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Research Article

Damage Characteristics and Mechanism of a Strong Water Inrush Disaster at the Wangjialing Coal Mine, Shanxi Province, China

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A serious groundwater inrush occurred at the Wangjialing coal mine on March 28, 2010. Great effort from all over the country was taken during the postaccident rescue. However, triggered by accumulated water in the upper abandoned tunnels and goafs of a nearby closed individually owned coal mine, it caused great damage, including 38 deaths and direct economic losses of over 49 million yuan. The inrush water was from the abandoned tunnels and goafs, which were filled subsequently by groundwater from the sandstone aquifer in the roof of the coal seam. The passage formed in the west roof of the heading face of the air return tunnel in the 20101 first mining face. Unidentified distribution and water-filled degree of the abandoned tunnels and goafs are critical bases for the accident. That important regulations for abundant groundwater exploration and release were not carried out thoroughly was another fatal cause leading to the accident. The poor awareness of water hazard controlling also contributed to the accident to a large extent.

1. Introduction

In recent years, due to the complicated geological conditions induced by increasing mining depth, water inrush disasters have occurred at several coal mines in China, although the numbers of accidents and deaths caused by them are decreasing [1, 2]. Detailed information is illustrated in Figure 1. Some strong water inrush disasters once brought great damage [3–6].

In fact, many researches have been conducted due to great damage of the water inrushes that occurred at coal mines all over the world. Formation mechanism, probability assessment, and control techniques of the water inrushes were key issues to be solved. As a basis, the formation mechanism was studied at first and some valuable theories were obtained [7–18]. Subsequently, more and more practical methods appeared and began to be used for probability assessing of the coal mine water inrushes. "Water inrush coefficient" method, "three maps-two predictions" method, "vulnerability index" method, and "five maps-two coefficients" method began to be applied gradually during underground coal mining [19–23].

Fortunately, with underground coal mining going on, many effective and comprehensive techniques formed and began to be applied for control of the water inrushes [24, 25]. According to practical effects, the above ones can be divided furtherly into exploration techniques, prevention techniques, grouting techniques, discharging techniques, draining techniques, and damming techniques [26, 27]. The exploration techniques include integrated geophysical prospecting technique and surface and ground drilling techniques [28–32]. The prevention techniques include construction of waterproof coal pillar, waterproof door, and sluice wall. The grouting techniques include fault grouting, fractured rock mass grouting, and karst collapse column grouting [33–35]. The discharging techniques are applied to decrease pressures of the confined water from the roof and floor of coal seams to safe values for the safe underground mining. The draining techniques include mainly the draining system and equipment. The damming techniques are applied

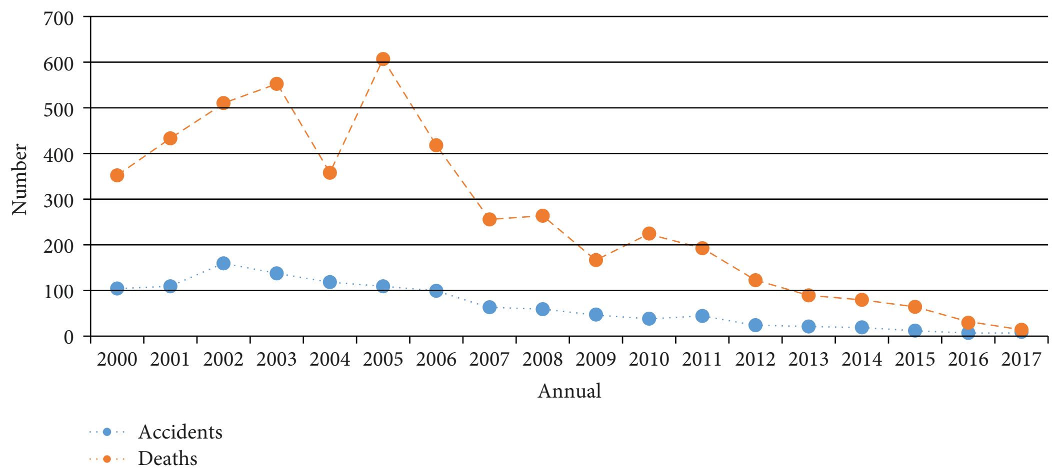


Figure 1: Feature of coal mine water disasters that occurred in China in recent years.

mainly to prevent surface water from rushing into adjacent pits. Finally, the above techniques should be applied individually or integratedly according to the special geological condition uncovered during underground mining.

