The hydrogeological exploration and test technology to precisely determine the location of groundwater recharge channel in mining area

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Abstract Siwan mine is threatened seriously by water disasters. The Ordovician carbonate (O_2) water lateral recharges the second thin-bedded limestone aquifer (L_2) through F_8 fault. It is difficult to determine the cross section only by single method. The cross section on the fault was confirmed within fifty meters by a multiple method. It contains hydrogeological condition analysis, dewatering and tracing test, transient electromagnetic method and hydrology drilling. This result provides a target for the curtain grouting. Because of the accurate assessment, the water plugging effect is remarkable. The water discharge rate per unit drawdown dropped from 12.0 – 7.0 m^3/h/m, and the water yield reduced 600 m^3/h.

Keywords curtain grouting, dewatering test, tracing experiment, hydrology drilling, recharge channels.

Introduction

The North China coal basins, in which approximately 70 % of all the identified coal resources in China are deposited (Gao and Liu 1985), and the coal deposits were mainly formed in the Carboniferous to Permian periods (Han and Yang 1984). In the basin, there exist 11 thin-bedded limestone aquifers in the Taiyuan Group, those aquifers are sequentially named L_1 through L_{11} from the bottom to the top (Wu and Jin 1995), and an extremely thick Middle Ordovician carbonate aquifer (O_2 aquifer). Those aquifers are the main water filling aquifer of the coal basin. In particular, the O_2 aquifer stores abundant water and accepts a considerable recharge of precipitation. It developed lots of fracture and karst features, and wide distribution of outcrop areas. Thus, it serious threats the coal mining operations. Once the water which comes from O_2 aquifer discharge to the mine, it will lead to large scale water bursting hazards or inundation.

Hebi coalfield is located in alluvial plain of the Taihang Mountain in Henan province. The hydrogeological condition is very complex in this area. The eighth thin-bedded limestone aquifer (L_8), the second thin-bedded limestone aquifer (L_2) and the O_2 aquifer are main water-filling aquifers.

In the northeast of the Hebi coalfield there is the Siwan mine, in which the main coal mining seam is the bottom coal of the Taiyuan group. The coal seam, which roof is L_2 aquifer and floor is O_2 aquifer. In the mine, F_8 fault is one of a fault with water permeability. It is the channel that the O_2 water lateral recharges L_2 water in Siwan mine. The existence of this fault increases the risk of water inrush. Thus, the key point to control the recharge process is pouring grout curtain at this fault. At present, pouring the grout curtain alone the whole fault (2.3 km long) is impossible, that the important point to solve this problem is confirming the discharge cross section. The cross section was confirmed within fifty meters by many methods through hydrogeological condition analysis and experiment. This result provides a curtain grouting target for the following project. Because of the accurate assessment, the water plugging effect is remarkable.

The Hydrogeological Background

In Hebi coalfield, the L_2 aquifer with an average thickness of 7 m has a stably distributed, but the karst fissure is poor-developed and inhomogeneous, and the water abundance is greatly different in spatial. According to the pumping test data, the specific yield is 0.012-2.619 L/s/m, the hydraulic conductivity is 0.392-28.84 m/d. Because of the L_2 aquifer has limited outcrop area and no recharge source. The karst water is mainly static reserves and easy to drainage. However, O_2 water and L_2 water has hydraulic connection in some area by the faults. For example, F_8 fault caused the relationship between L_2 aquifer and O_2 aquifer, and the Ordovician carbonate water from east lateral recharge west L_2 water. The specific yield is 3.2 L/s/m, the water yield of Siwan mine is 1200-1400 m^3/h.

The O_2 aquifer, which thickness is 400 m and the karst fissure is well-developed. According to the single drilling pumping test data, the minimum value of specific yield is 0.67 L/s/m and the maximum value is 83.91 L/s/m, the average value is 14.02 L/s/m. The O_2 aquifer is widely outcropped in the Taihang Mountain area, and it accepts the recharge of precipitation infiltration. In addition, the river leakage recharges the groundwater through the karst fissure. After accepts the recharge in mountain area, the water flows to the piedmont from west to east, and discharges by karst spring and mine drainage.

