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Study on the Safety and Prevention Technology of Coal Mining under the River in Xingyuan Coal Mine

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Abstract

Coal mining-induced surface subsidence poses significant ecological and infrastructural challenges, necessitating a comprehensive study to ensure safe mining practices, particularly in underwater conditions. This project aims to address the extensive impact of coal mining on the environment, infrastructure, and overall safety, focusing on the Shigong River area above the working face. The study employs qualitative and quantitative analyses, along with on-site engineering measurements, to gather data on crucial parameters such as coal seam characteristics, roof rock lithology, thickness, water resistance, and structural damage degree. The research encompasses a multidisciplinary approach, involving mining, geology, hydrogeology, geophysical exploration, rock mechanics, mine surveying, and computational mathematics. The importance of effective safety measures and prevention techniques is emphasized, laying the foundation for research focused on the Xingyun coal mine. The brief concludes by highlighting the potential economic and social benefits of this project and its contribution to valuable experience for future subsea coal mining.

Keywords

Coal Mining-Induced Surface Subsidence, Ecological and Infrastructural Challenges, Safe Mining Practices, Underwater Conditions, Multidisciplinary Approach, Safety Measures, Prevention Techniques

1. Introduction

As global coal demand continues to drive mining activities, it is imperative to prioritize the safety and sustainability of the mining process. Coal mining operations, especially in harsh environments such as underwater conditions, pose complex challenges that require comprehensive understanding and implementation of effective safety measures. Recognizing the multifaceted nature of these challenges, previous research on coal mining has extensively explored safety-related aspects, from ground stability to environmental impacts [1]. This study focuses on a specific and important aspect of coal mining: the operations carried out in rivers, with special emphasis on the Xingyuan coal mine. Although the present study provides valuable information on general safety measures in coal mines, the specific challenges posed by underwater conditions highlight the need for specialized investigation. Understanding the unique geologic and hydrogeological considerations of in-river mining is essential for developing targeted prevention technology [1] [2]. The novelty of this study lies in focusing on examining the prevention and safety technologies applied to riverside coal mining at Xingyuan Coal Mine. The specific challenges posed by riverbed instability, water resistance and potential ecological impacts require a tailored approach. This research not only aims to address the unique challenges of the Xingyuan coal mine but also provides insights and methods applicable to similar mining scenarios globally [3] [4] [5]. The benefits of this study become apparent as it aims to provide a comprehensive understanding of the precautions and safety measures required for river coal mining. By integrating expertise from various disciplines such as mining, geology, hydrogeology, geophysical exploration, rock mechanics, mining surveying and computational mathematics, research. This study applies a comprehensive and multidisciplinary approach. The knowledge gained is expected to not only improve the safety and sustainability of coal mining operations in Xingyuan but also serve as a reference for future efforts in equally cruel harsh mining environments. In the following sections, this study delves deeper into geological and hydrogeological considerations, safety measures, prevention technologies, and conclusions [6]. The overarching goal is to provide valuable insights to improve the safety and sustainability of riverine coal mining, with a particular focus on the unique context of the Xingyuan Coal Mine.

2. Overview

2.1. Project Research Content

1) Collect and analyze geological and mining technical data and drawings, and analyze the lithological and structural characteristics of the overlying rock. The data include: rock formation and surface movement parameters, histogram of nearby boreholes, excavation engineering plan, comparison map of up and down wells, geological profile, geological Reports and working face work procedures, etc.

2) Theoretical calculation and analysis of the development height of the overburden caving zone and fracture zone caused by mining: According to the geological mining technical data, analyze the lithological structure of the overlying stratum to determine the basic type of the overlying rock, and calculate and analyze the dynamic development height of the cracks in the overlying rock in

the stope. The study gives the "two zones" height value or contour map of overlying rock failure.

3) On-site observation and research on the development height of the water-conducting fracture zone in the mining face mining: According to the actual geological mining conditions of the mine and the mining situation of the underground working face, the field observation and design plan for the development height of the water-conducting fracture zone in the coal seam mining of the working face is proposed. The measured value of the development height of the water-conducting fracture zone in the coal seam mining of this mine was observed on-site by the liquid method and the borehole TV method.

4) Research on surface movement deformation and surface fractures caused by coal mining: According to the mining strata and surface movement laws and their parameters in this area, calculate and analyze the surface movement deformation value caused by mining in the working face, and analyze the development characteristics of surface fractures. Demonstrate the safety of coal mining under rivers.

5) Propose technical measures for mining under rivers and safety technical measures or plans for coal mining under rivers: According to the safety demonstration results of coal mining under rivers, put forward technical measures for underground mining and river protection.

6) Compile "Dengfeng Xingyun Coal Industry Co., Ltd. Under-River Coal Mining Safety Demonstration and Prevention Technology Research Report", and provide relevant technical consultation and technical guidance during the project research process.

2.2. Technical Route

According to the above research content and research methods, the technical route of this project is determined as shown in Figure 1.

3. Mine Overview and Geological Mining Conditions

3.1. The Basic Situation of the Mine

3.1.1. Location, Range and Traffic

Dengfeng Xingyun Coal Industry Co., Ltd. (hereinafter referred to as Xingyun Coal Industry) is located in Xiliubei Village, Daye Town, adjacent to Zhengzhou Rongchang Coal Industry Co., Ltd. in the northwest, 3 km away from Gaocheng Town in the west, and Ludian in the northwest. The town is 6 km away, and the northeast is 7 km away from Daye Town. The geographic coordinates are 113˚10'17" - 113˚11'19" east, 34˚23'54" - 34˚24'35" north latitude, and the field area is 1.1123 km^2. The mining area is 15 km away from the urban area of Dengfeng City. The Xinzheng-Shuizhai Railway passes through the southern part of the mining area. In the northern part of the mining area, there is another Da (Daye) ~ Huai (Huaishuping) asphalt road which is connected with Henan Provincial Highway 31. The mining area is connected with Dahuai Highway by a simple road, so the traffic is very convenient.

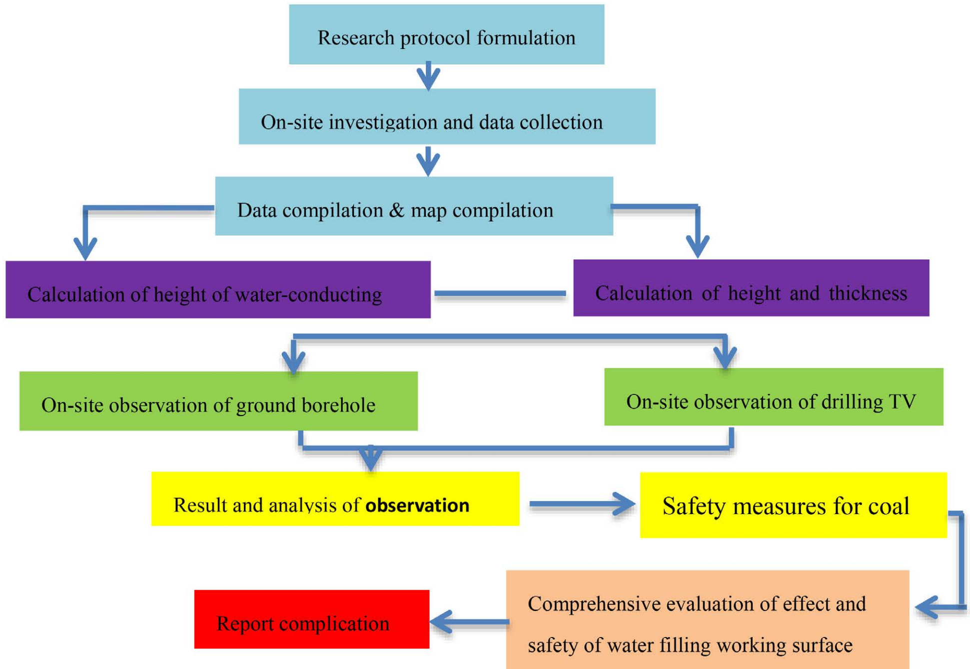


Figure 1. Technical flow chart.