Unfortunately, on March 28, 2010, a disastrous water inrush occurred at the drivage working face of the 20101 air return tunnel at the Wangjialing coal mine, Shanxi province, China. When the accident happened, 261 miners were working underground. 108 miners managed to escape shortly after the accident. However, 153 workers were trapped in the pit. 115 miners were saved after great rescue effort was conducted. Unfortunately, the accident drowned 38 miners and caused direct economic losses of over 49 million yuan in the end.

2. The Area

The Wangjialing coal mine, which is located in the southwest of Xiangning county, Shanxi province, China, is a newly built affiliate mine of Huajin Coking Coal Co. Ltd. Its design production capacity was 6.0 million tons of coal per year. The coal mine began to be built on January 16, 2007, and on March 27, 2010, the total length of the built tunnels in 20101 first mining face reached 2795 m. According to the original schedule, coal production would begin in October 2010.

The Wangjialing coal field shapes an abnormal rectangle and its long axis extends towards the NE direction. Its area is over 176 km^2 and the geological reserve is 2.287 billion tons. Its exploitable reserve is 1.100 billion tons.

3. Geological Conditions

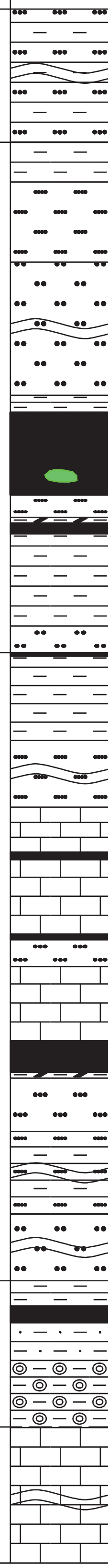
Coal-bearing strata in the Wangjialing coal field include the Benxi Formation and the Taiyuan Formation in the Carboniferous System and the Shanxi Formation in the Permian System. However, the main coal-bearing strata are in the latter two formations. 5-layer exploitable coal seams, named, respectively, the No.2, the No.3, the No.7, the No.10, and the No.12 from the top down, formed in the coal field. The No.2 and the No.10 are suitable to be exploited in the entire coal field. However, the No.3 is almost suitable and the No.7 and the No.12 are not suitable to be exploited in the entire coal field, respectively.

5-layer main aquifers from the top down formed in the coal field. They are loose gravel pore aquifers in the Quaternary System, sandstone fissure aquifer in bottom of the Upper Shihezi Formation of the Permian System, sandstone fissure aquifer in the Lower Shihezi Formation of the Permian System, karst fissure aquifer in the Taiyuan Formation of the Carboniferous System, and karst fissure aquifer in the Upper Majiagou Formation of the Middle Ordovician System, respectively. Rainfall, goaf area water, confined water from the sandstone aquifers, and karst water from the limestone aquifers in the Taiyuan Formation and the Upper Majiagou Formation are the main possible components of the mine water. Goaf areas, faults, caving, and fractured zones due to underground coal mining are the main possible passages for contribution of the mine water.

The strata and aquifer distribution is shown in Figure 2.

4. The Mining

4.1. Mining History. There once appeared many individually owned coal mines in the Wangjialing coal field. Their annual coal productions were all lower. There were 114 of them. Their mining began in the 1980s and lasted for 20–30 years. Up to several years before the above water inrush accident, they were almost closed due to the poor ventilation conditions and groundwater accumulations in their tunnels. However, 18 individually owned coal mines were still in mining. Their mining was concentrated in the No.2 coal seam, and the mining scope was concentrated in the southern part of the coal field, where the buried depth of the coal seam was relatively low. Their mining depths were about 100–300 m and the largest depth reached 500 m. Geological and mining conditions of these coal mines were almost unidentified, unrecorded, or missed. It brought great threat to the following underground mining at the Wangjialing coal mine.



Strata system	Average thickness/m	Rock name	Depth/m	Aquifier information
Lower shihezi formation P_2x	76.49	Sand-mud interbed	76.49	Sandstone fissure aquifer
Shanxi formation P_1s	48.32	Mudstone	79.49	
		Siltstone	85.49	
		Medium-grain sandstone	105.49	
		Mudstone	106.77	
		No.2 coalseam & location of the water inrush	112.97	
		Siltstone	114.66	
		Carbon mudstone	115.09	
		No.3 coalseam	115.89	
		Mudstone	122.81	
		Medium-grain sandstone	124.81	
Taiyuan formation C_2t	60.16	No.5 coalseam	125.06	
		Mudstone	131.41	
		Silt-fine sandstone interbed	140.41	
		Limestone	143.81	Karst fissure aquifer
		No.7 coalseam	144.36	
		Limestone	149.96	Karst fissure aquifer
		No.8 coalseam	150.38	
		Fine sandstone	152.38	
		Limestone	157.97	Karst fissure aquifer
		No.10 coalseam	160.31	
		Carbon mudstone	160.76	
		Fine sandstone	164.76	
		Mudstone-siltstone interbed	176.97	
		Medium-grain sandstone	184.97	
		Mudstone	186.88	
Benxi formation C_2b	10.98	No.12 coalseam	188.11	
		Sandy mudstone	190.95	
		Aluminum mudstone	195.95	
Upper majiagou formation O_2m	66.60	Limestone	262.55	Karst fissure aquifer

