Practical Technologies and Equipment for Preventing and Controlling Coal Mine Water Hazards in China

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Abstract This paper presents some of the most successful technologies and equipment for preventing and controlling coal mine water hazards in China, as well as introduces the application of some technologies and equipment. In addition, China's coal mine water hazard types are summarized, and the practical technologies and equipment for preventing and controlling coal mine water hazards are divided into four categories: 1) exploration technologies and equipment; 2) monitoring technologies and equipment; 3) predicting technologies and equipment; 4) controlling technologies and equipment.

Keywords Coal Mine Water Hazard, Prevention and Control Technology and Equipment, Exploration, Monitoring, Prediction, Control

Introduction

China, with large amounts of coal resources, has vast experience with underground coal mines, some of which operate under extremely complex hydrogeological conditions. In recent years, coal mine water disasters have occurred frequently, which has restricted the sustainable development of China's coal industry. To prevent and control coal mine water hazards, Chinese hydrogeologists have developed some practical technologies and equipment.

The purpose of this paper is to systematically review practical technologies and equipment for preventing and controlling China's coal mine water hazards, as well as exchange engineering experiences with coal mine hydrogeologists from all over the world.

Summary of China's Coal Mine Water Hazard Types and Their Prevention and Control Technology

Based on different water source and water inrush channels, coal mine water hazards can be divided into different types. Coal mine water hazards are divided into four groups (Shuning *et al.* 2008), according to the positional relation of the groundwater inrush source and the mining space: 1) groundwater inrush from the roof of the mining space, 2) groundwater inrush from the floor of the mining space, 3) groundwater inrush from the goaf, and 4) groundwater inrush from surface water. In addition, water hazards are divided into: fault water hazards, sink hole hazards, and poorly sealed borehole water hazards, according to differences in the water inrush channels.

In general, water hazard preventing and controlling technologies are divided into four main categories (Shuning *et al.* 2008). The first category is exploration technology, including geophysical exploration, drilling exploration and hydrogeological tests. The second category is monitoring technology. This includes for example coal mine water real time monitoring system, coal seam floor and roof water hazard monitoring or early warning technologies. The third category is prediction technology, including technologies such as coal mine water inflow prediction technology, coal mine roof or floor water inrush prediction technology. The fourth is coal mine water inrush control technology. It is imperative to control coal mine water inrush as soon as it occurs.

Coal Mine Water Hazard Exploration Technology and Equipment

1. Three dimensional seismic exploration technology and equipment

Three-dimensional seismic exploration is the most effective geophysical prospecting technology for high-resolution exploration of geological structures. It uses sound waves to form sharp three-dimensional images of underground formations. Experts in the Xi’an Research Institute of China Coal Technology & Engineering Group have successfully used this technology not only to detect the faults whose throw is less than 3 m in plain area, but also to obtain good results in mountainous area and deserts.

Equipment used for three dimensional seismic technologies includes the ‘ARISE’ digital seismic exploration device and the ‘Geovecteur Plus’ data processing system.

2. Electromagnetic detection technology and equipment

Electromagnetic detection technologies usually require less rigid earth surface conditions than seismic exploration technologies. Practical electromagnetic detection technologies include magnetic dipole source technology, high resolution earth resistivity technology, high density resistivity technology, direct current electric technology, transient electromagnetic technology, and audio-frequency electrical penetration technology.

In the Shendong coal mining area, there have been several serious accidents caused by water inrush accompanied with sand collapse. Magnetic dipole source and high resolution earth resistivity techniques helped mining engineers pinpoint the distribution of quaternary water-bearing area. This is very helpful for designing working face layout.

In March 2010, a severe accident caused by Ordovician limestone water inrush occurred in the coal seam 16 mining roadway in the Luotuoshan Coal mine. Thirty-two coal miners died in this accident. Ground transient electromagnetic technology was applied to detect the water inrush channels. In Fig. 1, the red point is water inrush point, and the blue low resistivity areas clearly show the water inrush channels of Ordovician limestone. Some boreholes were drilled at the low resistivity areas, which proved the accuracy of transient electromagnetic technology.

