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Yifan Zeng

Research on Risk Evaluation Methods of Groundwater Bursting from Aquifers Underlying Coal Seams and Applications to Coalfields of North China

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Research on Risk Evaluation Methods of Groundwater Bursting from Aquifers Underlying Coal Seams and Applications to Coalfields of North China

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Supervisor's Foreword

Mine water inrush events often occur during coal mine construction and production; they account for a large proportion of the nation's coal mine disasters and accidents in China. Between 2005 and 2014, 513 water inrush incidents have occurred with a total loss of 2753 lives. As mining depths and mining intensity continue to increase, the hydrogeological conditions encountered are becoming more complex. One challenge is to prevent or predict water inrushes from the aquifers that underlie many of the coal seams. Because water inrush from the underlying aquifers is a nonlinear dynamic process, its occurrence is controlled by multiple factors and involves complex mechanisms. Dynamic nonlinear processes are not readily amenable to mathematical equations. The water inrush coefficient, introduced in the 1960s, has been widely used by coal mine hydrogeologists because it had the advantages of being a simple physical concept, convenient to calculate, and easy to use. It has been modified several times to better reflect actual water inrush conditions and has played a positive role in resolving the dangerous problem of water inrush from underlying aquifers in China. However, the water inrush coefficient method only considers two factors: the potentiometric pressure of the underlying confined aquifer and the thickness of the aquitard that functions as a water barrier between the coal seam and the underlying aquifer. Other factors also govern water inrush from underlying aquifers. In addition, the water inrush coefficient threshold is empirical and typically determined using reported water inrush incident statistics. Because geological and hydrogeological conditions can vary significantly in different areas, considerable deviations can exist between results of water inrush assessments and reality.

In this thesis, Dr. Yifan Zeng developed an information fusion model with information fusion theory, geographic information system technology, and modern mathematical methods to evaluate the risks of groundwater inrushes from aquifers underlying coal seams. In the new model, the water inrush vulnerability index was calculated with a variable weights theory. This method overcomes the defect of the traditional vulnerability index method in which weights of the water inrush main factors are constant in the evaluation process. The innovative model was applied to two coal mines in China. The results proved better than the traditional vulnerability index method. The work reported in this thesis represents a significant advance in addressing the global issue of mine water control and management.

I congratulate Yifan for this excellent work. His dissertation is one of the best in China University of Mining and Technology, Beijing, because of the volume of reliable data, defensible scientific analysis, and world significance of the research results.

Beijing, China | Prof. Dr. Qiang Wu
December 2017

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Contents

Chapter 1
Introduction

1.1 Research Background and Purposes

1.1.1 Present Situation of Water Hazards in Coal Mines of China

The coal resource is abundant in China. By the end of 1988, the proved reserves were nearly 400 billion tons according to the statistical results of the "1989 World Energy Conference", ranking second in the world [1] and 30 billion tons less than the statistics published by the United States. With the rapid development of Chinese economy in recent years, the coal production has been ranked No. 1 in the world. For example, from 2010 to 2015, the average annual output reached 3.62 billion tons, accounting for half of the world's annual production [2]. However, the hydrogeological conditions in the coalfields of China are complex, and the types of water hazards are diverse. Because of the number of coal mines, the amount of coal reserves and the severity threatened by water bursting, preventing and controlling water have been a challenge. The water hazards mainly occur in the coal mines in south China and north China. The north China coal ore districts are mainly threatened with Carboniferous and Permian karst fissure water hazards while the coal fields in south China are mainly threatened with late Permian karst water. In the northwest coal-producing area, the Jurassic fissure water hazard is the main factor. In the northeastern part of China, there are not only sandstone fissure water hazards of the coal seam floor but also the hazards caused by the Quaternary pore water [3]. In addition, due to the long history of coal mining in China, old kilns and goafs are present in the shallow areas of many mine and the surrounding areas. Almost every ore district in south China and north China is faced with the threat of pooled water in abandoned kilns and goafs. In recent years, water disasters caused by old kilns have shown an upward trend.

Coal mine water inrushes and flooding accidents occurred frequently in China. Over the past decade, the number of heavy, large water inrush accidents was 513, which is unprecedent. A total of 2753 people was injured or lost their lives because of these water hazards (Table 1.1). In 21 days from April 6, 2012 to April 26, 2012, five large, major coal mine flooding accidents occurred with 49 fatalities [4, 5]. 12 people died in the water inrush accident in Jilin Fengxing Coal Mine on April 6,

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Table 1.1 Select water disasters in coal mine from 2005 to 2014

Year	Number of water disasters	Number of fatalities
2005	104	593
2006	38	267
2007	63	255
2008	49	263
2009	21	125
2010	18	167
2011	22	163
2012	13	107
2013	14	245
2014	13	217
Total	513	2753

2012. On April 10, 2012, four people were killed because of the water inrush in Kongzhuang Mine. On April 13, 2012, 11 people lost their lives in the accident of water inrush in Changzhifulianying Mine [5–7].

In addition, the water inrush (burst) and inundation accidents often resulted in huge economic losses and casualties. For example, in Henan Jiaozuo coalfield, there were nine significant water hazard accidents with bursting water quantity up to 60 m^3/min, resulting in a total mine discharge of 540 m^3/min. They not only caused serious over-exploitation of groundwater and waste of water resources, but also resulted in the high drainage cost in per ton coal, accounting for approximately 20% of raw coal prices. The annual drainage costs of the mine were 20–25 million Yuan in Renminbi (RMB) [8]. In 1984, two mines were flooded, and one mine was forced to stop production in the Fangezhuang Mine water inrush accident, resulting in direct economic losses up to 0.5 billion RMB. In 2005, the mine flooding accidents in Meizhou Daxing Coal Mine and Handan Niuer Zhuang Mine caused economic losses up to 47.25 million and 382 million RMB, respectively [9]. In 2005 alone, there were 109 coal mine accidents in China, killing 605 people, including 13 large-scale water hazard accidents with 360 deaths. On August 7, 2005, Meizhou Daxing coal mine flooding accident resulted in six people killed and 117 people missing [10].