Figure 2: The strata and aquifer distribution at the Wangjialing coal field.

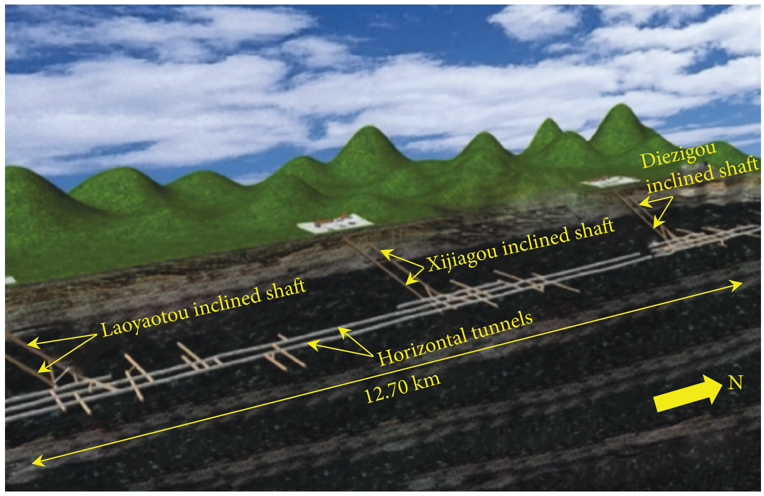


Figure 3: Distribution of tunnels at the Wangjialing coal mine.

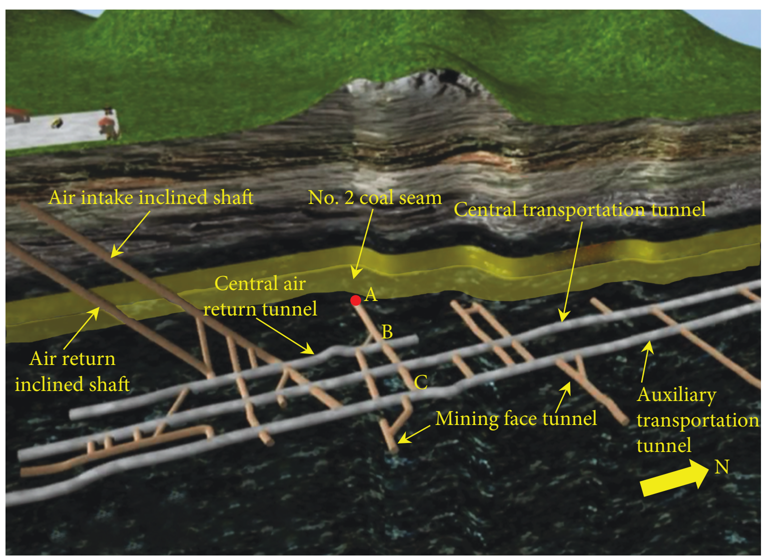
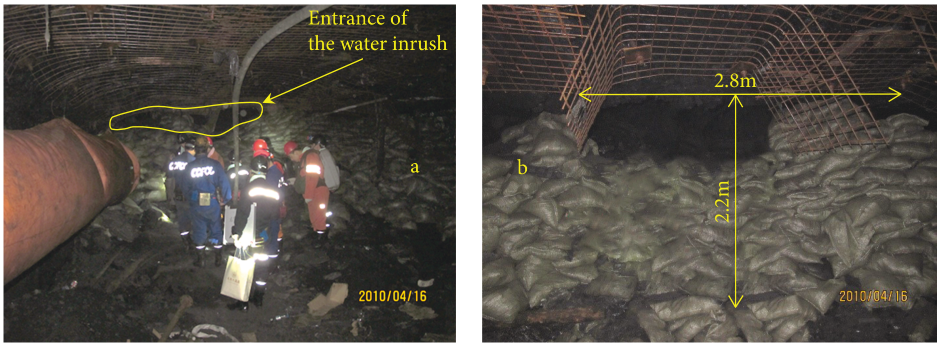


Figure 4: Distribution of tunnels at the Diezigou mining area.