The fault strike of F_9 fault (a normal fault) is NE22°, the dip is NW 63°, and it is the west boundary of the Siwan mine. According to the drilling data, the fault is a resistant water fault. The F_8 fault is the east boundary of the Siwan mine, and the strike is nearly north-south, the dip is W 63°-70°. The fault causes the L_2 aquifer joints with the O_2 aquifer. The O_2 water lateral recharges the L_2 water through the F_8 fault. It is the important recharge resource of L_2 limestone water (fig. 1).

Hydrogeological exploration and test

The channel that O_2 water recharged the L_2 on F_8 fault was confirmed within 50 m by a multiple method. It contains hydrogeological condition analysis, dewatering test, tracing test, transient electromagnetic method and hydrology drilling. This result provides a target for the curtain grouting. The whole exploration could be divided into three stages (fig. 2). The first was preliminary exploration stage, which from June 2006 to September 2007. Based on the data analysis, the water conductivity and the position of water channel of F_8 fault were confirmed by the hydrogeological exploration and testing. The second stage was curtain

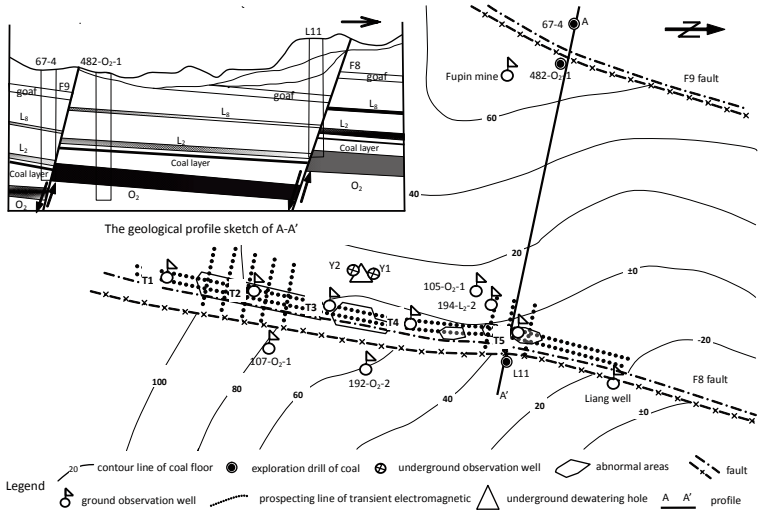

Fig. 1 *The layout sketch of hydrogeological exploration and experiment on F_8 fault.*

grouting, which from February 2008 to June 2008. The recharge channel on F_8 fault was plugged by the water plugging materials through ground drillings. The third stage was to verify the plugging effect, which from June 2008 to October 2008. It could be texted the effect of curtain grouting project for water plugging through comparing the dewatering test results before and after the grouting closure.

Dewatering test and tracing experiment

The dewatering tests were carried out 5 times. The first two tests were mainly to confirm the F_8 fault's transmissivity and position of the water channel, the purpose of the last three tests were to examine the effects of grouting for water plugging. In Siwan mine, There are twenty-one underground drillings, in which, two of them with manometer to observe water level (water pressure), the rest drillings to dewater the L_2 karst water when they turn on. Moreover, there have nine drillings on and under the ground to observe the dynamic of water level of the L_2 karst water and O_2 water. The unsteady flow dewatering test with three steps was carried on in June 2006. At the same time, two different tracer materials (potassium iodide and sodium fluoride) were input into two O_2 karst water observation drillings on the ground (192-O_2-2 and 105-O_2-1) at half an hour before the dewatering test (fig. 1). The tracers were pressed into the O_2 karst aquifer by continually injecting water in drillings. During the test, groundwater was sampled every two hours in dewatering well. The test was begun on 10:00 a.m., June 15 (tab. 1). Firstly, four dewatered holes were turn on. Steady water yield was 369.9 m^3/h. This stage lasted 72 hours. Secondly, five holes were increased on 10:00 a.m., June 20. Steady water yield was 674.4 m^3/h. This stage lasted 72 hours. Another three holes were turn on at 10:00 a.m., June 23. Steady water yield was 852.0 m^3/h. This stage lasted 72 hours. At last, all dewatered holes were closed on 10:00 a.m., June 25. The observation of water level was last 48 hours (Pan *et al.* 2007).

