mine gas (CMG) (Bibler et al., 1998; Cyrul, 1993). Frequent gas outbursts seriously endanger the lives of mine workers and production safety. Table 1 summarizes the major mine explosions since 2000. Besides production safety, environmental pollution of China also attracts more and more attention. The production and utilization of coal as the traditional high-carbon energy becomes highly controversial, and its severe greenhouse effects make low-carbon energy development become the mainstream of energy development (Warmuzinski, 2008; Ju et al., 2016). Methane emitted from domestic and international coal mines represents approximately 8% of the world's anthropogenic methane emissions and contributes 17% of the total anthropogenic greenhouse gas emissions (U.S. EPA, 2003, 2010). Therefore, how to deal with coal seam gas production is a major issue in coal mine production. The main component of gas coexisting with coalbed is methane (CH_4). Its calorific value is $>$33,000 kJ/m^3 (Zhao, 2005) and comparable to that of conventional natural gas, thus it is considered as a clean energy source. Most mined coal seams in China are Carboniferous and Permian and are rich in gas. Currently, CMG utilization technology has been widely applied worldwide (Karacan et al., 2011; Somers and Burklin, 2012). According to the statistics of China's 2015 National Energy Board, CMG reserve in China is about 1.023×10^{11} m^3 (Zhou et al., 2016). Such high gas content is both serious potential hazard to coal mine safety and resources for national economics if fully utilized.

As the face continuously advances, the overlying strata collapse and some regions are prone to forming fracture zones (Meng et al., 2016). The height, evolution process, and impacting factors of GFZ are often studied using empirical formula, physical experiments, numerical simulation and field tests. Zhang et al. (2009) analyzed the coupling mechanism of flow-stress using the flow-stress damage model-based RFPA^{2D} software, obtained GFZ height and further verified it using an empirical formula. Miao et al. (2011) obtained the GFZ height of Bulianta mining

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Table 1
Some of the major coal mine explosions that occurred after 2000 (modified from United Nations, 2010).

Country	Date	Coal mine	Fatalities
China	14 Feb., 2005	Sunjiawan, Haizhou shaft, Fuxin	214
USA	2 Jan., 2006	Sago, West Virginia	12
Kazakhstan	20 Sept., 2006	Lenina, Karaganda	43
Russia	19 March., 2007	Ulyanovskaya, Kemerovo	108
Ukraine	19 Nov., 2007	Zasyadko, Donetzk	80
USA	5 April., 2010	Upper Big Branch, West Virginia	29
Turkey	17 May., 2010	Karadon, Zonguldak	30

area through field tests and analyzed the causes for the difference between the field measured height and the calculated result using the empirical formula. Bai et al. (1995) acquired the empirical formula for GFZ height through field tests of multiple coal mines at the condition of stable gob. Zhang and Shen (2004) assessed the redistributed stress by field tests, physical modeling and numerical simulations and further studied GFZ height and strata destabilization mechanisms.

Due to the difficulties in predicting the development of crack initiation, expansion and penetration (Erarslan, 2016; Yang et al., 2014), current studies on GFZ height mainly focus on the field-statistics-based empirical formulas and experimentally unverified numerical simulations. Their results often differ greatly from the on-site reality. In addition, very few investigations focus on the real-time, quantitative description of GFZ height, as well as the status of cracks connection within GFZ. Therefore, quantitative study of GFZ height is of importance.

In this study, using the No. 7435 Face of Kongzhuang Coal Mine as the study subject, we applied the particle flow numerical model to simulate the collapse of the face roof, verified the simulation results using similar material physical experiments, and obtained GFZ height based on the simulated porosity distribution. The results are of significance for reducing gas disasters, improving the efficiency of gas drainage of high position boreholes, which are the construction boreholes drilled from the returning airway to the coal seam roof. In the field, the fractured space formed by caving was used as a gas flow path towards the boreholes under the action of negative pressure of suction, thus extracting large amount of gas to solve the issue of excessive gas concentration in the upper corner and drilling high position boreholes are the most effective way to ensure gas drainage and the safety of gas-bearing coalbed excavation and rationally gas and coal resources mining.