4.2. Tunnel Drivage. Horizontal and inclined tunnels were constructed for the underground mining of the No.2 coal seam whose thickness is 6.20 m on average. More specifically, as shown in Figure 3, the individual length of each horizontal tunnel was 12.7 km. Inclined tunnels consisted of the Laoyaotou inclined shaft, Xijiagou inclined shaft, and Diezigou inclined shaft. The water inrush occurred at the Diezigou mining area. As shown in Figure 3, construction objects of this mining area included an air intake inclined shaft, an air return inclined shaft, a central air return tunnel, a central transportation tunnel, an auxiliary transportation tunnel, and several mining face tunnels.

Before the accident, two inclined shafts had been constructed. The central air return tunnel, the central transportation tunnel, and the auxiliary transportation tunnel had been constructed more than half. The mining tunnels had been constructed over 20 percent. All tunnels in this mining area were constructed along the floor of the No.2 coal seam as shown in Figure 4 and fluctuated with ups and downs of the coal seam. The minimum and the maximum floor elevation of the constructed tunnels was 553.94 and 594.97 m a.s.l., respectively.

The precise location of the water inrush, point A in Figure 4, was located on the roof of the heading face of the air return tunnel, line AC in Figure 4, 20101 first mining face. The height of the tunnel was 3.7 m and its width was 5.6 m. The tunnel began to be constructed on October 1, 2009, and its length reached 797.8 m at 8 a.m. on March 28, 2010, i.e., line AC in Figure 4. The tunnel began to descend slightly from point B to point A as shown in Figure 4. Structural cables or bolts with meshes supported the tunnel. Detecting groundwater near the tunneling face in advance by applying geophysical techniques including direct current electric method and Rayleigh wave method accompanied the



(a) (b)

Figure 5: Location of the inrush water passage.

tunnels' constructing. However, drilling for verifying results of the geophysical prospecting was not conducted at the same time.

5. The Accident

5.1. Sequence of the Water Inrush. At 10 a.m. on March 28, 2010, the air return tunnel at the 20101 first mining face developed 3 m furtherly and the support began to be conducted. At 10:30 a.m., four streams of water inflow, about 7 m to the heading face and about 0.3 m to the floor, appeared obviously in the north wall of the tunnel. The diameter of each stream was about 0.1 m, and the water yield was about 3 m^3/h. In the following time, the water yield increased furtherly and the accumulated water under the inflow points increased consequently although the water drainage had been strengthened.

At 13:15, a stream with a depth of about 0.2 m flowed out continuously at point B from point A as shown in Figure 4, where the central air return tunnel and the air return tunnel in the 20101 first mining face intersected. What is more, the coal dust concentration in the air return tunnel was increasing dramatically. At 13:40, all underground workers were asked to escape and go up. However, the workers in the air return tunnel were out of touch by wire telephone. At about 14:10, the AB segment, as shown in Figure 4, of the air return tunnel was flooded wholly. At 16:40, the estimated elevation of the accumulated water reached 579 m a.s.l. and kept rising. At 10 a.m. on March 29, the measured elevation of the accumulated underground water reached 583 m a.s.l.

261 miners worked underground when the accident occurred. 108 miners went up successfully after the accident. Unfortunately, 153 miners were trapped.

5.2. The Rescue. On March 28, the former Chinese president and general secretary of the Communist Party of China (CPC) Central Committee, HU Jintao, and former Chinese prime minister, WEN Jiabao, made important instructions urgently and requested that effective rescue should be conducted instantly to save all underground miners. On the evening of that day, former vice prime minister, ZHANG Dejiang, public officials from former State Administration of Work Safety and Shanxi provincial government, and experts from all over the country reached the Wangjialing coal mine and took part in the site rescue. In the early morning on March 29, rescue instruction, whose content was groundwater draining and tunnel ventilating firstly to save the trapped miners scientifically, was made and implemented instantly. Subsequently, a detailed rescue scheme including a large-scale groundwater draining by high-power submerged pumps, ground boreholes' drilling to drain water, and underground horizontal boreholes' drilling to divert the accumulated water was carried out with our best efforts to save the trapped miners. Tens of professional teams took part in the site rescue and the number of the site rescuers was over 6000.

On April 1, a ground borehole crossed the auxiliary transportation tunnel and a great amount of high-pressure airflow ejected out. On the morning of April 2, the airflow ceased to eject. At about 14:00, continuous beat noise on the drill pipe, the first signal of the survivors, spread from the bottom of the borehole. At about 16:00, sufficient liquid food was conveyed to the auxiliary transportation tunnel through the borehole.