The Taoyuan coal mine, located in eastern China, had a water inrush accident at the No.1022 working face. To drain the water, ten boreholes were drilled without using geophysical prospecting technology at the beginning. Unfortunately, most of them were dry. Then, high resolution direct current electric technology was adopted to pinpoint the anomaly water-bearing area. According to the low resistivity anomaly area detected, additional dewatering boreholes were designed and drilled. All

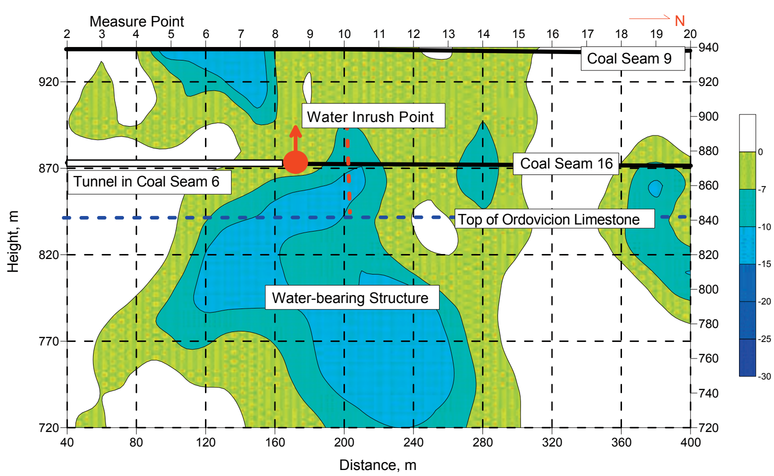

***Fig. 1** Diagrammatic cross-section of apparent resistivity for detecting water inrush channel*

of them worked well. This case proved the reliability of high resolution direct current electric technology.

3. Underground nearly-horizontal directional drilling technology and equipment

The underground nearly-horizontal directional drilling technology and equipment, which was first developed by Xi'an Research Institute of China Coal Technology & Engineering Group, is most advanced in the mining industry (Zhijun *et al.* 2011). The record of 1111 m drilling depth was made in underground in-seam directional drilling.

The calculation of borehole trajectory is the key to designing and constructing horizontal directional drilling boreholes. The calculation model of horizontal directional drilling borehole trajectory was established, with which three-dimensional trajectory can be obtained. Trajectory software was developed to arrange a uniform cluster of boreholes in the coal seam.

Directional drilling equipment came into use in 2008. Up to now, it has worked very well in China's coal mines. In the Hongliu coal mine, located in northwestern China, directional drilling technology was successfully used to explore undergroundwater-bearing areas which were near the mining roadway. In addition, in the Zhaogu coal mine, located in central China, directional drilling technology was employed to drill boreholes effectively which were used for underground grouting.

4. Dewatering test technology and equipment

Dewatering tests are an effective method in hydrogeological supplementary exploration of coal mines. The water source and water channels can be pinpointed, and countermeasures for preventing and controlling mine water hazard can be decided based on the tests. Furthermore, in order to pinpoint the groundwater recharge channel, dewatering tests are often combined with tracer tests which are based on hydrochemical analysis and environmental isotope technology. Successful dewatering tests can help coal mine hydrogeologists obtain important hydrogeological parameters, such as hydraulic conductivity, storage coefficient, and specific yield, so it is very popular in Chinese coal mines, especially in coal mines under very complex hydrogeological conditions.

For example, in the Feicheng mining area, which is seriously threatened by karst groundwater, dewatering tests of different scales have been conducted to explore hydrogeological conditions. With the data obtained in dewatering tests, numerical models were built to predict groundwater inflow. The equipment used in dewatering tests includes KJ117 monitoring system, water quality testing equipment, or groundwater modeling software.

Coal Mine Water Hazard Monitoring Technology and Equipment

1. Mine water real time monitoring system

Mine water real time monitoring system is a distributed serial digital communication network system based on Controller Area Network (CAN) technique. The monitoring system includes three parts: monitoring center (*e.g.* mainframe computer, printer, network communication adapter), monitoring substation (*e.g.* sensors, data acquisition unit, network communication interface) and data transmission network (Dewu *et al.* 2013).

The monitoring items include for example water level, water pressure, water temperature, precipitation, mine water inflow, maintenance condition of mine water facilities, real time condition of mine drainage system.

This system has been used in the Jiaozuo, Pingdingshan, Yongcheng coal mine areas in China in recent years. Main mine water monitoring equipment produced by Xi'an Research Institute of China Coal Technology & Engineering Group is KJ117 mine water monitoring system, YJSY(A) water level telemeter, YJSZ(A) water level recorder and YJS(A) mine water pressure recorder.

2. Coal seam roof water hazard monitoring and early warning

The roof water hazard monitoring and early warning system developed by Xi'an Re-

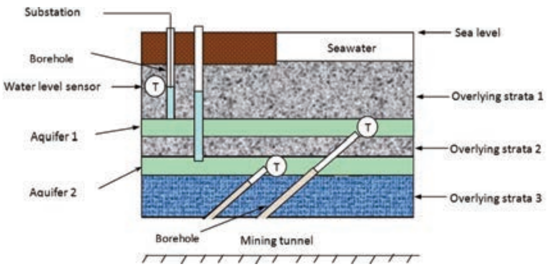

Fig. 2 *Roof water hazard monitoring system*

search Institute was successfully applied in the undersea working faces of the Beizao coal mine in Longkou, as shown in Fig. 2. Monitoring indexes of this monitoring system include water pressure, water quality, water temperature, and water inflow rate.