2. Mining and geological conditions of Kongzhuang coal mine

Kongzhuang Coal Mine has longitude of 116°57′13″ E and latitude of 34°41′55″ N. It is located on the southernmost tip of Datun Mining Area and is about 4 km north of Pei County, Jiangsu Province, and within the area of Weishan County, Shandong Province, China. Kongzhuang Coal Mine went into production in 1977 and has design capacity of 1.05 million t/a. Fig. 1 shows its location. The fully mechanized No. 7435 mining face has elevation of −267 to −188 m, designed advance length of ~1400 m, designed net face length of 134 m, and coalbed average thickness of 6.0 m. Its corresponding surface elevation is +32 m.

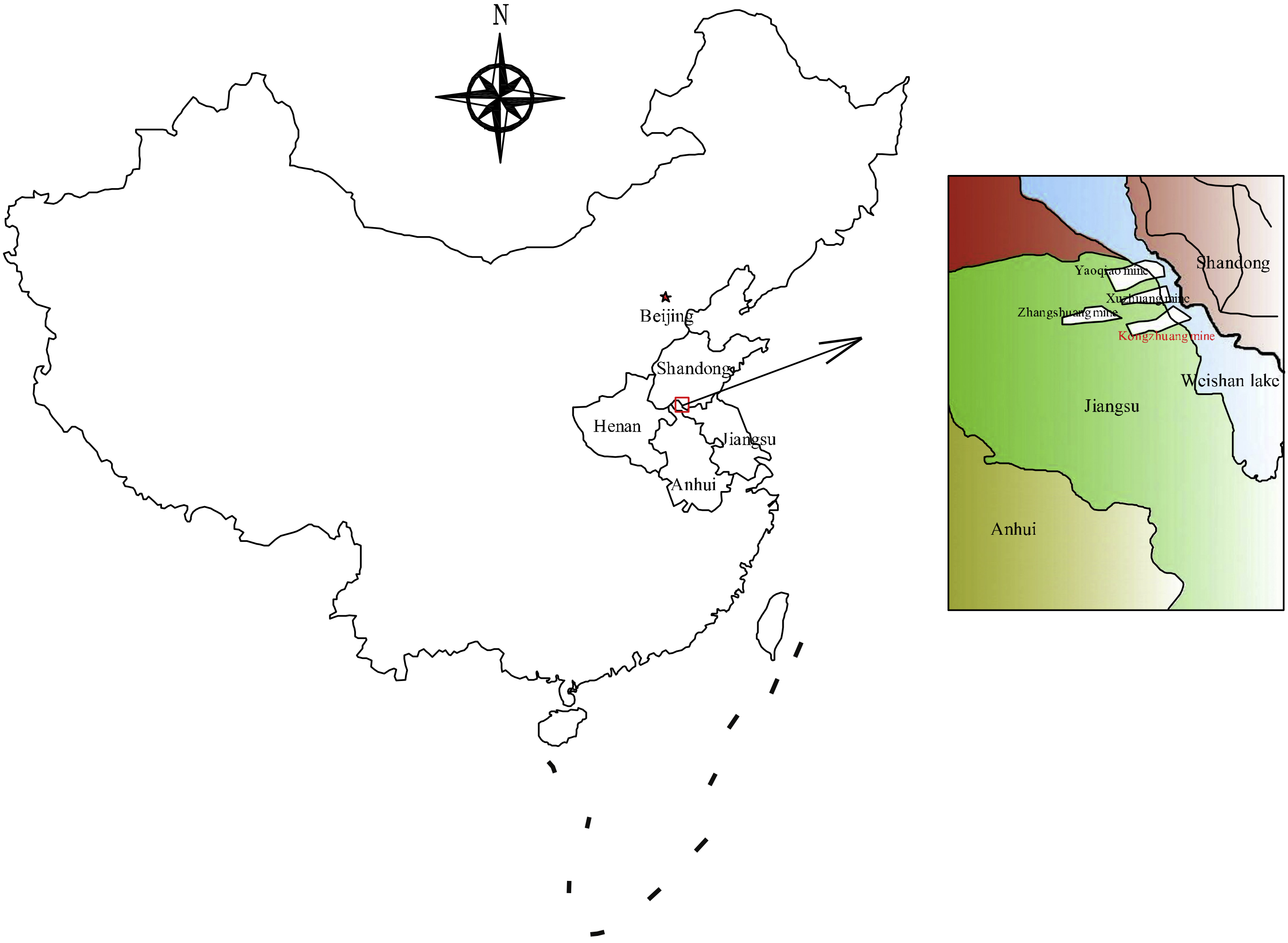

Fig. 1. Location of Kongzhuang Coal Mine modified from Yang (2004).

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