At 22:00 on April 4, the total drainage reached 0.3 million m^3 and the water table of the accumulated water got a 15 m drop down. Some submerged tunnels reappeared gradually. Tens of professional teams began to rescue the trapped miners into the tunnels instantly. At 23:30, 9 survivors were found in the central air return tunnel. An hour later, they succeeded to go up and got proper medical treatment. In the afternoon of April 5, 115 survivors in total went up and got proper medical treatment.

Unfortunately, 38 trapped miners were killed by the disastrous accident.

6. Site Reconnaissance after the Rescue

According to the site reconnaissance, as shown in Figure 5(a), the precise location of the inrush water passage, point A in Figure 4, was located in the roof of the heading face of the air return tunnel, line AC in Figure 4, in the 20101 first mining face. Based on site measurement, the elevation of the tunnel floor near the heading face was 549.2 m a.s.l. The elevation of the tunnel roof here was 553.0 m a.s.l. The maximum width of the inrush water passage was 6.3 m and the maximum height was 2.2 m.

The inrush water passage was almost a rectangle with a length of 2.8 m and height of 2.2 m as shown in Figure 5(b). The accumulated groundwater rushed into the tunnel under construction through the middle part of the rectangle intensively.

As shown in Figure 6, the distance between the heading face of the air return tunnel in the 20101 first mining face at the Wangjialing coal mine and east wall of the No.1 abandoned tunnel of the individually owned closed coal mine was 0.8 m. As shown in Figure 7, the distance between the floor of the No.1 abandoned tunnel and the roof of the air retune tunnel was 0.8 m, too. Due to strong washout of the accumulated water, obvious damage, including cavings in the roof and pits in the floor, appeared near the water passage in the No.1 abandoned tunnel. A new enlarged cross section with a width of 4.6 m and height of 4.6 m formed. However, the abandoned tunnel here had been almost filled up by coal mud and caving rocks. As shown in Figure 8, obvious roof caving with a height of about 2.2 m near the water passage in the abandoned tunnel formed. The No.1 abandoned tunnel was constructed along the roof of the No.2 coal seam and supported by horizontal timber beams and vertical timber posts as shown in Figure 9. The original height of the tunnel was 2.2 m and the width was 3.5 m. The tunnel descended towards north and the slope angle was about 3 degrees. As shown in Figure 10, much water still accumulated. The tunnel ascended south and the slope angle was about 10 degrees. As shown in Figure 11, the tunnel towards south was empty. Additionally, there existed other two abandoned tunnels. As shown in Figure 6, one was the No.2 abandoned tunnel and the other was the No.3 abandoned tunnel. The distance between the south wall of the No.2 tunnel and north wall of the air return tunnel was 3.7 m. The detected length of the No.2 tunnel was about 9.7 m as shown in Figure 12. The No.3 tunnel was supported by timber as shown in Figure 13. Cross-section sizes of these two tunnels were almost equal. Widths were both 2.4 m and heights were both 2.2 m.

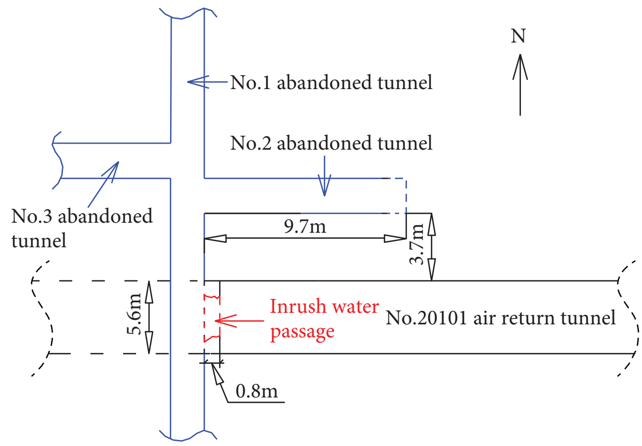


Figure 6: Plane location of the inrush water passage.

7. Inrush Water Features

7.1. Inrush Water Source. According to comprehensive analyses, the inrush water was from the abandoned tunnels and goafs due to nearby mining of the No.2 coal seam of the closed individually owned coal mines, which were filled subsequently by groundwater from the sandstone aquifer in the roof of the coal seam. Reasons are as follows.