Surface and underground boreholes were used to monitor water pressure, water temperature and water quality of target aquifers. Early warning thresholds of water quality indicators were determined by water matching tests.

3. Coal seam floor water hazard monitoring and early warning

The floor water inrush monitoring and early warning system consists of the water inrush point analysis system, the monitoring system, the early warning system and the contingency plan. The monitoring system is a multi-parameter and multi-channel sensor system whose hardware system includes a mainframe computer, underground line, converter boxes, and sensors of water temperature, water pressure and stress.

The coal seam floor water inrush monitoring and early warning system developed by the Xi’an Research Institute of China Coal Technology & Engineering Group has been successfully used in the Liuqiao and Dongpang coal mines.

Coal Mine Water Hazard Prediction Technology and Equipment

Coal mine water hazard prediction technology includes coal mine roof water inrush prediction technology, coal mine floor water inrush prediction technology, and coal mine water inflow prediction technology. In this paper, the last of these is introduced. The most practical methods for predicting coal mine water inflow in China’s coal mines include hydrogeological analogue method, Q-S extrapolation method, analytical method, artificial neural network method and groundwater modeling method.

If a coal mine under construction has similar hydrogeological condition and mining method to some operating coal mines, Chinese hydrogeologists often use hydrogeological analogue method to predict the water inflow of the coal mine under construction. The limiting condition of this method is that these operating coal mines must have long-term observed water inflow data. In some older coal mine area located in Eastern China, the hydrogeological analogue method usually is the best choice for water inflow prediction, even better than groundwater modeling method.

An analytical method which is called ‘big well’ method is very popular in predicting coal mine water inflow. It conceptualizes the entire coal mine tunnel system as an ideal ‘big well’, and makes the area of the big well the same as tunnel system’s. The water inflow of the ‘big well’ is equivalent to the whole tunnel system’s inflow. Based on this information, the radius of the big well can be calculated according to geometric theory. This method is often used in preliminary exploration of coal mines.

With the rapid development of computer and hydrogeological exploration techniques, numerical modelling method is widely used to calculate coal mine water inflow. In engineering applications, geophysical prospecting, dewatering test and tracer test techniques are combined to support the numerical model. Some advanced groundwater modeling software, such as GMS (Groundwater modeling system), Visual Modflow, Feflow, are very popular in the process of coal mine water inflow prediction.

Coal Mine Water Hazard Control Technology and Equipment

1. Water-retaining wall construction technology

The Xi'an Research Institute of China Coal Technology & Engineering Group has carried out some sink hole water inrush control engineering in several coal mines, including the Donpang coal mine (2003–2006), the Jiulong coal mine (2008), the Huangsha coal mine (2010–2012), the Luotuoshan coal mine (2010), the Sangshuping coal mine (2011), the Shenjiazhuang coal mine (2012) and the Taoyuan coal mine (2013).

Generally, to control a sink hole water inrush, the first stage is to construct a water-retaining wall in the mining tunnel to stop flooding. The second stage is to construct a water stopper in the sink hole to seal the water inrush channel thoroughly.

There are four steps for constructing water-retaining wall. The first step is to inject aggregates into the running water to form an aggregate accumulation body; the second step is to use rotary jet grouting to form water-blocking concrete body; the third step is to drill additional boreholes for grouting, and build an intact water-retaining wall; and the fourth step is to increase grouting pressure to increase the wall's strength and permeability resistance. These four steps for constructing water-retaining wall are shown in Fig. 3.

2. Sink hole water stopper construction technology

A sink hole water stopper is constructed successfully by grouting in a proper position to block the sink hole water inrush channel in the Dongpang coal mine (Shenghui *et al.* 2008). Grouting and monitoring boreholes were drilled with directional drilling technology to ensure designed trajectory. There are four grouting steps to construct a water stopper: regular grouting, pressure grouting, drainage grouting and reinforcement grouting. The effectiveness of water stopper can be evaluated by underground dewatering tests.

Fig. 4 shows a sink hole water stopper built in the Dongpang coal mine in northeastern China. The column stopper was built by Xi'an Research Institute of China Coal Technology & Engineering Group. The total

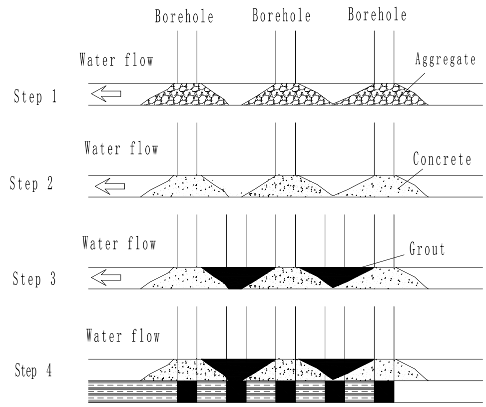

Fig. 3 *Four steps of constructing water-retaining wall*

grout volume of the water stopper was 49 340 m^3.

