The Hydrogeological Characteristics of Thick Alluvium with High Water Level and the Influence on Zhaogu Mining Area, Henan Province, China

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Received 31 August 2022; Accepted 18 October 2022; Published 27 October 2022

Academic Editor: Zhiyuan Wang

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In parts of North China Plain, there are several aquifers in the thick alluvium over the coal seam, which overlays a large amount of coal resources. Roof water inrush accident occurred during coal mining often caused by multiple reasons. Based on the case of roof water inrush in Zhaogu Mining Area, by hydrologic supplementary exploration of the north flank, the stratum data were obtained; combined with previous geological drilling data of the mine, the structural characteristics of five main aquifers and five main aquicludes in the alluvium of the north flank were classified. By pumping test of the No. 1 and the No. 2 supplementary exploration drill holes, the water richness of the 5th aquifer of north flank is identified as medium level. Three thin layers of gravel aquifer beneath the 5th aquifer were found in No. 1 drill hole, and the water richness of the lowest thin gravel (2.95 m thickness) was identified as medium by the followed pumping test, which reveals an important factor leading to the insufficient size of the safety pillar. The leakage self-closed aperture test on the sand soil of the 5th aquiclude clarifies that in case of fracture connection, it cannot resist water and sand crushing under high water pressure of the 5th aquifer. Based on the mechanism of high-pressure water on the working face supports, the calculation method of support resistance under high water pressure alluvial layer is put forward, and the main reason of roof support failure and water inrush is the insufficient support resistance, which leads to abnormal height caving. The methods of experiment and calculation are clarified for preventing water and sand inrush accident of working faces with the similar mining background.

1. Introduction

The central region is one of the main coal production bases in China. According to the 4th National Coal Resource Potential Survey and Evaluation, the total coal resources of the five provinces in the central region are about 391.924 billion tons, accounting for about 24% of the total national coal resources [1–4]. Some coal fields are generally covered by thick alluvium, and the thickness of alluvium in some mining areas in Henan Province and Anhui Province reaches more than 400 m, which covers over 6.13 billion tons coal resource, and belongs to the typical thick alluvium covering area of the North China type coal fields. Thick alluvium aquifers generally contain multilayer sand aquifers and gravel aquifers with extremely different water richness, which overlays huge coal resources. Solving mining under alluvial aquifers is beneficial to ease the supply-demand relationship of coal resources in China. Meanwhile, it remains serious safety and technical problems in mining under alluvial aquifers: (1) there are generally a number of uneven thickness of the aquifers in the alluvium with complex geological structure; when the bedrock of coal seam is thinner than the water-conducting fracture zone, the fractures may connect more alluvium aquifers, and it is likely to collapse
water sand into mining working face, such as the water inrush accidents happened in mining working faces under thick alluvium aquifers in Huainan Mining Area, Anhui Province [5–8]. (2) With the development of coal mining technologies such as large mining height, top coal caving, and large mining length, the scope of roof stress destruction and the height of water-conducting fracture zone have both increased, connecting the water body that is previously untouched, such as the water inrush accident caused by separation layers in mining under the huge thick alluvium aquifers in Binchang Mining Area, Shanxi Province [9–12]. (3) The alluvial aquifers in some mining areas have high water level and high water pressure. The pipiing is more likely to occur under the influence of high water pressure; the water and sand collapse between supports into the working face from the overlying alluvium, such as the roof water and sand inrush accident in Zhaogu Mining Area, Henan Province [13, 14].