(1) According to results of the water quality analysis conducted in the postaccident, as shown in Table 1, hydrochemical components of the inrush water and that of the water from the sandstone aquifer are almost similar. Their hydrochemical types are the same, i.e., HCO_3-Na waters. However, its main hydrochemical components are obviously different with those of the water from the nearby Ordovician limestone aquifer. The hydrochemical type of the latter is Cl·SO_4-Ca·Mg water

(2) The maximum elevation of the inrush water accumulated in the tunnels at the Wangjialing coal mine was about 583 m a.s.l. However, the elevation of Ordovician limestone water at the coal mine varied from 442 m to 559 m a.s.l. The former was 24 m higher than the maximum of the latter. The Diezigou No.1 groundwater supply well, which was mining the Ordovician limestone water, was 1320 m away from the water inrush site. As the nearest one to the accident site, the elevation of the Ordovician limestone water in the well was 526 m a.s.l. It was 27 m lower than that of the water inrush site. Therefore, the underlying Ordovician limestone water did not supply the accumulated groundwater in the abandoned tunnels of the individually owned closed coal mine. On the other hand, the elevation of the sandstone water in the roof of the No.2 coal seam varied from 829 m to 919 m a.s.l. What is more, the floor elevation of the abandoned tunnels varied from 554 m to about 585 m a.s.l. As a result, the sandstone water filled the abandoned tunnels and goafs of the individually owned closed coal mine

(3) According to the investigative record, within 26 minutes after the initial water inrush, i.e., from 13:12 to 13:38 on March 28, the tunnels with a volume of 18,387 m^3 were flooded. As a result, the peak inflow rate was 42,432 m^3/h. However, in the following time, i.e., from 13:38 on March 28 to 10:00 on March 29, the inrush water filled the equal volume of the tunnels, i.e., 18,387 m^3 to 583 m a.s.l. Therefore, the second peak inflow rate was 5661 m^3/h. Dramatic decrease of the inflow rate behaved in a typical characteristic of the inrush water from the goaf

(4) On the basis of results of the inrush water drainage and its drop down, the water table dropped 0.01 m, i.e., from 582.265 m to 582.255 m a.s.l., from 17:00 to 18:00 on March 31. Meanwhile, the outflow rate was 1354.5 m^3 in this period. However, the water table dropped 0.13 m, i.e., from 571.09 m to 570.96 m a.s.l., from 10:00 to 11:00 a.m. on April 4.

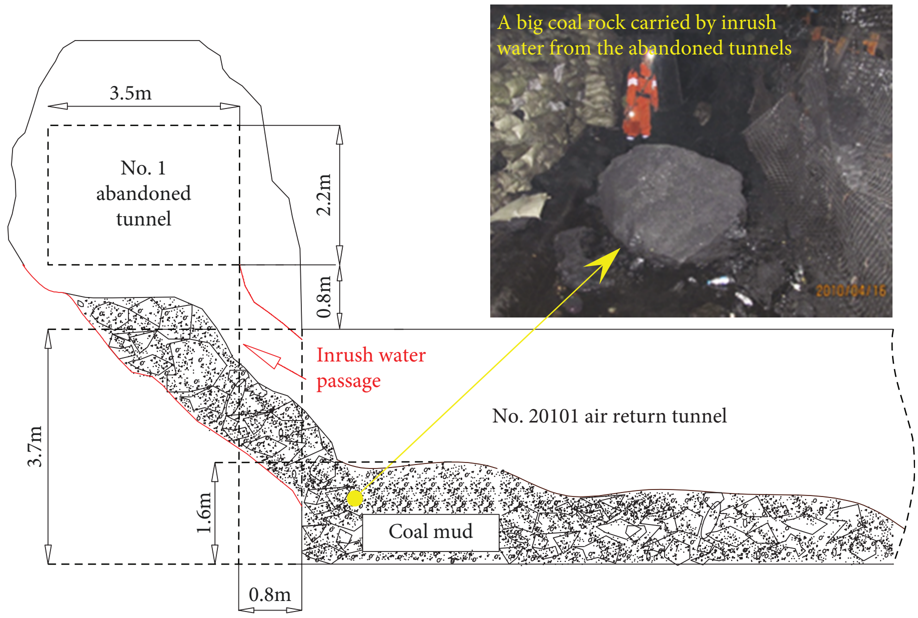


FIGURE 7: Cross section of the inrush water passage.

FIGURE 8: Roof caving in the No.1 abandoned tunnel.