3.1.2. Mine Production Overview

Dengfeng Xingyun Coal Industry Co., Ltd. is a newly established company after the integration of the former Shengfa Coal Mine in Dengfeng City and the fourth joint coal mine of Dengfeng Daye Town Grain Management Office. The original Shengfa Coal Mine, Daye Town, Dengfeng City, was built in June 1991. A total of 4 pairs of shafts were dug, namely the main well, the auxiliary well, the 3rd well, the 4th well, the 5th well, the 6th well and the pair of vertical wells in the west, with a production capacity of 6 tons/year. The Fourth Coal Mine of the former Daye Town Grain Management Institute is located in the north of Shengfa Coal Mine. It was built in 1997 and has a pair of vertical shafts, namely the main shaft and the auxiliary shaft, with a production capacity of 60,000 tons per year. In 2005, according to the spirit of Henan Provincial Resources Integration Office Yumei [2005] No.11 document, Dengfeng Shengfa Coal Mine and Dengfeng City Daye Town Grain Management Office Fourth Coal Mine were integrated into Dengfeng Xingyun Coal Industry Co., Ltd. [7], After the integration, the main and auxiliary wells of the original Shengfa Coal Mine will be used for production, and the second 1 coal seam will be mined, and the mining level will be +85 - +270 m. From November 2019 to September 2020, the technical transformation of the mine was carried out in accordance with the "Preliminary Design Modification" and relevant approval opinions, and the production capacity after the technical transformation of the mine was 300,000 tons/year. The mine adopts a single horizontal mixed development of vertical and inclined shafts. The main inclined shaft is used for coal extraction and air intake, the auxiliary inclined shaft is used to lift personnel, discharge materials and air intake, and the air shaft is exhausted for return air. The coal mining method is the retreating type towards the long wall, and the ventilation method is the central row type [6].

3.1.3. Physical Geographic Features

1) Climate and Meteorology

Xingyun coal mining area experiences a semi-humid, semi-arid monsoon climate. Annual precipitation, influenced by the monsoon, is concentrated in July-September, ranging from 472.1 to 699.7 mm (average 590.13 mm). The three seasons of autumn, winter, and spring are dry. Observations from 2005 to 2017 show an annual evaporation of 1473.3 to 1809.4 mm, average relative humidity of 52% - 66%, and a maximum snow depth of 18 mm (January 20, 2006). June-July temperatures reach a high of 40.10˚C (June 24, 2009), while January experiences lows of −14.0˚C (January 31, 1979). The annual average temperature is 14.83˚C. Prevailing winds include easterly and northeasterly in spring, summer, and autumn, and westerly in winter. Winter and spring see stronger winds, reaching a maximum speed of 9.6 to 15.7 m/s, with a peak of 26.7 m/s on April 15, 2007 [8].

2) Hydrology

Xingyun Coal Mining Area, part of the Yinghe River System in the Huaihe River Basin, is connected to the Ying River, originating in Yingyang, Dengfeng. The Ying River joins the Huaihe River, passing through various locations. According to Jiacheng Hydrological Station, Yinghe River's volume ranges from 0.015 to 5130 m^3/s, with a historical highest flood level of +238 to +242 m (1902). Main water bodies include Shicong River and Liubei Reservoir. Shicong River, originating from Songshan Mountain, flows westward to join Yinghe River. Liubei Reservoir, in the central-eastern part of the mining area, is now abandoned following approval for scrapping on March 29, 2021 (Dengshuizi [2021] No. 53) [6]. Due to heavy rainfall on "7.20", the reservoir dam collapsed during flood discharge, but the river now flows smoothly.

3) Topography

Xingyun coal mining area is a low mountain and hilly area. The highest elevation in the mine field is +318 m, the lowest is +265 m, and the relative elevation difference is 53 m. The terrain is high on the east and west sides and low in the middle, with a large ground slope and developed gullies, which are conducive to the flow and discharge of atmospheric precipitation.

4) Earthquake

According to the Henan Provincial Earthquake Administration, no major destructive earthquake occurred in Dengfeng and its surrounding areas. Historically, earthquakes of magnitude VII to VIII occurred in Changge, Xuchang, Yanling, Qixian, Zhengzhou, Gongyi, and Lankao in the southeast (the time is unknown), which had a certain impact on the mining area. During the Ming and Qing dynasties, two earthquakes occurred in Dengfeng, the intensity of which was unclear. From 1974 to 1975, there were two earthquakes of magnitude 2 or higher, with an intensity of 5 to 6 degrees and a maximum magnitude of 2.8. An earthquake that occurred in January 1992 had the strongest intensity, with a magnitude of 4.7 between Dengfeng City and Yuzhou City. According to records, "strongly felt, a few houses had tiles falling off", but no major economic losses were caused. See Table 1 for details. According to the "Seismic Parameter Zoning Map in China" (GB18306-2001) issued by the National Quality and Technical Supervision, the peak acceleration g of ground motions in Dengfeng City and its surrounding areas is 0.05, and the corresponding basic seismic fortification intensity value is degree VI [4].

3.2. General Situation of Mine Geology

3.2.1. Strata

Xingyun coal mining area is a low mountain and hilly area, and the Quaternary system is widely distributed. Only scattered bedrocks are exposed in the Shiconghegou. According to the surface and drilling data, the strata of the Xingyun mine field from bottom to top include the Upper Cambrian Changshan Formation, the Middle Ordovician Majiagou Formation, the Upper Carboniferous Benxi Formation and Taiyuan Formation, and the Lower Permian System Shanxi Formation, Upper Permian Upper Shihezi Formation and Quaternary System. The Shanxi Formation above the Second 1 coal seam of the Lower Permian, all the lower parts of the Lower Shihezi Formation and the Upper Shihezi Formation were lost by sliding structures. The layers are described below from bottom to top:

1) Cambrian (∈)

Changshan Formation (∈ 3ch)

The lower part of the lithology is blue-gray, and the upper part is gray-white dolomitic limestone. There are 5 holes exposed in the area, and the thickness of the drilling holes is 11.25 (Xing 14) - 128.69 m (for 3). Integrate contact with the underlying formation.

2) Ordovician (O)

Central Majiagou Formation (O 2m)

Table 1. Survey table of basic earthquake situation.

Time of occurrence		Location occur	Earthquake situation	Source
Gregorian calendar	Lunar calendar			
1484	Ming·Xianhua twenty years in March	Dengfeng	Great drought and earthquake, pray for Zhongyue	Dengfeng County Chronicle
May 13, 1695	In April of the thirty-fourth year of the Qing Emperor Kangxi	Dengfeng	On the sixth day of April, the earthquake	Dengfeng County Chronicle
May 6, 1974		Dengfeng	Magnitude 2.2, depth 30 km	Henan Seismological Bureau
November 2, 1975		Dengfeng	magnitude 2.8	Henan Seismological Bureau
January 8, 1992		Dengfeng	magnitude 4.7	Zhengzhou Seismological Bureau

It is gray, blue-gray, light gray thick layered dolomitic limestone, intercalated with calcareous mudstone bands and light gray marl. The top is uneven and weathered fractures are developed, and the lower part is karst. There are 11 holes exposed, the thickness of drilling exposure is 3.35 (12,210 holes) - 23.83 m (Xing 15 holes), the thickness of 4 holes through the whole layer is 14.96 - 23.83 m, and the average thickness is 20.15 m.

3) Carboniferous (C)

a) Upper Benxi Formation (C 2b)

It is mainly composed of light gray and gray oolitic bauxite, bauxite mudstone, mudstone and lenticular limestone, with local pyrite nodules and grains. There are 12 holes exposed in the well field, 11 holes through the whole layer, the thickness is 2.62 (13,005 holes) - 11.74 m (Xing 11), and the average is 6.92 m. Parallel unconformity contact with the underlying Ordovician strata.

b) Shangtong Taiyuan Group (C 2t)

From the top of the Benxi Formation to the top of L9 limestone or siderite mudstone. The lithology is mainly composed of gray to dark gray limestone, dark gray mudstone, sandy mudstone, gray fine, siltstone and thin coal seams. This group, also known as the first coal section, is one of the main coal-bearing strata in this area, with a thickness of 59.11 - 81.48 m and an average thickness of 61.48 m. According to different lithologic combinations, it can be subdivided into lower limestone section, middle sand mudstone section and upper limestone section. Integrate contact with the underlying Benxi Formation.