Bases on the experimental results, the water level in O_2 water observation drilling on the east side of F_8 fault (O_2-192-2) and the L2 water in Siwan mine (such as 194-L2-2) has the same decreasing trend. The maximum drawdown in dewatering hole is 73 m. Meanwhile, the water level descends 3.14 m in O_2 water drilling (O_2-192-2). In addition, the tracer KI was captured 58 hours later in 192-O_2-2 observation drilling. That means the O_2 water recharges L_2 karst water through the F_8 fault. The recharge channel of F_8 fault is estimated roughly which exists in a triangle-shaped area delimits by 192-O_2-2 hole, 107-O_2-1hole and dewatering area.

Hydrogeological drilling

At downthrown side of F_8 fault, along strike, the five hydrological exploration holes which

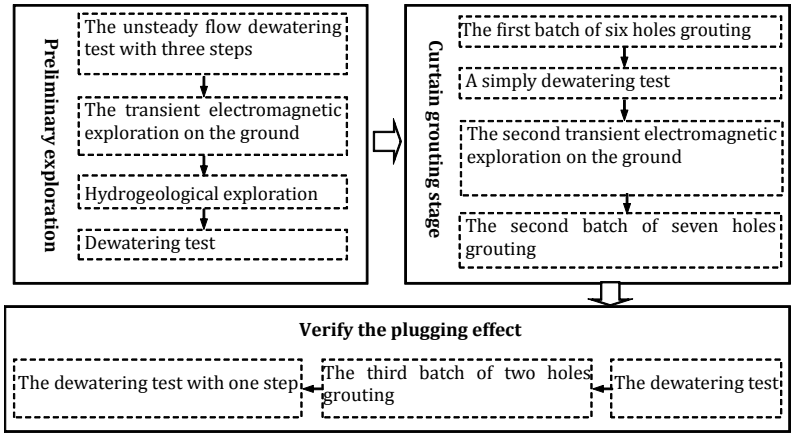

Fig. 2 *The flow chart of the curtain grouting for F_8 fault in siwan mine*

Dewatering Test stage	Water yield (m^3/h)	The drawdown of L_2(m)				The drawdown of O_2(m)		
		Y1	Y2	194-L_2-2	Fupin mine	105-O_2-1	192-O_2-2	107-O_2-1
Ⅰ	366.9	17	21	15.48	11.73	0.09	1.10	0.38
Ⅱ	674.4	56	53	35.49	26.61	0.20	2.56	0.64
Ⅲ	852.0	73	67	44.34	33.08	0.34	3.14	0.72

Table 1 *Development of IMWA membership between January 2008 and December 2012.*

interval was 200 m were arranged (fig. 1). The finished stratum of the drill-hole was L_2 aquifer. Drilling results confirmed that the secondary fault and karst system well-developed between T_2 and T_4. The coal layer in T_3-hole is missing; stratigraphic sequence is confusing with broken rock. Solution fissure and small karst caves are developed which proves the existence of karst collapse column at this area. It is the runoff channel of karst water.

Transient electromagnetic method

The transient electromagnetic method was carried out two times. Based on the results of dewatering tests, two parallel transient electromagnetic survey lines along F_8 fault were arranged. The distance between the two lines was 20 m, the dot spacing was 5 m, the length of the survey lines was 1230 m, and the coordinate points were 494. Additional eight survey lines were arranged perpendicular to F_8 fault in the abnormal area of water-bearing. The dot spacing of these lines was 5 m, the length was 150 m, and the coordinate points were 248. The results of transient electromagnetic method shows that there are two recharge channels on F_8 fault, the one locate between T_1-hole and T_2-hole, the anther is between T_3-hole and T_4-hole.