Extensive researches on safe mining under water body have been carried out. Wu et al. proposed the GIS-based multi-information fusion "water abundance index method," which describes the multidimensional and complexity of the influencing factors of aquifer water richness by comprehensively analysing the basic hydrogeological data of mines [15]. Singh and Kendorski have proposed the important role of the key aquiclude between the water body and the goaf [16]. Coe and Stowe analysed the main influencing factors of longwall mining on the overlying strata of coal seam [17]. Booth studied that the influence of overlying aquifer on the working face of coal mining mainly depends on the relationship between the strata and the goaf [18]. Gogorza et al. measured the Holocene fluvial deposits in the southern Sierras Pampeanas (Argentina) by matching paleomagnetic secular variation to a geomagnetic field model [19]. Yu and Chi formed a safe mining mode of “upper protection and lower dredging” for mining under water body in Bangladesh [20]. Yellishetty et al. examine water–soil interactions occurring in the mining by flame atomic absorption spectroscopy in India [21]. Under normal circumstances, the roof water flowing into the coal mine often happens a few days later after mining, when the water-conducting fracture zone stretching and connecting overlying aquifer. However, the water inrush accident happens during mining process while the water-conducting fracture zone has not fully formed, so this phenomenon is relatively rare, and seldom relevant researches have been conducted [22–25].

1.1. General Situation of Mine. The Zhaogu No. 1 coal mine is located in North China Plain, which is in the north of Henan Province and the south of Taihang Mountains (Figure 1). The buried depth of mining No. 2-1 coal seam is 410 m ~ 860 m, the average coal thickness is 5.92 m, and production capacity is 2.4 million t/a. The mining methods are mainly longwall inclining slicing mining, fully mechanized caving mining, and large mining height.

The average thickness of the overlying alluvium in Zhaogu No. 1 mine is over 400 m, and the thickness of the bedrock is between 2.82 m and 248.09 m [26]. The coal field is divided into the south flank and the north flank by fault F16. It has been mined for 14 years in the south flank, and 17 thin bedrock working faces have been finished. The north flank is the main production area of the mine in the next 10 years, adopting the same standard of the safety pillar in thin bedrock working face of the south flank, but a roof water and sand inrush accident happened in 2019. On this background, the hydrogeological condition of the overlying alluvium is the prerequisite factor to determine the water and sand crushing from the alluvial layers [4, 12, 27]. Two alluvial supplementary exploration drill holes were constructed on the north flank in 2021.

The main water-filling sources of roof water are sand and gravel aquifer in the middle and lower Neogene,
bedrock weathering zone aquifer, and Permian sandstone aquifer in coal seam roof (Figure 2). According to the data collected from the exploration period and the production of the south flank, the most influencing roof aquifer to mining is the middle and lower Neogene sand and gravel aquifer, which contains 1-3 layers of medium sand, fine sand, and gravel aquifer. The aquifer specific field of the south flank is 0.393 L/s·m, which belongs to the medium water-richness aquifer, and the permeability coefficient is 2.082 m/d, and water level elevation is +87.61 m. Generally, there is a set of well-consolidated mud and argillaceous water-repellent layers beneath the aquifer, which can effectively block its filling of water to the mine. However, in the thin bedrock area and “skylight” area (the area of roof waterproof layer missing), roof water, and sand inrush accidents still happened.

2. Structure and Characteristics of the Thick Alluvium

2.1. Distribution Characteristics. According to the drilling histograms of previous 47 exploration drill holes in the north flank and 2 hydrogeological supplementary exploration drill holes completed in 2021, the alluvial strata characteristics of the north flank were analysed, and three parameters were obtained: the thickness of alluvium, the thickness of sand gravel aquifer in the lower part of alluvium, and the thickness of clay layer at the bottom of the alluvium (Table 1). According to the statistical data, the contour map of the alluvium thickness of the north flank (Figure 3) and the contour map of the thickness of clay layer at the bottom of the alluvium of the north flank (Figure 4) are drawn.

The following conclusions can be drawn:

(1) The north alluvium is mainly composed of clay, sandy clay, clay mixed with gravel, gravel, fine sand, and medium sand. The thickness of alluvium ranges from 304.8 m to 539.2 m, with an average thickness of 459.8 m. The thickness distribution is uneven, and the maximum thickness difference is 234.4 m. Since the surface is plain, the difference in alluvial thickness is mainly due to the fluctuation of the bedrock bottom.