4) Permian (P)

a) Lower Shanxi Formation (P 1s)

This group has a small exposure on the southern edge of the area. From the top of L9 limestone or siderite mudstone to the bottom boundary of casserole kiln sandstone. The lithology is mainly composed of medium to fine-grained sandstone, sandy mudstone, mudstone and coal seam. This group, also known as the second coal section, is the main coal-bearing strata in the area, and the second 1 coal seam is the main mineable coal seam in the area. Since the sliding structure in the later period (early stage of Himalayas) slipped from the outcrop of the Er1 coal seam from the northeast to the southwest along the coal seam, the 17 holes in this area except for the supply 3 (the Er1 coal outcrop) and the supply 5 (south of the F2 fault) 2 Except for the hole, the other 15 holes are affected by the sliding structure. The residual thickness (17 holes) exposed in the Shanxi Formation ranges from 3.25 to 34.67 m, with an average thickness of 16.78 m. The Shanxi Formation, the Lower Shihezi Formation and the lower part of the Upper Shihezi Formation above the 21st coal seam were lost. This group is in contact with the underlying Taiyuan group.

b) Upper system upper stone box group (P 2s)

There are outcrops near the Shicong River in this area, and the drilling revealed that it is all the residual strata on the Lu F1 sliding structural belt, with a thickness of 34.45 - 168.05 m and an average of 115.14 m. It is in fault contact with the underlying Shanxi Formation.

5) Fourth Department (Q)

The lower part is sand and gravel layer, the middle and upper part is brownish-yellow clay, containing ginger stones, and the surface layer is loess. Covering each layer, it is in unintegrated contact with the underlying layers. The thickness is 1.0 - 25.65 m, and the average thickness is 11.01 m. 6 holes have no gravel, 12 holes have sand and gravel, the thickness is 1.05 - 22.65 m, and the average is 6.31 m.

3.2.2. Coal-Bearing Strata

The coal-bearing strata in the mining area are mainly the Upper Carboniferous Taiyuan Formation (C 2t) and the Lower Permian Shanxi Formation (P 1s). Taiyuan Formation is habitually called Coal Formation 1, Shanxi Formation is habitually called Coal Formation 2, and is described as follows from old to new:

1) Taiyuan Group (C 2t)

Bounded with the Benxi Formation by a coal seam floor and is in integrated contact. This group, also known as a coal group, is one of the main coal-bearing strata in this area. It is composed of gray to dark gray limestone, dark gray mudstone, sandy mudstone, gray fine, siltstone and thin coal seams, with an average thickness of 61.48 m. According to different lithologic combinations, it can be subdivided into lower limestone section, middle sand mudstone section and upper limestone section.

a) Lower limestone section

From the bottom of a 1 coal seam to the top interface of L4 limestone, the thickness is 12.84 - 29.28 m, with an average of 17.63 m. The lithology is mainly composed of gray to dark gray L1 - L4 limestone, dark gray mudstone, sandy mudstone, sandstone and 1-1-4 coal seams. The limestones all contain flint, of which the L1 limestone is thicker. L1 limestone is 9.90 - 13.87 m thick with an average thickness of 11.55 m, L2 limestone is 1.65 - 4.35 m thick with an average thickness of 2.58 m, L3 limestone is 1.27 - 3.50 m thick with an average thickness of 2.24 m, and L4 limestone is 1.67 - 4.70 m thick m, with an average of 3.14 m. Among the four layers of coal, one 1 coal has a thickness of 0 to 1.98 m, with an average thickness of 0.84 m, which belongs to most of the mineable coal seams; one 2 coal has a thickness of 0 to 0.64 m, an average of 0.27 m; 9 holes contain 1-2 layers of gangue, the thickness of gangue is 0.08 - 0.52 m, and the average thickness is 0.35 m, which belongs to the local mineable coal seam with complex structure. One 4 coal thickness 0 - 0.51 m, average 0.23 m. The DLW, HG and HGG curves of limestone, mudstone and coal seam in this section are in the form of high and low phase combination, which is a good physical property marker layer group in the area.

b) Middle sandy mudstone section

From the top of L4 limestone to the bottom boundary of L7 limestone, the thickness is 23.27 - 36.12 m, with an average of 29.93 m. The lithology is mainly composed of gray medium-fine-grained quartz sandstone (Hushi sandstone), L6 limestone, gray-black sandy mudstone, mudstone and coal seams of L5, L6 and L7. L6 limestone gray, cryptocrystalline, containing pyrite nodules, 0.27 - 3.71 thick, with an average thickness of 2.64 m. 1.5 Coal thickness is 0 - 2.44 m, with an average of 0.57 m. 16 Coal thickness is 0 - 2.33 m, with an average of 0.47 m. 17 Coal thickness is 0 to 2.88 m, with an average of 0.23 m. Although the coal thickness of these three layers of coal is larger at individual points, their gangue content is relatively thick, which is larger than the thickness of the upper and lower coal layers, and they are all non-minable coal seams.

c) Upper limestone section

From the L7 limestone floor to the L9 limestone or siderite mudstone top, the thickness is 8.78 - 21.58 m, with an average of 13.92 m. The lithology is mainly composed of dark gray, gray limestone and gray-black mudstone, sandy mudstone, fine sandstone and a 8 coal. The L7 and L8 limestones contain a small amount of pyrite nodules and a large number of Nephidae fossils, which are generally developed and have obvious characteristics, and are the main marker layers in the area. L7 limestone is 4.26 - 8.99 m thick, with an average of 6.34 m. L8 limestone is 0.20 - 7.01 m thick, with an average of 3.18 m. 1.8 Coal thickness is 0 - 0.29 m, with an average of 0.05 m, which is a non-minable coal seam. The thickness of L9 limestone is small, generally about 0.2 m, and it is unstable, and sometimes it is transformed into siderite mudstone.

2) Shanxi Formation (P 1s)

From the top of L9 limestone or siderite mudstone to the bottom boundary of casserole kiln sandstone, it is in conformity with the Taiyuan Formation. The lithology is mainly composed of medium to fine-grained sandstone, sandy mudstone, mudstone and coal seam. This group is also known as the second coal group. There are three coal layers (two 1, two 12, and two 2) in the area. Among them, the second 1 coal seam is the main mineable coal seam in the area, and the second 12 and the second coal seam are only found in the remaining individual holes., are all non-minable coal seams. Due to the sliding structure in the later period (early stage of Himalayas) from the Er1 coal seam outcrop along the coal seam from the northeast to the southwest, the 17 holes in this area except for the supply 3 (the Er1 coal outcrop) and the supply 5 (south of the F2 fault) 2 Except for the hole, the other 15 holes are affected by the sliding structure. Except for 6 holes (Xing 2, Xing 3, Fu 12210, 13005, Xing 13 and 13001) where 8.45 - 20.67 m of Er1 coal seam roof remained, the other 9-hole caprocks all slide along the Er 1 coal seam, and the thickness of the broken zone is 1.8 - 21.10 m, average 8.30 m. The remaining thickness (17 holes) exposed in the Shanxi Formation is 3.25 - 34.67 m, with an average thickness of 16.78 m. The Shanxi Formation, the Lower Shihezi Formation and the lower part of the Upper Shihezi Formation above the 21st coal seam were lost.

3.2.3. Construction

The Dengfeng coalfield is located in the Songji fault-uplift community of the Songji tectonic area of the ancient plate of North China. The main structural lines in the coalfield are: near east-west normal faults, mainly Yuewan fault, Songbiao-Guogou fault, Wangtun-Guishan fault, etc. The NW-trending translational faults mainly include the Wuzhiling fault and the Songshan fault. The gently dipping faults (slip structures) mainly include Ludian slip structures, Baiping slip structures, etc. The slip structures are widely developed coal-controlling structures in coal fields and have an important impact on the occurrence of coal seams.