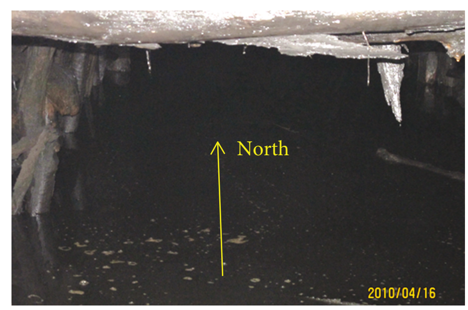


FIGURE 10: The accumulated water in the No.1 abandoned tunnel.

FIGURE 9: Timber support in the No.1 abandoned tunnel.

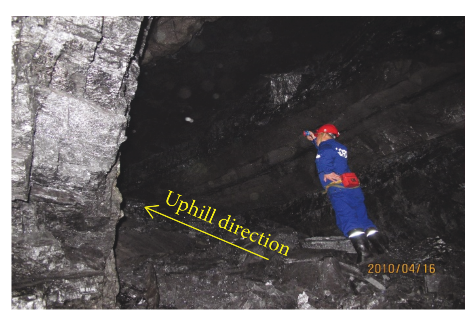


FIGURE 11: Uphill direction in the No.1 abandoned tunnel.

Meanwhile, the outflow rate was 1382.5 m^3/h. The latter drop down of the water table underwent a dramatical rise, i.e., 13 times larger than that of the former, when the two outflow volumes were almost equal. Based on the above fact, a conclusion, which the supply of the inrush water was not in positive correlation with the water table drawdown, was drawn. The fact also behaved in a typical characteristic of the inrush water from the goaf

7.2. Inrush Water Passage. The inrush water passage formed in the west roof of the heading face of the air return tunnel in the 20101 first mining face as shown in Figure 6. With the tunnel's driving, as shown in Figure 7, when the width of the coal wall between the heading face and the proximal wall

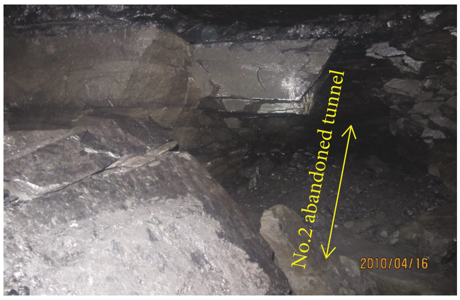


Figure 12: No.2 abandoned tunnel.

Figure 13: No.3 abandoned tunnel.

of the No.1 abandoned tunnel decreased to 0.8 m, the thin wall, where it had been damaged by the accumulated goaf water before the accident and its effective waterproof thickness was less than 0.8 m, was eventually broken by the high-pressure inrush water accumulated previously in the abandoned tunnels and goafs of the individually closed coal mine. In the following time, a great amount of the accumulated water flooded the tunnels of the Wangjialing coal mine to 583 m a.s.l. and caused great damage.

8. Causes of the Disaster

Some key causes inducing the disastrous accident are inferred as follows.

(1) Unidentified hydrogeological conditions near the air return tunnel in the 20101 first mining face, especially the unknown distribution and water-filled degree of the abandoned tunnels and goafs of the closed individually owned coal mine, are critical bases for the groundwater inrush disaster. As stated above, a great number of goafs formed due to the almost 30-year underground coal mining of the closed individually owned coal mines in the Wangjialing coal field. Their distribution, water-filled condition, and supply source were all unidentified, which were all great handicaps for the following coal mining at the Wangjialing coal mine. In fact, the tunnels' construction once uncovered some abandoned tunnels and goafs two times. What is more, some site investigations and three-dimensional seismic exploration were conducted subsequently to identify the locations of the abandoned tunnels and goafs. However, the exploration was not carried out in the entire coal field. During construction of the air return tunnel, the exploration in the 20101 first mining face was not completed

(2) Some regulations for exploration and release of abundant groundwater were not carried out thoroughly. Additionally, adopted exploration techniques were not comprehensive. Before the accident, geophysical exploration techniques including electrical resistivity method and Rayleigh wave method were completed in late March 2010 for the driving safety of the air return tunnel in the 20101 first mining face. What is more, some abnormal areas of abundant groundwater were identified. Unfortunately, its serious effect was not anticipated. Drilling was not conducted to verify the water abundance in the abnormal areas for assessing probable consequence. On the contrary, the conclusion whose content was that the following tunneling would be safe was made. It is a great mistake

(3) Miners' awareness of water hazard controlling was poor. Although some obvious signs that indicated the forthcoming water inrush appeared, the miners did not take effective measures for their life safety. Some water accumulated on the floor and some water seeped from the roof several times in the air return tunnel of the 20101 first mining face from March 2010. However, any effective measure was not carried out for its controlling. More seriously, the time lasted for about 2 hours and 42 minutes from the moment of obvious sign appearing to the moment of large-scale water inrush, i.e., from 10:30 to 13:12 on March 28, 2010. During this period, although some on-site inspections were conducted, effective response measures for ensuring the safety of the miners' lives, for example, miners retreating, were not taken. As a result, many miners were trapped by the water inrush. It was a great decision-making mistake