(2) The thickness of sand gravel aquifer in the lower part of alluvium is in the range of 0.8 ~ 68 m; the average thickness is 5.28 m.

(3) The overall distribution of alluvial thickness has obvious difference in the west part and the east part. In general, the thickness of alluvium in the west part is thicker, the thickness in the east part is thinner, and the variation of the thickness in both parts is obviously inconsistent. In the west part, there is a set of well-consolidated mud and argillaceous water-repellent layers beneath the aquifer, which can effectively block its filling of water to the mine. However, in the thin bedrock area (the area of roof waterproof layer missing), roof water, and sand inrush accidents still happened.

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Figure 2: Comprehensive histogram of coal seam roof.
Table 1: Structural characteristics of north flank alluvium.

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<th>Thickness of clay layer (m)</th>
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Figure 3: Contour map of the alluvium thickness of the north flan.
part, the thickness of alluvium increases from 410 m to 500 m from west to east, and the thickness distribution is relatively even. In the east part, the alluvium thickness is 480 m in the middle section and gradually thickens to 500 m to the east and west directions and then thins to 450 m in the east side.

(4) It can be seen from Table 1 that the thickness of the clay layer at the bottom of the alluvium ranges from 0 m to 127.48 m, with an average thickness of 41.2 m. And it can be seen from Figure 4 that the overall distribution of clay layer is complex. Furthermore, there are bottom clay layers in most areas; however, in some areas, the clay layer is missing, and the sand and gravel layers directly covers the bedrock, which forms the “skylight” area.

2.2. Structure Characteristics. According to the lithology of the boreholes in the north flank of Zhaogu No. 1 mine, the aquifers and aquicludes in alluvium are classified. The stratigraphy classification standard is as follows: the thickness of single clay layer is more than 10 m and is widely distributed in the whole north flank, which is identified as the aquiclude. The sand and gravel layers with a single thickness of more than 5 m are identified as the aquifer, and the regional aquifer is widely distributed in the whole north flank. If there are other interbedded thin clay and gravel layers, they are incorporated into the upper or lower aquifers or aquifers depending on the ratio of clay or sand. According to the location of exploration boreholes in the north flank, four alluvial profile maps (Figure 5) were made (the profile lines are shown in Figure 3): the north-south profile I (profile line A-A’), the north-south profile II (profile line B-B’), the east-west profile I (profile line C-C’), and the east-west profile II (profile line D-D’). According to the 4 profiles and stratigraphy statistics, the overall structural characteristics of alluvium are obtained.

The following conclusions can be drawn from Figure 5:

(1) The alluvium of the north flank is classified into five aquifers and five aquicludes. The five aquifers and the four upper aquicludes are relatively nearly flat. The thickness variation of the 5th aquiclude leads to the change of alluvium thickness, and the thickness variation of the 5th aquiclude is mainly caused by the fluctuation of bedrock surface. The bedrock surface appears generally high in the north and low in the south, with the Taihang mountain area in the north, so it conforms to the regional stratigraphic structure.

(2) The sand and gravel layers in the middle or lower part of the 5th aquiclude and the 5th aquifer have a direct influence on coal mining in the thin bedrock area. Due to the barrier of thick clay layer between each aquifer, the aquifers above the 5th aquifer have no direct influence on coal mining.

(3) According to the profiles, the east to west alluvium structure condition is obviously more complicated than the one of north to south, which is mainly showed in profiles that the uneven thickness of the 5th aquifer and the 5th aquiclude. There are generally sand and gravel lenses in the 5th aquiclude, and the interface between the bottom boundary of alluvial layer and bedrock is inclined, resulting in the sand and gravel lens at the bottom of alluvium in this region directly contacting with bedrock, forming the structure of “sand and gravel lens with high water pressure”.

(4) The hydrogeological characteristics of the 5th aquifer and the lower thin gravel layers determine the incidence of water and sand inrush.