Dengfeng Xingyun Coal Industry Co., Ltd. is located in the east section of the south wing of the Yingyang-Ludian syncline, between the NW-trending Songshan and Wuzhiling translational faults, most of which are affected by the Ludian sliding structure [4].

1) Folds

Xiliubei syncline: It is the syncline below the sliding structural plane of the Xingyun coal mine. The syncline axis is located on the Dongjialing-Xiliubei village line, with the axis N79˚E. The west end of the syncline axis is cut by the F3-2 fault, and the east is cut by the F2 fault. The axis is 1470 m long. The east end is raised. The strata in the north wing strike nearly east-west, dip southward, with an inclination angle of 7˚ to 23˚, generally 13˚; the strata in the south wing strike N75˚E, incline to N15˚W, with an inclination angle of 8˚ to 25˚, and are skew folds with a south-dipping axial plane. The southern wing is cut by the F1 and F2 faults. The occurrence and syncline axis of the northern flank of the fold have been closely controlled, and the occurrence of the southern flank has been basically controlled.

The Xiliubei syncline, the Gaocheng fault (F1), and the Shiconghe normal fault (F2) are all zonal compressional structures, and folds are formed first. The zonal structure trended east-west (slightly southeast) in the early stage, and was later transformed by the Songhuai arc structure.

2) Fault

There are two faults in the mine field with a drop greater than 60 m: F1, F2; and two faults less than 25 m: F5, F3-2. Divided by nature: 2 reverse faults (F3-2, F5), others are normal faults. Among them, there are 3 compression faults (F1, F2, F5). There are 3 NE-trending faults (F1, F2, F5), which are strike faults.

a) Complete the normal fault (F1)

The Shicong River and the south bank of Shipenggou are located in the south of the mine field. The extension length is more than 2 km, the strike is N73˚E, the inclination is N17˚W, and the dip angle is 70˚. The fault has been basically controlled. Based on:

i) The bottom of the Shicong River in the south of Lines 2 and 3 and the bottom of the Shipenggou in the south of Lines 4 and 6 are exposed in a large area to the south of the line at the bottom of the Shipenggou, and form a steep ridge. The bottom of the ditch and its north are scattered The limestone and mudstone in the upper Taiyuan Formation are exposed, and the middle and lower Taiyuan Formation, Benxi Formation and Ordovician strata are missing, and the fault throw is estimated to be greater than 180 m.

ii) The elevation of the coal bottom for hole 5-1 is +199.64 m, and the elevation of 144 m to the south along Line 4 is +290 m to see Cambrian limestone, and the fault distance is estimated to be greater than 180 m.

iii) The bottom elevation of Xing 14-11 coal bottom is +128.25 m, and the elevation of 240 m + 295 m to the south along Line 3 shows Cambrian limestone, and the fault distance is estimated to be greater than 180 m.

iv) The bottom of the Shicong River in the southern part of the 1st line has an elevation of +200 m, and it is in contact with the Cambrian limestone in the southern part, and the fault distance is >180 m.

b) Shiconghe normal fault (F2)

It is located in the middle of Xiliubei Village, with an extension length of more than 2 km, trending to N66˚E, inclination to N24˚W, and an inclination of 68˚. The central and eastern parts of the fault area have been controlled, and the western part has swings. Based on:

i) The depth of hole 13001 below 133.13 m is all composed of broken Taiyuan Formation limestone and bauxite mudstone interposed by fault breccia. Above it is the top of the 21 coal seam, and below it is Upper Cambrian limestone, lacking Taiyuan Formation, Benxi Formation and Part of the Ordovician stratum is about 90 m.

ii) The 77.85 - 90.44 m of the Xing 14 hole is the fault fracture zone. Above it is the upper Shihezi formation and below it is the Er1 coal seam. Combined with the comprehensive analysis of the 3rd and 4th line sections, the drop of the fault is about 100 m.

3.2.4. Characteristics of Mineable Coal Seams

The coal-bearing strata in the mine field include the Carboniferous Taiyuan Formation and the Permian Shanxi Formation. The coal formations are the first coal formation and the second coal formation. The average thickness of the coal-bearing strata is 78.26 m, containing 11 layers of coal. The average total thickness of the coal seams is 9.76 m, and the coal-containing coefficient is 12.47%. The average thickness of the Carboniferous Taiyuan Formation is 61.48 m. There are 8 coal layers in the first coal group from bottom to top: −1, −2...−8 coal. The average coal seam thickness is 3.91 m, and the coal content coefficient is 6.36%. Among them, most of the 1-1 coal can be mined, and some of the 1-3 coal can be mined. Other coal seams are thin coal seams that cannot be mined.

The average exposed residual thickness of the Shanxi Formation is 16.78 m, the average total coal seam thickness is 5.85 m, and the coal content coefficient is 34.86%. Among them, coal seam No. 21 is generally mineable in the entire area, coal seam No. 2 is not mineable, and coal seam No. 12 is partially mineable. Due to the sliding structure, some sections of the coal seam No. 21 are cut off and thinned, and some sections are thickened. The coal thickness of the No. 21 coal seam changed greatly after being damaged by the structure.

1) Second 1 coal seam

The second 1 coal seam occurs at the bottom of the Shanxi Formation and is the main mineable coal seam in this area. Except for 12215 holes and Xing 12 holes, 2 holes are broken, and 5 holes (Xing 1, Xing 4, 13001, Xing 11, Xing 14) are broken and unrecoverable, and the other 10 holes see coal points that can be recovered. The coal thickness is 0.32 - 16.56 m, with an average of 4.46 m (15 points). 2 holes contain gangue, 12402 holes contain 2 layers of gangue, and 13005 holes contain 1 layer of gangue. The gangue is mainly mudstone or carbonaceous mudstone, with a thickness of 0.48 - 0.66 m and an average thickness of 0.58 m. The structure is simple. There are 2 holes and 2 1 coal to produce bifurcation, for 5 holes 2 12 coal thickness 1.37 m, 0.19 m gangue, 13005 hole 2 12 coal thickness 3.76 m (1.67 m gangue). 13001 hole two 2 coal thickness 2.62, gangue 2.10 m [9].

The 21 coal seam has 6 holes (Xing 2, Xing 3, Fu 12210, 13001, 13005, Xing 13) with a mudstone, sandy mudstone and sandstone roof of 8.45 - 20.67 m, with an average of 14.20 m, of which Fu 12210 has a 0.36 m Carbonaceous mudstone pseudo-top. The indirect roof is fine sandstone, and the other holes are sliding structural fracture zones. The floor is mudstone or sandy mudstone, and partly carbonaceous mudstone pseudo-bottom. The distance between the second 1 coal and the L8 limestone is 6.60 - 21.01 m, with an average of 9.89 m.

2) One 3 coal seam

The 13 coal seam occurs between L3 and L2 micrite bioclastic limestones in the lower part of the Taiyuan Formation. The horizon is stable, and the roof and floor features are obvious, making it easy to identify and compare. There are 13 holes in the mine field exposed, 2 holes are duplicated (for 12402 and for 3 holes), 1 hole (13001) is lost without coal, and the other 10 holes see the real thickness of coal points of 0 - 2.42 m, with an average of 1.25 m. 13 Coal has 9 holes containing 1-2 layers of gangue, the thickness of gangue is 0.08 - 0.52 m, the average is 0.35 m, and the structure is relatively complex. The pure coal that is really thick and can be mined has 2 holes, which is a partially minable coal seam. The top plate L3-4 limestone is dark gray flint-bearing limestone, with a thickness of 2.40 - 8.03 m and an average of 3.49 m. The direct floor is L1-2 limestone, 3.57 - 19.13 m thick, with an average thickness of 11.81 m, and the lithology is dark gray flint-bearing limestone. Only pay 12402 holes to see the 0.25 m carbonaceous mudstone pseudo-bottom.