Curtain grouting

Along the downthrown side of F_8 fault to form a continuous water-blocking curtain that can cut off the recharge channel (O_2 water recharges to L_2 water). There were 15 grouting holes which distribute between T_2 and T_4 hole to drill and grout by stages. The first batch of grouting holes focused on the recharge channel between T_2 and T_3 holes. There were 6 grouting holes (from Z_1 to Z_5 and an observation hole T_2) in this batch. In total, 1260 t of cement, 53.8 t of sodium silicate and 4.75 t of industrial salt were injected. Then the simply dewatering test was carried out. The result shows that the efficiency of grout is unobvious. The second batch of grouting holes focused on the water channel between T_3 and T_4 holes. At the same time, the grouting holes were increased between T_2 and T_3 holes. In this batch there were 7 grouting holes (Z_6-Z_9, Z_{11}, Z_{13} and an observation hole T_4), and in total, 991 t of cement, 41.1 tons of sodium silicate, and 5.15 t of industrial salt were injected. After this work, the water level of O_2 aquifer increased 0.5-0.8 m at 192-O_2-2 hole which located upthrown side of F_8 fault, and L_2 water level dropped 3-5m of the downthrown side. Then the dewatering test showed that water discharge rate per unit drawdown dropped from 12.0 – 7.9 $m^3/h/m$. It proves that Z_{11} hole played an important role in water shut off. According to the results, Z10 and Z12 were arranged on both sides of the Z_{11}. In this stage, total 648 tons of cement, 32.2 t of sodium silicate and 3.2 t of industrial salt were injected.

Then the grout curtain project of water channel on F_8 fault was completed. This project had 13 grouting hole, and the amount of drilling works was 2912.03 m. 13 grouting hole and 2 observation holes were grouting, and the cumulative injected cement was 2,899 t, sodium silicate was 127.1 t, industrial salt was 13.1 t.

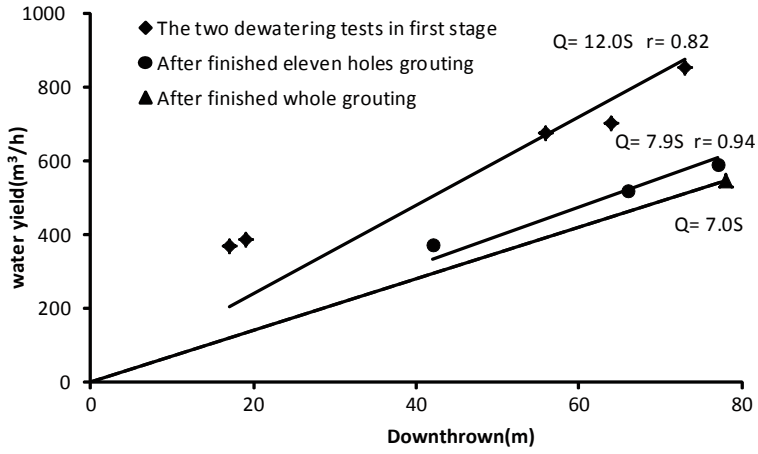

Fig. 3 *The relations of water level drawdown and water yield for previous dewatering tests.*

Examine the effect of grouting for water plugging

In order to examine the efficiency of curtain grouting, the dewatering tests were completed after each batch of grouting respectively. The results showed that, the water discharge rate per unit drawdown dropped from 12.0 – 7.0 $m^3/h/m$, decreasing amplitude was 42 % (fig.3). After grouting, the Siwan mine water yield dropped from 1400 m^3/h to 800m^3/h. Siwan mine was almost shut down due to the serious threat of O_2 aquifer before grouting. It began to resume production and the annual production of raw coal was 350 kt after grouting. Grouting project total investment was 600,000,000 yuan. The water yield reduced 600 m^3/h. The drainage cost was saved 1,000,000,000 yuan. It could reduce the waste of water resources.

Conclusion

The dewatering and tracing test confirmed that the F_8 fault was a water-conductive fault. Groundwater of O_2 aquifer recharged the L_2 aquifer through this fault.

The hydrogeological drilling and transient electromagnetic exploration determined the recharge channel on F_8 fault. It provided a target for curtain grouting.

Through a three stage curtain grouting, the water discharge rate per unit drawdown dropped from 12.0 — 7.0 $m^3/h/m$, and the water yield reduced 600 m^3/h. It provided the condition for Siwan mine safety mining.

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