3. Water Richness of the 5th Aquifer and the Lower Thin Gravel Layer

3.1. Pumping Test Position. To test the water richness of the 5th aquifer, pumping test was conducted. According to the
(a) The north-south profile I

(b) The north-south profile II

Figure 5: Continued.
drilling data, the No. 1 drill hole pumping test section is from 407 m to 522 m, which includes the section of 409.07 m ~ 412.80 m, 440.43 m ~ 449.50 m, 456.01 m ~ 459.04 m, and 516.13 m ~ 517.63 m (Figure 6). The pumping equipment is stainless steel submersible pumps and the machine models are 100QJ4-340/7.5 and S13QJY22-73/11-7.5.

The No. 2 drill hole pumping test position is from 407 m to 522 m, which includes the gravel layer and fine sand layer in the section of 422.57 m ~ 425.13 m (Figure 7).

3.2 Results of Pumping Test. The specific field of the 5th aquifer of the No. 1 drill hole is 0.3855 L/s·m; according to the judgment standard [28], the mixed aquifer of the 5th aquifer and the lower gravel layer of No. 1 drill hole is medium water richness. The steady water level is +77.062 m. The specific field of the 5th aquifer of the No. 2 drill hole is 0.4190 L/s·m. According to the judgment standard, the 5th aquifer of No. 2 drill hole is medium water richness. The steady water level is +76.667 m.
Since there are three thin gravel layers in the lower part of the 5th aquifer, the specific field of the lowest thin gravel layer is obtained by the way of sectional hole sealing and pumping. The specific field of the lowest thin gravel layer of the No. 1 drill hole is 0.1408 L/s·m. According to the judgment standard, the lowest thin gravel layer beneath the 5th aquifer is medium water richness. The steady water level is +74.012 m.

3.3. Flow Logging Verification. In order to verify the water richness of the 5th aquifer and the lower thin gravel aquifer, the flow logging was carried out. When the flow velocity is faster, the water supply is better and water richness is stronger.

According to the comparison of flow logging, the water outlet section of the No. 1 drill hole is in the section of 420 m to 476 m depth, which is consistent with the location of the 5th aquifer and the lower thin gravel layer. The water outlet section of the No. 2 drill hole is in the section of 417 m to 424 m depth, which is consistent with the location of the 5th aquifer (Figure 8). The measured flow rate of the No. 1 drill hole is 17.20 m³/h, and the measured flow rate of the No. 2 drill hole is 11.97 m³/h. The thickness of the fifth aquifer and the flow rate of the No. 1 drill hole are both greater than that of the No. 2 drill hole.

4. Analysis of the Sand Soil Permeability of the 5th Aquiclude

4.1. Natural Condition of the 5th Aquiclude. The 5th aquiclude is located between the No. 5 aquifer and the bedrock, mainly composed of clay, sandy clay, and sandy soil, which plays a key role in preventing the No. 5 aquifer from rush into the coal mining. The water tightness of sand soil needs to be verified by laboratory test. According to soil mechanics analysis of leakage conditions, under natural conditions, when the water level of aquifer reaches a certain height, the seepage force acting on the soil also increases; when the upward osmotic force overcomes the downward gravity, the soil is damaged. According to the water level of the No. 1 and the No. 2 drill hole, the water level of the 5th aquifer is about +77 m, the elevation of the aquifer is mostly about -350 m, the waterhead is more...
<table>
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(a) Flow curve of No. 1 drill hole

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(b) Flow curve of No. 2 drill hole

Figure 8: Flow curve of No. 1 and No. 2 drill holes.
than 400 m, and the water pressure is higher than 4 MPa. Under the influence of high water pressure, sand particles are prone to suspension and movement, resulting in sand and soil flow.

4.2. Leakage Self-Closed Aperture Test. In order to test the leakage mechanism of sand soil in the 5th aquiclude, special laboratory tests were carried out to study the change of leakage aperture, the relationship between water inrush time and water inflow, and the destruction pattern of sand soil caused by leakage.