9. Conclusions and Suggestions

The strong water inrush caused great damage. The postaccident effective rescue obtained a great success. The inrush water was from the abandoned tunnels and goafs due to nearby mining in the No.2 coal seam of a closed individually owned coal mine, which were filled subsequently by groundwater from the sandstone aquifer in the roof of the coal seam. The passage formed in the west roof of the heading face of the air return tunnel in the 20101 first mining face. Unidentified hydrogeological conditions near the air return tunnel, especially the unknown distribution and water-filled degree of the abandoned tunnels and goafs of the closed individually owned coal mine, are critical bases for the accident. That important regulations for exploration and release of abundant groundwater were not carried out thoroughly which was another fatal cause leading to the accident. The poor awareness of water hazard controlling also contributed the accident to a large extent.

Table 1: Results of the groundwater quality analysis unit: mg·l^{-1}/X%.

Source	The inrush water			The Ordovician water	The P+C sandstone water in the roof of the No.2 coal seam
Sampling site	The water pump outlet			No.1 supply well	S5 hydrological hole
Sampling time	2010.3.28	2010.3.31	2010.4.2	2009.3.11	2008.8.6
Total hardness	101.17	91.88	73.8	1454.2	12.46
Ca^{2+}	23.45/4.88	26.22/3.54	20.58/4.48	324.97/48.76	3.33/1.06
Mg^{2+}	10.35/3.55	6.41/2.23	5.44/1.95	156.06/38.60	1.01/0.53
Na^{+}	495.00/0.70	495.93/91.36	489.18/92.80	94.67/12.38	355.40/92.28
K^{+}	6.60/89.76				
Fe^{3+}	1.60/0.36	0.19/0.04	0.23/0.04	1.52/0.24	0.34/0.10
Total cation	540.52/100	532.20/100	518.31/100	577.30/100	360.20/100
Cl^{-}	69.51/8.00	60.98/7.28	50.33/6.19	515.92/43.75	52.86/9.48
SO_4^{2-}	204.42/17.33	205.39/18.11	195.92/17.78	537.55/33.65	159.70/21.14
HCO_3^{-}	1110.01/74.10	1072.74/74.46	1015.83/72.61	456.29/22.48	580.09/60.44
F^{-}	2.64/0.57	2.96/0.68	3.40/0.78	—	
Total anion	1386.66/100	1340.99/100	1285.89/100	1512.17/100	835.36/100
pH value	7.62	7.91	8.35	7.44	8.3
Salinity	—	1310	1350	2089.47	1195.56
Hydrochemical type	HCO_3-Na	HCO_3-Na	HCO_3-Na	Cl·SO_4-Ca·Mg	HCO_3-Na

Great lessons are drawn as follows.

(1) The important principle in Regulations on Coal Mine Water Hazard Controlling must be carried out thoroughly during underground coal mining. It can be detailed into four steps [25]. Step no. 1: based on the hydrogeological condition identification, water rush risk should be assessed and forecasted to the coal mining threatened by groundwater. Step no. 2: exploration should be conducted for controlling or even eliminating the probable water inrush according to the risk assessment result. Step no. 3: tunneling should be permitted only after site explorations and groundwater draining are conducted to ensure the tunneling safety. Step no. 4: underground coal mining should be permitted only after the probable water inrush is controlled thoroughly. Basic hydrogeological work should be emphasized furtherly. Theoretical and practical research whose content concentrates on water hazard exploration, prevention, and elimination should be conducted regularly. The important principle that geophysical exploration must be followed by drilling to verify the former's result should be abided by unswervingly in underground hydrogeological exploration

(2) Independent organization and perfect system should be constructed for coal mine water hazard controlling. Sufficient funds should also be provided. Afterwards, medium and long-term controlling plans should be put forward and implemented in the future

(3) The awareness for water hazard controlling of the miners must be strengthened. Their ability to recognize some signs of the hazard should be developed so that the hazard can be treated quickly and properly

(4) The underground mining distribution in different time periods should be identified to secure the present mining at a coal mine

(5) The underground mining of individually owned coal mines should be supervised strictly. Their mining should follow some related regulations and laws. Their mining depths and boundaries should be limited strictly. Their illegal mining must be punished judicially

Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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