Deep mining water control cooperative system based on 3-D directional drilling and controllable grouting techniques

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Abstract In order to solve deep mining water hazard prevention and groundwater resource protection problems, 3-D directional drilling and controllable grouting techniques were studied to form the deep mining water control cooperative system. 3-D directional drilling design method was used to improve the effectiveness of horizontal wells in the whole mining area and to reduce unable detecting zone. Artificial grouting foundation and controllable grouting techniques were studied to limit the grouting body scope and to reconstruct the deep Ordovician limestone aquifer. According to an engineering practice, water inrush quantity was reduced effectively during grouting process.

Keywords 3-D directional drilling, grouting, deep mining, mine water control cooperative system

Introduction

With the development of China's coal industry, frequent water inrush disasters led to very serious person casualties and economic losses. In all kinds of water inrush problems, the coal floor water inrush problem as known as mining over confined aquifer water hazard problem in north China coal field has always been a key research hotspot and the research difficulty. Hanxing coal mine area, located in Hebei province, is a typical north China coal field threaten by the basal Ordovician limestone aquifer. When mining activities once revealed areas with conditions of too high basal aquifer pressure, insufficient aquiclude water resistance ability or with existence of water conducting channel, there is a large possibility of water inrush accident (Zhao 2014).

In Hanxing coal mine area, there are 12 coal mines with mining depth more than 800m with 4 coal mines deeper than 1 000 m. For deep mining working faces, hydraulic pressures under coal seam floor are higher than 7.0 MPa, with the highest pressure of 13.2 MPa. During deep coal mining process, water inrushes through coal seam floor are often related to mining activities and accompanied by rock mass stress dynamic phenomena. Deep mining faces a series of problems such as high cost of mine water drainage, water resources waste and highly risk of water inrush. In past twenty years, there were 11 coal seam floor water inrush accidents which flooded 3 mines and 2 mining levels with water flow from 160 m^3/h to 24 000 m^3/h (Zhao 2015).

There was a terrible shortage of water resources in Hebei province with water resources per capita ownership of 302 m^3 which is 13.8 percentage of national average. The water scarcity has seriously affected industrial and agricultural production and also people's everyday life while coal mining activities influence the groundwater environment inevitably. Meantime,

every water inrush accident also causes a large amount of water loss. So the implementation of protective exploitation of water resources which can reduce the influence of coal mining on the groundwater environment has a very important practical significance (Yin 2016).
To solve these problems, deep mining water hazard detection and prevention methods were studied based on 3-D directional drilling and controllable grouting techniques which were applied to a deep coal mine with mining depth from 1 030 m to 1 270 m in north China. Mining and water control cooperative system was established by comprehensive overall planning of mining, drilling, testing and grouting processes. The water control cooperative system is a further development of the regional governance technology. Based on the water control cooperative system, water bursting points were plugged, possible water inrush disasters were prevented, new groundwater problems were controlled immediately and the groundwater resources were protected effectively.

Site description

Mining production situation

The deep mining area of Xingdong coal mine which located in Xingtai Hebei province was studied. The main working bed of Xingdong coal mine is No. 2 coal. The mining overall height, comprehensive longwall coal mining method was used. The mine has multiple working levels and uses vertical shafts including one main and one auxiliary shaft. The deep working level is -980 level. Working faces which are deeper than -980m in Xingdong coal mine belong two working areas distributed beside downhill roadways. The shape of the study area where mining working faces are deeper than -980m is an irregular rectangle with the size of 3.1 km long from north to south and 1 km wide from east to west. The No. 2 coal geological reserves of this area is 11.523 million tons among which 4.7663 million tons coal can be produced.

In the whole study area, No. 2 coal seam floor elevation is from -980 m to -1250 m, the Ordovician limestone hydraulic pressure is +66.84 m, distance from No. 2 coal seam floor to the Ordovician limestone surface is from 85.05 m to 262.5 m with an average of 156.92 m and the water inrush coefficient is from 0.07 MPa/m to 0.098 MPa/m which is bigger than the critical water inrush coefficient of structure development zone.

Formation lithology from No. 2 coal seam floor to the Ordovician limestone surface mainly includes sandstone, mudstone, limestone, alumina, etc. there are ten coal seams and three thin-layer limestone aquifers in this aquiclude layer.

Argillaceous rocks including mudstone, alumina are significant to prevent the Ordovician limestone confined water from inrushing to mining space. Soft and hard rock combination can enhance the Formation water resistance ability. So the key of mine water control cooperative system is to detect hidden water conducting channels to ensure the integrity of the coal seam floor water-resisting layer.

Groundwater inrush cases

Before the mine water control cooperative system was established, there were three Ordovician limestone water inrush accidents as shown in table 1. Two water inrush accidents which are coal seam floor water inrush accidents happened during 2127 working face and 2222 working face mining steps. The No. 15 borehole water inrush accident happened in -980 concentrated supply roadway was caused by a drainage borehole.