3) One 1 coal seam

The 11 coal seam occurs at the bottom of the Taiyuan Formation with stable horizons and is easy to compare and identify. The roof is L1 + 2 limestone, and the immediate floor is gray bauxite mudstone, with a thickness of 2.62 - 11.74 m and an average of 6.92 m. There are 13 holes in the mine field exposed, 1 hole is faulty (13001), 2 holes are deposited without coal (Xing 4, Su 5), and the other 10 holes have a real thickness of 0.22 - 1.98 m, with an average of 0.84 m. There is 1 hole (pay 12215) with 1 layer of gangue, the thickness is 0.2 m, and the structure is simple [9].

3.3. General Situation of Mine Hydrogeology

3.3.1. Aquifer

The formations in the mine field include Cambrian, Ordovician, Carboniferous, Permian and Quaternary. The types of groundwater can be divided into three types: karst fracture water, clastic fracture water and pore water. There are mainly 6 aquifer groups, which are described from top to bottom as follows:

1) Quaternary Sand and Gravel Aquifer:

Widely distributed in surface and valley areas, primarily in lower sand and gravel layers. Quaternary thickness ranges from 1 to 25.65 m (average 10.85 m). Varied thickness in 12 holes (1.05 - 22.65 m average 6.31 m). Water richness is uneven, relying on precipitation recharge with seasonal water level fluctuations. Generally, it has minimal impact on No.1 coal seam mining due to Shihezi Formation's effective water barrier, except near sand and gravel skylights.

2) Bedrock Weathering Zone Fissure Aquifer:

Lithology varies, influenced by topography (10 - 50 m depth). Diving-type aquifer directly recharged by precipitation, with strong water richness. Shallow areas lack developed weathered cracks, and fissures do not increase with depth.

3) Er1 Coal Seam Roof Sandstone and Fractured Zone:

Fractured zone with direct coal pressure on the 21 coal seam, 1.8 - 21.10 m thick (average 9.40 m). Mainly upper rock box group sandstone and mudstone. Functions as a water-filled aquifer on the coal roof, recharged by various sources, including outcrop weathering fissure zone and sand and gravel skylights.

4) Upper Carboniferous Taiyuan Formation Limestone Karst Fissure Confined Water Aquifer: Composed of L7 and L8 limestones with well-developed karst features. Average thickness of L7-8 pure limestone is 9.52 m. Recharge from outcrop precipitation, gravel skylights, and supply from Cambrian Ordovician limestone on the F2 fault's southern plate. Direct water-filled aquifer on the second 1coal floor with potential gushing during mining.

5) Lower Carboniferous Taiyuan Formation Limestone Karst Fissure Confined Water Aquifer: L1-4 limestones with dense, hard, and flint-containing characteristics. Karst caves and fissures hold confined water with strong conductivity. Sand-mudstone section in the middle of Taiyuan Formation blocks hydraulic connection between upper and lower limestone aquifers. Direct water-filled aquifer for No.1 and No.3 coal seams, indirectly filling No.1 coal seam.

6) Cambrian Ordovician Limestone Karst Fissure Confined Water Aquifer: Middle Ordovician Majiagou Formation and Upper Cambrian System contain confined water in karst fissures, primarily recharged by precipitation. Acts as an indirect water-filled aquifer for the Er1 coal seam but poses a threat to coal seam mining in the southeast corner due to its connection. Benxi Formation's bauxite mudstone serves as a water-repellent layer during mining.

3.3.2. Water Barrier

The main water-repellent layers in the minefield are from new to old: the interlayer water layer between the Permian sandstone aquifers, the fine clastic rock aquifer on the floor of the second 1 coal seam, the sand-mudstone aquifer in the middle of the Carboniferous Taiyuan Formation, and the Carboniferous Benxi Formation bauxite mudstone aquifer.

1) Interlayer water layer between Permian sandstone aquifers: Between the Permian sandstone aquifers, there are mudstone, sandy mudstone and other argillaceous rock layers with different thicknesses. The lithology is relatively tight and impermeable, which blocks the hydraulic connection between the aquifers and acts as a layer interval, water action.

2) Fine Clastic Rock Water-Retaining Layer of the Second 1 Coal Seam Floor: Located from the bottom of the 21 coal seam to the top boundary of the Taiyuan Formation limestone. Primarily sandy mudstone and fine-grained sandstone with a thickness of 6.60 - 21.01 m (average 9.89 m). Vulnerable during mining due to its thin effective water barrier, especially in damaged or structurally compromised sections.

3) Sand-Mudstone Aquifer in the Middle of the Carboniferous Taiyuan Formation: Clastic rock section between the top boundary of L4 limestone and the bottom boundary of L7 limestone. Mainly composed of sandy mudstone, fine-grained sandstone, and medium-grained sandstone. Stable position with poor water permeability. Normally effective in water isolation, blocking hydraulic connection between upper and lower limestone aquifers in the Taiyuan Formation.

4) Carboniferous Benxi Formation Bauxite Mudstone Aquifer: Overlies Cambrian and Ordovician limestone aquifers. Composed of Benxi Formation bauxite mudstone with continuous deposition and a stable horizon. Thickness ranges from 2.62 - 11.74 m (average 6.92 m). Dense rock with underdeveloped cracks, providing effective water resistance. Normally blocks the impact of confined water from lower Cambrian Ordovician limestone karst fissures on water filling in the Second Coal Formation deposit or loses water barrier effect under certain conditions [2] [3].

4. Calculation of Height of Water-Conducting Fracture Zone

After the coal seam is mined, it will inevitably cause the rock mass to move to the goaf, and during the movement of the rock layer, mining cracks will be formed in the overlying rock. Mining fissures become water-conducting and gas-conducting channels, causing water and gas flow in the surrounding coal and overlying rocks, resulting in underground gas accidents and water inrush accidents. Especially in coal mining under water bodies or aquifers, the water-conducting fracture zone should be controlled so as not to penetrate the aquifer to prevent water inrush and well flooding accidents. Overburden lithology and combined structure, mining method and roof management method, mining height and working face size, coal seam dip angle, time and other factors will affect the development height of the water-conducting fracture zone [3].

1) Overling litholology and composition structure

The "two zones" of overburden failure (also known as water-conducting fracture zones) are closely related to the lithology, structure and physical and mechanical properties of the overburden. According to the one-way compressive strength, the overlying rock can be divided into four types: hard type, medium-hard type, soft type and extremely soft type.

Hard type: Both the direct top and the old top of the overlying rock are hard rock formations with good stability. Due to the fragmentation of the rock mass, the caving rock blocks almost fill the mining space and the space of the caving rock layer itself. The subsidence of the overlying rock is small, and the caving process is most fully developed. After the overlying rock layer is cracked, it is not easy to close and recover, its original water resistance.

Medium-hard type: the direct top of the overlying rock is a hard rock layer, the old top is a soft rock layer, and the mechanical structure is hard at the bottom and soft at the top. The mining space and the space of the caving rock layer itself are almost completely filled by the caving broken rock blocks, and the caving process is also fully developed. During the initial mining, the height of the caving zone has the development law of hard cladding, and the height of the water-conducting fracture zone has the development law of medium-hard cladding. During repeated mining, due to the weakening of the overlying strata, the height of the caving zone gradually transitions from the development law of hard cladding to the development law of medium-hard cladding, and the height of the water-conducting fracture zone changes from the development law of medium-hard cladding to that of medium-hard cladding. Gradually transition to the development law with weak overlying rocks. Such overlying rock conditions are very beneficial to safe coal mining under water.

Soft type: The mechanical structure of the overlying rock is soft on the bottom and hard on the top. After the direct top caving occurs, the overlying stratum sinks, reducing the mining space and the space of the caving stratum itself. Therefore, the caving process cannot be fully developed, and the height of the water-conducting fracture zone is small.