1.1.2 Current Situation of Water Hazards from Coal Floor in Coalfields of North China

North China Carboniferous Permian coalfields are the most important coal-bearing regions and coal production bases in China. They are distributed in more than 70 ore districts in 12 provinces such as Shanxi, Mongolia, Hebei, Shandong and Henan. The coal reserves and production account for approximately 68 and 65% nationwide, respectively [11, 12]. Maintaining the stability of the coal production scale is of great importance to China's economic and social development. However, the hydrogeological conditions of the north China coalfields are extremely complex and vary. The water hazard accident has become the second killer of the coal mines only after the gas accidents. The water hazards seriously threaten the safe production of the coal mines.

Water discharge and bursting into mines occurred frequently in north China coalfields. When the water yields were large, they seriously affected the normal production of coal mines. In addition, the coal mines had to pay enormous cost of drainage, which not only increased the cost in per ton of coal but also caused a great waste of the valuable groundwater resources. The coal seams in the middle and deep of the north China coalfields were threatened by the strong aquifers at their bottom. Tens of billions of tons of safe pillars could not be recovered [13, 14].

High stress areas were formed, and the coal seam pressure became higher and higher in north China coalfields as the mine was gradually developed deeper and deeper. The underlying karst aquifer of the middle-deep lower coal group was supper thick because of deposition. Due to the multi-period crustal movement and post-tectonic transformation, the karst aquifer was seriously damaged, resulting in a high degree of karst development. The aquifer was not only rich in water but also highly permeable. The effective thickness of confining bed between the karst aquifer and the middle-deep lower coal group got smaller and smaller due to the disturbance of the mine engineering. Pressure on the coal seam floor was also increased as coal mining approached to the deep constantly. Under the combined influence of several negative factors, like high pressure, high water abundance and thinner thickness of confining bed, the coal exploitation became more and more difficult. The risk of coal seam floor water inrush significantly increased with mining space and degree of mechanization improved [15–17]. Therefore, it is of great practical significance to study the targeted prevention and control measures to relieve the threat of water hazard and to safely and efficiently exploit the lower group coal [17, 18].

1.2 Research Status of the Subject

1.2.1 Current Situation of Research in the World

The development of coal industry provides a basis for the study of coal seam floor water inrush. The history of large-scale development of the coal industry in the former Soviet Union, Hungary, Germany and other countries has been nearly a hundred years. In the coal mining practices, both experience and technologies in the management of floor water hazard have been accumulated and several theoretical doctrines have been brought up.

In 1944, Wegger Frens, a Hungarian and the originator of studying the floor water hazard, based on static mechanics, gave the definition and calculation formula of the relative aquifer [19, 20]. Using water pressure and the thickness of floor aquifuge to quantitatively assess the possibility of water inrush opened the prologue to the study on water hazard from coal floor, and the associated floor water inrush assessment methods had been applied in China until now. In the same period, Slalesh Lev, based on the idea of material mechanics, proposed a simplified calculation model of floor water inrush, that is, the floor aquifuges were idealized as fixed beams on both sides and the water pressure were assumed to be the stress acting on beams [21], and then a calculation formula of safe hydrodynamic pressure for safe mining was deduced.

In the 1960s, the Hungarian had officially written the technical method of using relative thickness of the aquifers to assess floor water inrush into national norms, named "Mining Safety Regulations". Different statements of calculation were illustrated according to different water and hydroelectric geological conditions. Over this period, various kinds of water hazard from coal floor that were encountered during the development of the coal industry promoted coal workers to pay attention to and study the floor water problems based on the static mechanics theory.

From 1970s to the 1980s, the study of coal floor water hazard began to introduce the research results of rock mechanics. In the study of the failure mode of the waterproof rock group, Santos concluded the strength criterion of Hoek-Brown rock mass. The energy release point was used to quantitatively determine the compressive stress of the waterproof rock group [22, 23]. Sammarco found that early warning of water bursting can be achieved by monitoring precursor information of water inrush such as rapid changes in water levels [24, 25]. V. Mironenk firstly proposed that water-resisting layer would be destroyed by mining disturbance when he studied the floor water hazard [26, 27]. He believed that the floor water gushing-out was the result of water resisting floor to be broken under the action of mining disturbance and water pressure.

After the 1980s, the seepage theory of groundwater in the rock fracture has made great progress since the discovery of the cubic law of the permeability coefficient of the plane fracture network. Erichsen constructed a coupled model of groundwater seepage-geostress interaction [28, 29]. Elsworth built a flow-fluid-solid coupling model for calculating the bias current of groundwater in rock fissures [30, 31]. All the above results were absorbed into the floor water inrush research, improving the research on floor water permeability mechanism and water hazard prediction method.

1.2.2 Current Situation of Research in China

Before 1949, the hydrogeological work in the mining areas was very weak. Although coal production was low and mining depth was shallow, mine flooding accidents happened quite often. In 1935, the catastrophic water inrush accident in Zibo North Mine resulted in 350 deaths, and the entire mine was flooded and scrapped. After 1949, the coal industry has been rapidly developed. The scale, scope and depth in coal mining continuously extended with the progress of mining technology. Meantime, the encountered problem of floor water hazard became increasingly prominent, and the hydrogeological work of the mine became an indispensable part in the coal mine