3. (3) Technology of grouting controlled by drilling tool

Grouting controlled by drilling tool is a patented technology developed by Xi'an Research Institute of China Coal Technology & Engineering Group. This technology supplies a combined drilling tool hidden in a high strength non-woven fabric grout protection bag. The device can be sent to water inrush channel by drilling rig. The drilling fluid channel near the drilling bit will be plugged by a bowling method to push off the drilling rig and the grout protection bag. Rapid gel filling material will be injected to the grout protection bag through the drilling tool to form a controllable grouting body to seal water inrush channel.

This technology was applied in the Yubujie coal mine to seal a water inrush point in March 2012. Twenty-four grouting boreholes were drilled and twenty-four grout protection bags were used to grout 849 m^3 concrete. Compared with traditional grouting techniques, this technique can reduce construction cost and duration significantly.

Conclusion

Water hazard prevention and control technologies and equipment can be divided into

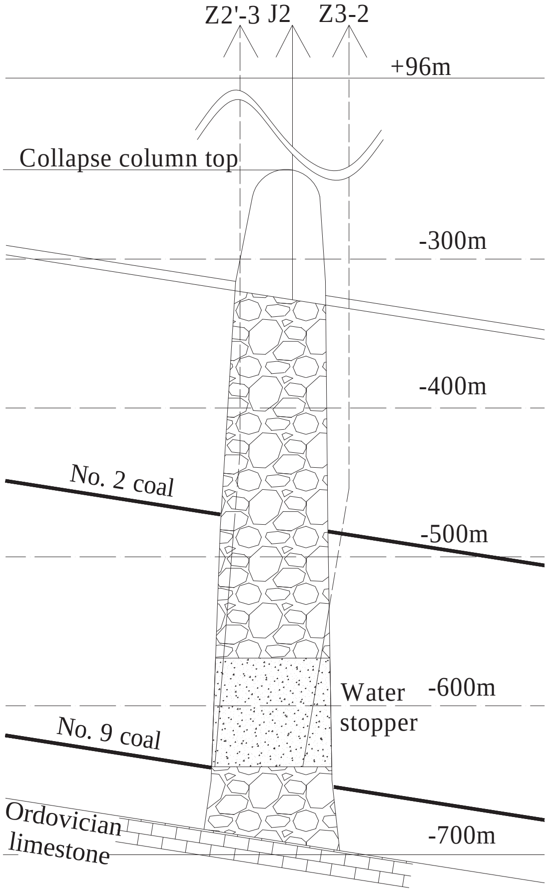

Fig. 4 *Water stopper in Dongpang Coal mine*

four categories, which are exploration, monitoring, prediction and control technologies and equipment.

Exploration technology and equipment, such as three dimensional seismic exploration, electromagnetic detection, underground nearly-horizontal directional drilling, and underground dewatering test, are very useful in underground structure and water-bearing anomaly area detection, as well as hydrogeological parameters identification. Monitoring technology and equipment, such as mine water real time monitoring system, coal roof and floor water hazard monitoring and early warning technology and equipment, which provide latest information of water level, water temperature, and surrounding rock to coal mine hydrogeologists, are the 'underground eyes' of coal mine hydrogeologists. Prediction technology and equipment, including coal roof & floor water inrush prediction, as well as coal mine water inflow prediction technology and equipment, if used properly, can help avoid most of coal mine water disasters. Control technology and equipment, containing water-retaining wall construction, sink hole water stopper construction and grouting controlled by drilling tool techniques and equipment, have been well developed to control water inrushes caused by sink holes, faults, and goaf water.

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References

Zhijun SH, Shuning D, Ningping Y, Dongzhuang T (2011) The underground directional drilling technology and equipment for kilometre deep borehole with MWD in coalmine. Procedia Earth and Planetary Science 3: 17–22

Dewu J, Yingfeng L, Zaibin L, Jianyuan C (2013) New progress of study on major water inrush disaster prevention and control technology in coal mine. Coal Science and Technology 41(1): 25–29

Shenghui N, Qinming J, Xiaoshan G, Kangkang L, Zaibin L, Lei S (2008) Construction technique of groundwater-preventing piston in Karst flow sink hole. Coal Geology and Exploration 36(4): 29–33