Very weak type: The mechanical structure of the overlying rock is characterized by two soft combinations, the stability of the overlying rock layer is poor, and the roof of the working face falls with the mining. In the process of roof caving, the overlying strata subsides greatly, and the mining space and the space of the caving stratum itself are continuously reduced due to the subsidence of the overlying strata. Therefore, the caving process is not fully developed, and the overlying stratum is easy to close and restore its original water-blocking capacity after cracking, and the height of the water-conducting fracture zone is the smallest.

Rigid and brittle rock strata are more prone to cracks than plastic and ductile rock strata. Rock strata with rigid-plastic and thin-thickness matching have better waterproof and crack resistance. The lithology of the overlying rock is from hard to soft, the water-conducting fracture zone is less and less obvious in the “saddle shape”, and finally the “saddle shape” almost disappears.

Under certain geological and mining conditions, the thickness of the bedrock column of the overlying strata will also have different effects on the height and distribution of the water-conducting fracture zone. In general, the height of the water-conducting fracture zone decreases as the thickness of the bedrock column decreases; when the thickness of the rock column is small, the height of the water-conducting fracture zone is also smaller. The greater the mining height, the greater the reduction in the height of the water-conducting fracture zone with the decrease in the thickness of the rock column. The main reason is that the smaller the thickness of the rock column and the larger the mining height, the higher the proportion of the water-conducting fracture zone entering the bedrock weathering zone. Because the lithology of the bedrock weathering zone is mostly soft, it generally has a significant inhibitory effect on the development height of the water-conducting fracture zone [1] [2] [3]. Therefore, the height of the water-conducting fracture zone decreases more. This is very beneficial for raising the upper limit of coal mining under the water body and further liberating the coal pressing under the water body.

2) Mining method and roof management method

Mining method and roof management method are important factors affecting the development height and distribution pattern of the water-conducting fracture zone in overlying rock failure, and are also factors that can be changed artificially. The main reason is that different coal mining methods correspond to different initial or primary mining thicknesses, layered and repeated mining thicknesses, and mining times.

The thickness of fully mechanized mining is generally 2.5 - 3 m, and the thickness of fully mechanized caving mining is generally 5 - 10 m, sometimes even thicker. The roof management method determines the basic characteristics and maximum height of overburden failure. Common roof management methods include all caving, all filling and pillar support.

When the roof is managed by the full caving method, the overlying rock damage is the most serious, the caving is the most sufficient, and the height of the water-conducting fracture zone is the highest. The height of the water fracture zone is the smallest, which is the most favorable for suppressing the maximum height of overlying rock damage, but it is the most unfavorable from an economic point of view.

In addition to forming different mining spaces, the combination of different mining methods and roof management methods is also manifested in the different movement modes of coal and rock blocks that cause caving in the goaf.

3) Mining height and working face size

Mining height and goaf area are the fundamental factors that cause overburden damage. When mining a single thin coal seam, medium-thick coal seam and the first layer of a thick coal seam, the height of the caving zone, the height of the water-conducting fracture zone and the mining height are approximately linear; The fracture zone height and mining height no longer have a linear relationship, but an approximate fractional function relationship [8].

The mining height of the first mining plays a decisive role in destroying the height of the water-conducting fracture zone in the overlying strata. Although the subsequent mining of the layers will lead to an increase in the height of the water-conducting fracture zone, the increase in the height of the water-conducting fracture zone caused by the first layer is gradually higher than that of the first layer which becomes smaller.

Among them, the "Code" gives the empirical formula for the estimated overburden fracture zone height for top coal mining in thick seam caving under the conditions of hard, medium-hard and soft overlying rock, as shown in **Figure 2**.

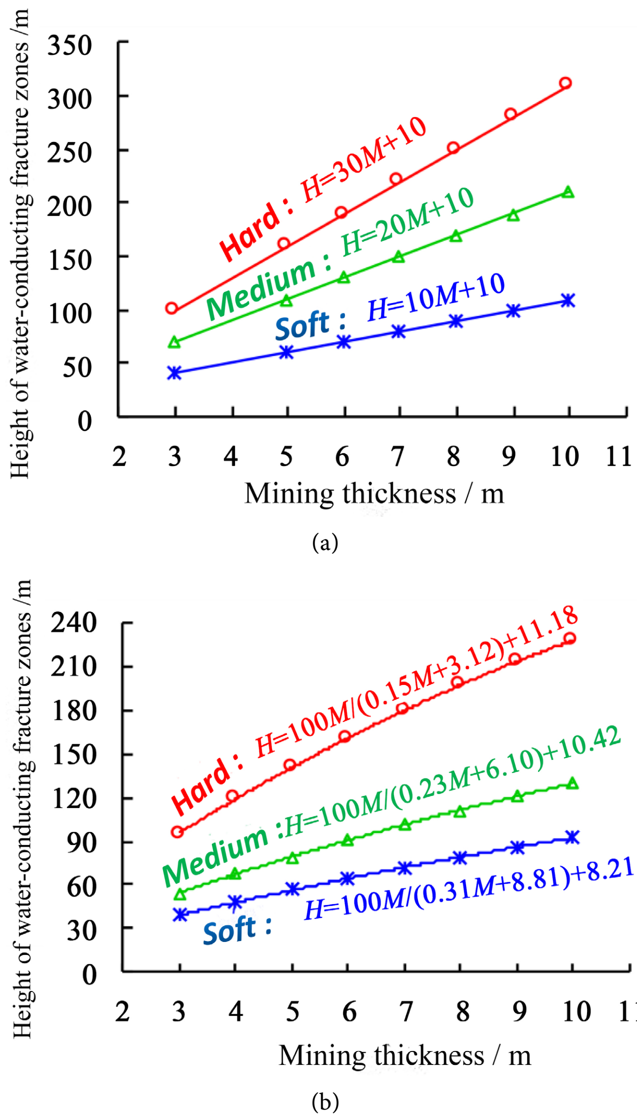


Figure 2. The relationship between the height of the water-conducting fracture zone in the overlying rock and the mining thickness in the "Specifications". (a) Calculation formula 1; (b) Calculation formula 2.

Field production practice and numerical simulation results show that the parameter that determines the final height of the water-conducting fracture zone is the minimum length of the working surface (incline length or strike length), which is generally the inclination length of the working surface. When the inclination length of the working face is constant but does not reach the full mining length, the height of the water-conducting fracture zone increases with the increase in strike length; when the working face reaches full mining or super-full mining, the water-conducting fracture zone height no longer increases with strike length. When the direction and tendency of the working face have reached full mining, the working face parameters have almost no effect on the height and distribution shape of the water-conducting fracture zone.

4) Coal seam dip

There are obvious differences in the height and distribution of water-conducting fracture zones in overlying rock failure. When the mining coal seam is a gently inclined seam, the height of the water-conducting fracture zone increases slowly with the increase of the inclination angle; when the mining coal seam is an inclined coal seam, the water-conducting fracture zone height increases rapidly with the increase of the inclination angle; when the coal seam is mined When the coal seam is steeply inclined, the height of the water-conducting fracture zone first decreases with the increase of the dip angle, and then increases with the increase of the dip angle. The smaller the dip angle of the coal seam, the more likely the distribution pattern of the water-conducting fracture zone of overlying rock failure is "saddle shape". The main reason is that with the increase of the dip angle of the coal seam, the tangential sliding force of the overlying rock layer along the layer increases, while the pressure acting on the layer decreases; It slides along the floor from the uphill direction to the downhill direction, resulting in a larger caving space in the uphill direction than in the downhill direction, and the more severe the damage to the overlying rock.

The influence of the coal seam inclination angle on the failure height of the overlying rock is also reflected in the differences in failure forms. When mining horizontal and gently inclined coal seams (α = 0˚ - 35˚), the caving rock mass does not move again, but is accumulated and compacted on the spot. However, due to the suspended roof phenomenon at the boundary of the working face, the caving zone and water conduction. The crack zone is saddle-shaped with a low middle and high ends. When mining inclined coal seams (α = 36˚ - 54˚), the collapsed rock mass slides toward the lower boundary of the goaf under the action of its own weight, resulting in insufficient collapse of the lower boundary rock mass and excessive collapse of the upper boundary rock mass., so that the caving zone and water-conducting fracture zone are distributed in a parabolic shape in the inclined direction. When mining steeply inclined coal seams (α = 55˚ - 90˚), the damage height of the upper boundary overburden is higher, and the damage height of the lower boundary overburden is lower. The damage range changes from parabolic to elliptical.