Table 1 *Ordovician groundwater inrush accidents.*

Location	Time	Peak value/m^3h^{-1}	Stability value/m^3h^{-1}	Observation borehole distance/m	Water levels fall/m
2127 face	4-13-2011	210	142	800	28.662
-980 roadway	5-19-2014	150	92	720	11.98
2222 face	3-1-2015	268	200	724	44.593

Cooperative system establishment

For the deep mining area, existing water bursting points are difficult to govern and new water inrush accidents also still could happen. For the drilling engineering, ground drilling conditions are confined by ground buildings, roads, pipelines, high-voltage power lines, etc. Meantime, this area had a very tight mining schedule. There was no suitable condition for advanced management before mining. Deep Ordovician lime stone has a very low degree and non-uniform karst development, so the detectable and controllable limestone section is very thin.

A series of technologies were studied to solve above difficulties. Flexibility of the ground construction location was improved by reverse and lateral displacements directional drilling techniques. Adaptive capacity to formation conditions was enhanced by long distance bedding countertendency drilling techniques. Mine water control availability was improved by comprehensive test procedures formed by mud displacement, well flushing, pump-in test and grouting test. The water resource was protected during coal mine exploration by the reconstruction of the aquifer system. Deep mine water servosystem was established to control new water inrush accidents and reduce the influence of water inrush. Mining, drilling and grouting processes were orderly planned by the deep mine water control cooperative system to ensure the safety of mine production and to improve the production efficiency.

3-D directional drilling technology

Horizontal Directional drilling

The 3-D directional drilling technology is a development of the horizontal directional drilling. The study of grouting reinforcement techniques on coal floor with multi-branch horizontal well was carried out through ground drilling (Wang 2015, Shen 2016, Chen 2016).

By the control of measuring instrument and geo-steering instrument, and the use of wall materials, horizontal drilling can be achieved in the Ordovicion limestone. Horizontal well is the directional well extended to a certain length, its borehole trajectory is nearly level. Horizontal directional branched drilling on ground is drilling technology. Opening vertical holes from the ground, then change it to horizontal well at a certain angle in the target layer. Advantages of horizontal directional drilling technology are sitting flexibility, high efficiency drilling, disadvantages are more invalid footage and large blind area.

3-D directional wells

3-D directional drilling design method was used to improve the effectiveness of horizontal wells in the whole mining area and to reduce unable detecting zone. Inclined straight borehole which can make the inverse displacement and the lateral deflection which can decrease the angle of curvature were designed to adapt the site condition. Each well can be divided to four parts which are straight inclined section, lateral torsional section, uphill climb section, and control function section, as shown in figure1.

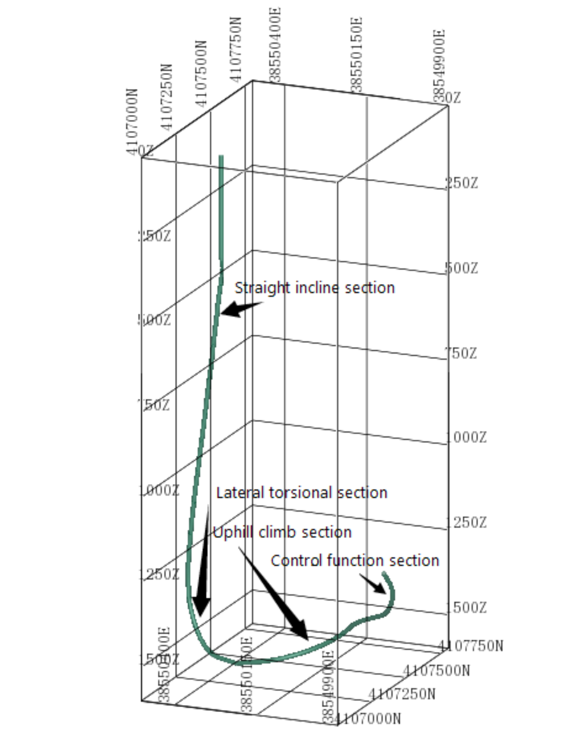

***Figure 1** 3-D directional well structure.*

The study area was controlled by one main well and 22 branch wells which were divided to three different zones, as shown in figure 2. The distribution of branch wells were controlled by working faces distribution and main structures condition.