According to the test planning, the combined thickness of soil column and soil in the funnel is 12 cm, and the waterhead is two times higher than the thickness of soil column, namely, 26 cm. During the test, the water flow direction is from top to bottom, and the top is constantly injected with water to maintain the constant waterhead. The gasket with different aperture is placed at the bottom of the funnel. When all the sand and mud water flow out with a certain gasket aperture, the aperture is the critical point of leakage. When the gasket of a certain aperture is measured, the part of sand and mud water flows out and then stops; the aperture is leakage self-closed aperture.

The test samples were taken from the sand soil with a depth of 457 m~458 m in the No. 1 drill hole (Figure 9(a)). The samples were yellow, and the cores were wrapped with plastic wrap and kept moist.

(1) Firstly, the leakage damage under natural condition (no fracture conducting) was tested; a measuring jug was established under the testbed to calculate water flow. The test lasted for 23 hours and 30 minutes, from No. 1 aperture (2 mm) to No. 6 aperture (15 mm), during which a small amount of surface soil floated, but no leakage of mud and sand water occurred. It is proved that under natural conditions, the leakage does not occur (Figures 9(b) and 9(c)).
(2) Secondly, in order to simulate the leakage self-closed condition of water-conducting fracture, a metal rod with a length of 3 mm and a width of 1 mm was used to penetrate the sand layer, observing the change of water flow and the leakage self-closed condition in unit time. According to the test results, the flow-time relation diagram of leakage self-closed aperture was drawn (Figure 10). It can be seen from the test results that the size of gasket aperture has an increasing relationship with the initial water amount and an inverse relationship with the closed time; that is, the larger the gasket aperture is, the larger the initial water amount is, and the longer the closed time is. The No. 1 and No. 2 apertures closed within 20 minutes, and the flow decreased sharply to a certain extent and then gradually decreased. The No. 3 aperture self-closed time was 138 minutes (the final water flow was 0.12 mL/min), and the water flow increased during 20 to 50 minutes; it suggested that the water flow accumulated to a certain pressure and repeatedly scoured and deposited sand and stone at the aperture; the water flow decreased slowly at about 50 minutes, and the leakage closed gradually. During the observation period of No. 4 and No. 6 apertures, the water flow gradually increased, judging that the leakage could not close. Therefore, the leakage self-closed aperture is 6 mm (No. 3 aperture).

According to Figure 11, the shape of sand soil leakage channel generally presents a trumpet shape, which is narrow at the top and wide at the bottom. Leakage channel is mainly upper and internal parts closed; the bottom is still open. The overall law is as follows: the larger the gasket aperture size is, the smaller the top size of the channel is, and the larger the bottom size of the channel is. The main reason is that the faster the leakage velocity is, the more turbulence in the channel, and the sand and mud near the top will be sucked into the channel and scoured towards the bottom at a relatively high speed, continuously expanding the bottom hole. After the channel is blocked by larger sand or grave, the mud and sand deposit gradually, covering the top of the channel, while the aperture of the channel bottom remains unchanged.

5. Case Analysis of Roof Water Inrush during Mining

5.1. Working Face Condition. 16031 working face is the fifth working face of the north flank. The working face is 241.1 m long; the roadway is 1214.6 m long. The average dip angle of coal seam is 5°, the average coal thickness is 6.23 m, and the mining height is 3.5 m. Comprehensive mechanized coal mining method is adopted. According to preliminary demonstration, the maximum over burden pressure is 8200 kN; therefore, the working face is equipped with 154 supports, and each support’s working resistance is 10000 kN. The thickness of alluvium ranges from 458.54 m to 491.14 m, with an average of 474.84 m. Before the mining of the working face, 66 roof drilling holes were conducted from drilling sites in the working face roadway to explore the alluvium’s condition and drain off roof water. The top side of drilling position was 5 m vertical above the bedrock. The thickness of the bedrock of the working face was 32.9–59.9 m, only two drilling holes’ water flow was more than 2 m³/h, and the water flow of all the drilling holes decreased to less than...
0.5 m³/h within 24 hours, which proved that the poor water richness of the alluvium within 5 m above the bedrock and the clay has good water-repellent effect. According to the mining under alluvium aquifer verification reports of the south flank, 30 m safety pillar is remained.