5) Time factor

Coal mining causes deformation, movement and destruction of overlying rock. Since coal seam mining is carried out step by step, the occurrence and development of overlying rock caving zones and water-conducting fracture zones must be directly related to the position changes of the mining face, and must gradually develop upward starting from the roof rock layer. Research shows that the deformation and displacement of rock mass starts in front of the working face and ends behind the working face. However, the caving and cracking of rock mass develop and occur within a certain range behind the working face. The time process has a certain influence on the increase and decrease of the overlying rock failure height. The time effect in the viscoelastic-plastic analysis of various overlying rock failure patterns on the boundary also illustrates this point.

The time process of the height development of the water-conducting fracture zone can be divided into two stages. Before the water-conducting fracture zone develops to the maximum height, it grows with the passage of time. For medium-hard overburden, it usually takes 1 to 2 months after mining for the height of the water-conducting fracture zone to reach its maximum value; for hard overburden rock, it takes longer for the height of the water-conducting fracture zone to reach its maximum value; for weak overburden, it takes longer to reach the maximum height. In rock, the time for the height of the water-conducting fracture zone to reach the maximum value is shorter. For fully mechanized caving working surfaces with large roof caving, it usually takes 3 to 6 months, and some may even take longer.

When the water-conducting fracture zone develops to its maximum height, as the advancement distance continues to increase and time goes by, the height of the water-conducting fracture zone will decrease to varying degrees. The degree of reduction is related to the overlying rock lithology, composite structure, and physical and mechanical properties. It is closely related to the location of the working surface. When the overlying rock is a hard rock layer, the maximum height of the water-conducting fracture zone basically does not change as time increases. The reduction in the maximum height of the water-conducting fracture zone affected by time factors is more obvious in the middle of the goaf than near the boundary; repeated mining in layers is more obvious than initial mining or one-time mining of the entire layer.

The height of the water-conducting fracture zone also has a certain relationship with the advancing speed of the working face. As the working face advances faster, the height of the water-conducting fracture zone decreases to a certain extent. Therefore, appropriately increasing and stabilizing the advancement speed of the mining face will become an effective technical way to reduce the development height of the water-conducting fracture zone under certain conditions [3]-[8].

4.1. Overview of Working Face

4.1.1. 12051 Planning the Working Face

12051 is planned to have a strike length of 325 m and an inclination length of 80 m. It is planned to adopt the strike longwall retreat mining method. This working face mines the 21 coal seam, the coal seam is stable, the horizontal bedding of the coal seam is relatively developed, the integrity is good, but the strength is low, the local cracks are developed, and it is easy to collapse, the coal seam structure is relatively simple, and the coal seam thickness of the working face is 0.2 - 11.6 m, the average thickness is 5 m, and the dip angle of the coal seam is 5˚ - 8˚. 12051 Planning working face mining area coal seam floor elevation +125 - +147 m, ground elevation +270 - +300 m, working face buried depth 132 - 166 m.

4.1.2. 12071 Working Face

The strike length of the 12071 working face is 310 m and the inclination length is 75 m, and it adopts layered mining. This working face mines the 21 coal seam. The coal seam in this area is relatively stable, the horizontal bedding of the coal seam is relatively developed, the integrity is good, but the strength is low, and the local fractures are developed, which is easy to collapse, the coal seam structure is relatively simple, and the coal seam Thickness varies greatly [10] [11]. The average thickness of the coal seam in the working face is 6.5 m, the mining thickness is 2.4 - 3 m, and the dip angle of the coal seam is 5˚ - 8˚. 120 7 1 Working face mining area, the coal seam floor elevation is +125 - +153 m, the ground elevation is +270 - +300 m, and the working face buried depth is 118 - 135 m.

4.2. Lithology and Structural Characteristics of the Overlying Rock in the Working Face

4.2.1. Overburden Lithology of Working Face

The lithology of the overlying rock can be evaluated by obtaining the comprehensive evaluation coefficient P of the overlying rock. Among them, the comprehensive evaluation coefficient P of the overlying rock depends on the lithology and thickness of the overlying rock, and can be expressed by the following formula:

$$P = \frac{\sum_i^n m_i Q_i}{\sum_i^n m_i} \tag{4-1}$$

where: m_i—the normal thickness of the layer i of the overlying rock, m;

Q_i—the lithology evaluation coefficient of the layer i of the overlying rock, which can be found in **Table 2**; when there is no measured strength value, the Q_0 value can be found in **Table 2**.

According to the plan of the excavation project, the working face will pass under the river during the mining process. Therefore, the 13005 boreholes closest to the study area are selected to calculate the comprehensive evaluation coefficient P of the overlying rock. The calculation results are shown in **Table 3** below.

Table 2. Layered lithology evaluation coefficient.

Rock sex	Unidirectional tensile strength (MPa)	rock name	first time mining $Q0$	repeated mining	
				$Q1\_$	$Q2\_$
Firm hard	≥90	Very hard sandstone, limestone and clay shale, quartz veins,	0.0	0.0	0.1
	80	very hard iron ore, compact granite, amphibole, diabase	0.0	0.1	0.4
	70	Hard limestone, hard sandstone, hard marble, not hard granite	0.05	0.2	0.5
	60		0.1	0.3	0.6
Middle hard	50	Harder limestone, sandstone and marble	0.2	0.45	0.7
	40	Ordinary sandstone, iron ore	0.4	0.7	0.95
	30	Sandy shale, flaky sandstone	0.6	0.8	1.0
	20	Hard clay schist, not hard sandstone and limestone, soft	0.8	0.9	1.0
	>10	conglomerate	0.9	1.0	1.1
Weak	≤10	All kinds of shale (not hard), compact marl, soft shale, very soft limestone, anthracite, ordinary marl, broken shale, bituminous coal, hard topsoil-granular soil, compact clay, soft sandy clay, loess, humus, loose sand	1.0	1.1	1.1

***Q*0 of the initial mining strata**

Stratigraphic age $Q0$ value lithology	Sinian Cambrian Ordovician	Silurian Devonian	Carboni-ferous	Permian	Triassic	Jurassic	Cretaceous	Tertiary	Quaternary
sandstone	0.00	0.05 - 0.15 (0.10)	0.15 - 0.30 (0.22)	0.30 - 0.50 (0.40)	0.40 - 0.60 (0.50)	0.50 - 0.70 (0.60)	0.70 - 0.85 (0.78)	0.85 - 0.95 (0.90)	0.95 - 1.00 (0.98)
shale Marl	0.00	0.10 - 0.30 (0.20)	0.30 - 0.50 (0.40)	0.50 - 0.70 (0.60)	0.60 - 0.80 (0.70)	0.70 - 0.85 (0.78)	0.85 - 0.95 (0.90)	0.85 - 0.95 (0.90)	
sandy shale	0.00	0.10 - 0.20 (0.15)	0.20 - 0.40 (0.30)	0.40 - 0.60 (0.50)	0.50 - 0.70 (0.60)	0.60 - 0.80 (0.70)	0.80 - 0.90 (0.85)	0.85 - 0.95 (0.90)	

Table 3. Calculation table of comprehensive evaluation coefficient.