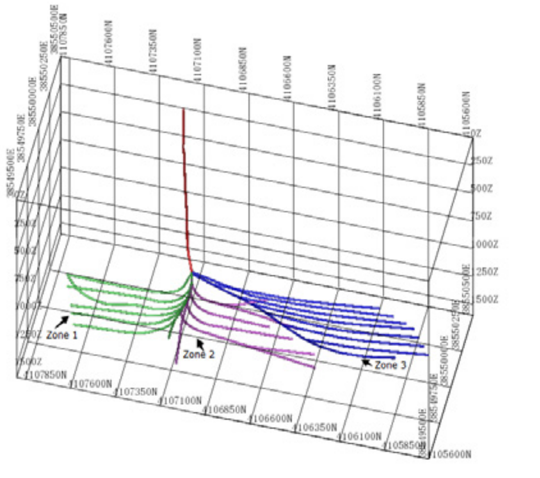

__Figure 2__ Directional wells distribution.

Controllable grouting technology

Wellhead grouting process

The wellhead grouting process is shown by figure 3. Jet mixing system was used to ensure continuous pulping and grouting. Cement and fly ash are main grouting material. Grouting process includes filling grouting and pressurized grouting stages. In the filling grouting stage, large discharge capacity from 260 L/min to 600 L/min grouting pumps were used. In the high pressure grouting stage, continuous pressurized grouting can increase the diffusion distance and fill tiny cracks.

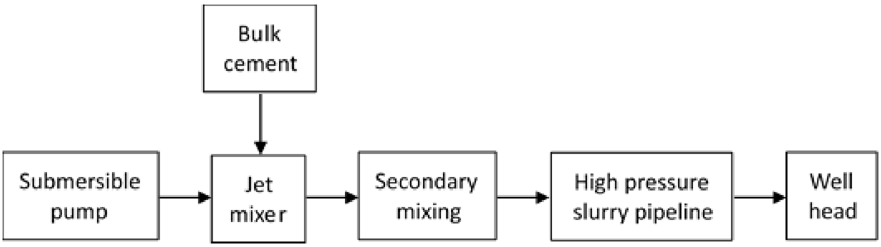

__Figure 3__ Grouting process flow diagram.

Artificial grouting foundation construction

Artificial grouting foundation and controllable grouting techniques were studied to limit the grouting body scope and to reconstruct the deep Ordovician limestone aquifer. The grouting layer was confined from 80 m to 100 m under the Ordovician surface. During drilling process, encountered structures were analyzed according to mud consumption, pumping and pump-in tests. Different materials including gravel aggregate, sand and fly ash were applied to build artificial foundation.

The grouting body was confined in particular layer to ensure the integrity of the water-resisting layer and can and to block groundwater inrush, as shown in figure 4.

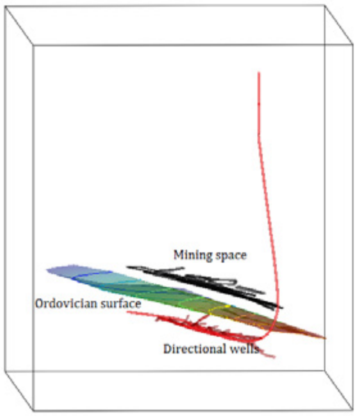

Figure 4 *Spatial position relationship.*

Mine water control effect

The mining and water control cooperative system was established to accomplish mine water whole process management, to reduce water inrush probability advanced, to reduce current water quantity and to response to new occurrence of water inrush instantly. During the grouting process, water inrush quantity was reduced effectively, as shown in figure 5.

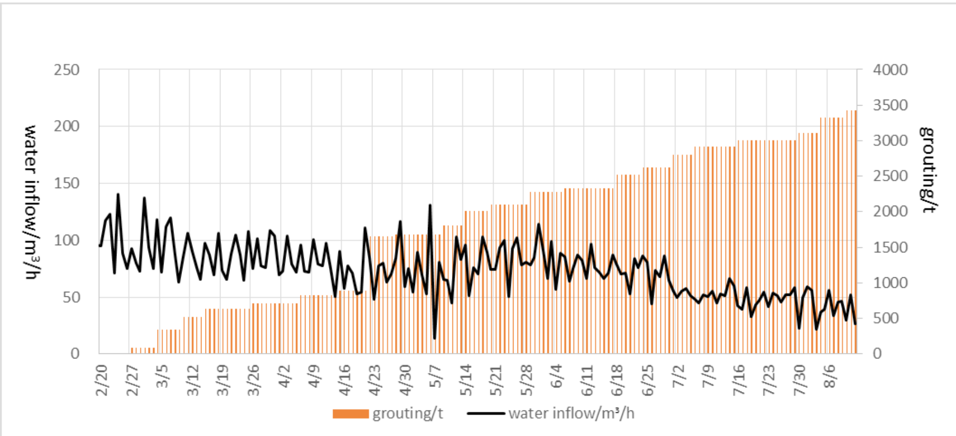

Figure 5 *Mine water reduction during grouting process*

Conclusions

Deep mine water control engineering practices confirmed that water hazard prevention and groundwater resources protection can be controlled cooperatively during mining process. The 3-D directional drilling technology which is a further development of horizontal directional drilling technology can detect formation conditions and ensure working faces safety. Controllable grouting technology can reduce grouting quantity, reconstruct the Ordovician aquifer and reduce mine water flow. Multi-source engineering data should be used to analyze hydrogeological information in future.

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