5.2. Details of the Accident. The initial mining weighting of the working face occurred when working face advanced 12 m, which resulted in conveyor and coal cutter buried; some supports were pressed to the lowest height and hardly to be lifted. On the day of the initial mining weighting occurred, intermittent roof water dropped into working face with the roof caving, the water colour was yellow, and the amount of water decreased gradually, but then suddenly increased; the maximum water amount was 40 m³/h. The working face advanced by repairing the supports and mining at the same time, attempting to get rid of the periodic pressure. Finally, the roof water and sand inrush accident happened after the working face advanced 47 m, with 280 m³ water inrush amount and 1360 m³ sand amount.

5.3. Analysis of the Mechanism of Water Inrush during Mining

(1) The 66 drilling holes have covered the range of safety pillar, and the water amount of drilling holes decreased fast, which indicate the sand soil at the bottom of alluvium has a good character of leakage self-close; this situation is coincident with the leakage self-closed test No. 1 and No. 2 apertures. The roof water dropped during the working face mining when the initial mining weighting occurred, and the water amount decreased from large to small and then increased, which was coincident with the leakage self-closed test No. 3 aperture. It indicates that the fracture’s aperture is close to the leakage aperture and stretched into the upper medium water-richness aquifer. In the case of water inrush accident, the roof water rushed into working face with a large amount of mud and sand, which is similar to the leakage self-closed test No. 4 and No. 6 apertures. It indicates that the piping occurs as the water flow continuously scours and expands the channel.

(2) The location of water and sand inrush accident happened in the working face and upon the supports, rather than in the goaf behind the working face, indicating that the water channel is not the fracture caused by the collapse of the overlying strata after coal mining in the traditional sense. The accident happened with the failure of a part of supports, and the overburden rock constantly collapsed and fell into the working face, resulting in fractures with abnormal height, which directly connect to the thin water-bearing sand layer in the lower part of the alluvium.

(3) According to the supplementary exploration results of the north flank, the water pressure of the 5th
aqueous and the lower gravel layer in north flank of the mine is over 4 MPa. Therefore, except for the load of the overlying strata, the additional load of the support caused by high-pressure water when the fracture connects the aquifer should also be considered in the working face support resistance. The calculation formula [29, 30] is summarized as

\[ F = \frac{2(E_H + E_p - \lambda l)}{x}, \]  

where \( E_H \) is the energy of confined water; according to the calculation results of references, 1234 J is taken; \( E_p \) is potential energy; and \( \lambda l \) is energy loss along the water conducting channel. According to the permeability test and the situation of water inrush in working face, when the piping occurs, the water channel is smooth, and the confined water can reach the working face through potential energy; the potential energy is offset with the energy loss along the way. \( x \) is the compression amount of the supports; according to the measured data of the working face, 1.3 m is taken.

Take the numerical value into equation (1). 

\( F \) is obtained as 1899 kN.

Based on the above analysis, due to the increased impact load caused by water pressure when roof water inrush happens in the working face, the support resistance \( P' \) is

\[ P' = P + F, \]  

where \( P \) is overburden pressure; according to the design of 16031 working face, 8200 kN is obtained; \( F \) is the impact of water flow; according to result of equation (1), 1899 kN is obtained. Therefore, on condition of roof water connection, the total resistance of supports should be 10099 kN, which has exceeded the design of the working face support load. It reasonably explained that the support load increased significantly in the zone of roof water dropping, leading to the failure of support roof water inrush accident in the end.

6. Discussion

According to pumping test, the water richness of the 5th aquifer and the lower gravel layer (thickness of 2.95 m) is medium; in order to prevent the roof water inrush, it needs to remain the safety pillar under water body [31], which ensures that the water-conducting fracture zone cannot connect to the aquifer. Because there has not been sufficient argumentation of safety pillar based on the hydrogeological studies in the north flank before, the sand prevention safety pillar (allows the water-conducting fracture zone to connect to the aquifer) was remained, which leads to the insufficient thickness of the safety pillar. It is the main reason for water and sand inrush in the north flank of the Zhaogu No. 1 coal mine.

In some areas of the north flank, the bedrock surface fluctuates greatly, resulting in the thinning or missing of the 5th aquiclude. Besides, there is structure of “sand and gravel lens with high water pressure” in the 5th aquiclude; when mining under such geological conditions, it is more likely for the water and sand inrush with large instantaneous peak value to occur.

According to the leakage self-closed aperture test, when the water-conducting fracture zone does not connect the aquifer, the leakage does not occur. However, when the water-conducting fracture zone connects the aquifer and the leakage aperture is less than or equal to 6 mm under the condition of 2 times ratio gradient, the leakage aperture of sand soil can close itself; otherwise, the water-conducting tunnel will gradually expand and form the piping. In addition, the water pressure of the No. 5 aquifer in the north flank is higher than 4 MPa; the possibility of water and sand inrush will increase when the water-conducting fracture zone is close to the aquifer or the fracture aperture is less than 6 mm.

The roof water inrush during mining process is formed by coupling of various factors, and an important reason is that the impact force of the overlying high-pressure water on the support is not taken into account for the support selection, resulting in insufficient support and abnormal high caving, connecting the high water pressure aquifer above the safety pillar, and causing water inrush. In addition, the water inrush location is in the working face during mining process; the extent of injury to personnel and equipment will be severer than that in the goaf.

7. Conclusion

The alluvium of the north flank of Zhaogu No. 1 coal mine is classified into five aquifers and five aquicludes. The five aquifers and the four upper aquicludes are nearly flat. The thickness variation of the 5th aquiclude leads to the change of alluvium thickness, and the thickness variation of 5th aquiclude is mainly caused by the fluctuation of bedrock surface.

The No. 5 aquifer is mainly composed of sand and gravel, and its specific field is 0.3874 L/s·m⁻¹·0.4190 L/s·m⁻¹, which belongs to medium water richness. There is also 2.95 m gravel aquifer beneath the No. 5 aquifer in the No. 1 drill hole area, with the specific field of 0.1408 L/s·m⁻¹, which also belongs to medium water richness.

The leakage self-closed aperture test of the sand soil shows that the No. 5 aquiclude can effectively prevent the water and sand inrush to the mine working face under the condition that the water-conducting fracture zone is not connected. However, when there is water-conducting fracture connection, under the influence of 4 MPa water pressure, water and sand inrush accident to mining working face will be more likely to happen, and the leakage tunnel will not be self-closed.

The water inrush accident happened in the working face during mining process has a certain relationship with the water richness of the overlying aquifer, the high pressure of confined water, the insufficient size of the safety pillar, the leakage self-closed ability of sand soil, the support ability of supports, and the management of mining operation and equipment. Above all, the direct reason is that the roof high-pressure water impact force is not taken into account.
during the calculation of the resistance of the working face supports, which leads to the insufficient support force, and the newfound lower thin medium water-richness aquifer, which leads to the insufficient thickness of the safety pillar.

Data Availability
The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest
The authors declare no conflicts of interest.

Acknowledgments
The authors are grateful to the Zhaogu No. 1 Coal Mine for their partial funding, providing field testing sites and related data. This work is supported by the National Natural Science Foundation of China (Fund number: 51934008) and the National Key Basic Research Development Program of China (the Fundamental Research Funds for the Central Universities (2021YQNY09)). The authors are also very grateful for this generous support.

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