Lithology	Thickness (m)	Evaluation coefficient	$m_i{}^*Q_i$
loess	2.00	1	2
gravel	4.00	1	4
sandy mudstone	11.00	0.6	6.6
fine-grained sandstone	13.00	0.3	3.9
sandy mudstone	4.00	0.6	2.4
mudstone	6.75	0.55	3.7125
medium-grained sandstone	15.40	0.4	6.16
sandy mudstone	3.35	0.6	2.01
mudstone	7.30	0.55	4.015
fine-grained sandstone	2.10	0.3	0.63
mudstone	11.60	0.55	6.38
fine-grained sandstone	2.50	0.3	0.75

Continued

sandy mudstone	18.38	0.6	11.028
2 1 3 seams	0.62	1	0.62
mudstone	1.80	0.55	0.99
2 1 2 seams	1.64	1	1.64
carbonaceous mudstone	0.79	0.8	0.632
sandy mudstone	4.27	0.6	2.562
total	110.5		60.03

According to the above algorithm, the calculation result in Table 4 shows that the comprehensive evaluation coefficient of the overlying rock in the 13005 hole is $P = 0.54$. The lithology influence coefficient (D) of the stratum is 1.71, which shows that the comprehensive evaluation of the overlying lithology of the working face and its surrounding area is medium hard.

4.2.2. Structural Characteristics of Working Face Overlying Rock

1) Aquifer above the working face

The types of groundwater can be divided into three types: karst fissure water, clastic fissure water and pore water. There are three aquifer groups above the working face, which are described from top to bottom as follows:

a) Quaternary sand-gravel pore water aquifer

Widely distributed on the surface and in valleys, mainly in the lower sand and gravel layers. The thickness of the Quaternary is 1 - 25.65 m. The average is 10.85 m. There are 6 drill holes without gravel in the lower part, and the sand and gravel layer in 12 drill holes is 1.05 - 22.65 m thick, with an average thickness of 6.31 m, and the thickness varies greatly. There are still gravel skylights on the Shicong River and its two sides in the northwest corner of the well field. The water richness is extremely uneven, and it is mainly supplied by precipitation, and its water level and water volume vary greatly with the seasons. Under normal circumstances, the sand and gravel water has little effect on the mining of the No. 1 coal seam, because the thick sand and mudstone of the Shihezi Formation can be regarded as a good water barrier. But in the sand and gravel skylights and coal seam outcrops and their vicinity, they can infiltrate or infiltrate into the well directly or through fissures.

b) Fissure aquifer in bedrock weathering zone

The lithology of the aquifer varies from place to place, and the thickness of the weathering zone is affected by topographic fluctuations. The depth is generally 10 to 50 m. The aquifer is generally of the diving nature and is directly recharged by atmospheric precipitation, and no weathered cracks are developed in the shallow part. The water richness is strong, and the weathering fissures do not develop as the depth increases.

c) 21 Coal seam roof sandstone and fractured pore confined water aquifer in the fractured zone of sliding structure

Table 4. Corresponding relationship between the comprehensive evaluation coefficient P and coefficient D of lithology.

Hard	P	0.00	0.03	0.07	0.11	0.15	0.19	0.23	0.27	0.30
	D	0.76	0.82	0.88	0.95	1.01	1.08	1.14	1.20	1.26
Medium hard	P	0.30	0.35	0.40	0.45	0.50	0.55	0.60	0.65	0.70
	D	1.26	1.35	1.45	1.54	1.64	1.73	1.82	1.91	2.00
Weak	P	0.70	0.75	0.80	0.85	0.90	0.95	1.00	1.05	1.10
	D	2.00	2.10	2.20	2.30	2.40	2.50	2.60	2.70	2.80

No.2 coal seam, there is a sliding structural fracture zone of direct coal pressing, with a thickness of 1.8 to 21.10 m and an average of 9.40 m. Most of it is sandstone and mudstone of the Upper Shihezi Formation. There are 6 drill holes (Xing 2, Xing 3, Fu 12210, 13001, 13005 and Xing 13) between the broken zone and the Er1 coal seam, and the Dazhan sandstone section of 9.23 - 21.00 m is retained [9] [10]. The Dazhan sandstone is gray fine, medium Grain sandstone, thickness 0.65 - 7.86 m, average 3.50 m. The fracture zone and sandstone have well-developed pores and fissures, but most of the fissures are filled with calcite, containing confined water in the pore and fissures, and it is a direct water-filled aquifer on the roof of the No.1 coal. The main sources of recharge are the weathering fissure zone at the outcrop, the sand and gravel skylight, the kiln fracture and the precipitation recharge at the shallow open pit.

2) Water barrier above the working face

According to the 13005 borehole histogram and the coal mine production geological report, it is found that there is only one layer of aquifer in the overlying rock above the working face [9].

a) Interlayer water layer between Permian sandstone aquifers

Between the Permian sandstone aquifers, there are mudstone, sandy mudstone and other argillaceous rock layers with different thicknesses. The lithology is relatively tight and impermeable, which blocks the hydraulic connection between the aquifers and acts as an interval layer for water action.

4.3. Calculation of Development Height of Water-Conducting Fracture Zone

4.3.1. Basis for Calculation

According to the existing experience, the development form of the water-conducting fracture zone is mainly affected by the dip angle of the coal seam. The coal seam inclination angle of the working face in the study area is 5˚ - 8˚, which belongs to the gently inclined coal seam. The caving rock mass does not move again, but accumulates and compacts on the spot. However, due to the overhang phenomenon on the working face boundary, the caving zone and water conduction. The fracture zone is in the shape of a saddle with a low middle and high ends, as shown in **Figure 3**.

According to the occurrence of the coal seam, the mining method of the working face and the lithological characteristics of the overlying strata, the top coal

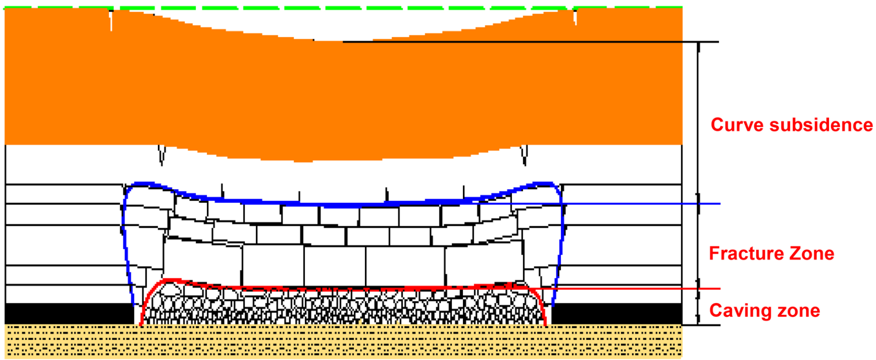


Figure 3. Development form of water-conducting fracture zone.

caving in the gently inclined thick seam should be adopted in the "Guidelines for Coal Pillar Retention and Coal Pressing Mining in Buildings, Water, Railways and Main Roadways" See **Table 5** and **Table 6** for the calculation formulas for the height of the mining cavitation zone and the water—conducting fracture zone.

According to the calculation of the overburden evaluation coefficient *P*, the overlying lithology in the study area is medium-hard. Therefore, the calculation formula of caving zone in top coal caving mining in thick seam under medium-hard lithology conditions is as follows:

$$H_k = 6M + 5 \tag{4-2}$$

The formula for calculating the height of water-conducting fracture zone in top coal caving mining in thick seam under medium-hard lithology conditions:

$$H_{li} = \frac{100M}{0.23M + 6.10} \pm 10.42 \tag{4-3}$$

$$H_{li} = 20M + 10 \tag{4-4}$$

In the formula: *M*—mining thickness.

4.3.2. Calculation Results and Analysis

The calculation results of the height of the caving zone and the water-conducting fracture zone in the Guide are mainly affected by the mining thickness. Since the coal mine adopts the top coal mining technology to mine the working face, the heights of the caving zone and the water-conducting fracture zone are calculated according to the coal thickness of the coal exploration boreholes [10]. The calculation results show that the height of the overburden caving zone caused by the mining of the working face is 17 - 74.6 m, and the development height of the water-conducting fracture zone is 40.9 - 242 m. Finally, through the statistics of the proven coal thickness of the coal exploration boreholes within the scope of the 12071 working face, formulas 4-2, 4-3 and 4-3 are used to calculate the height of the caving zone and the pouring fracture zone above the working face, and use The surfer software performs visualization processing to generate contour maps of the overburden failure height above the working face (**Figure 4** and **Figure 5**).

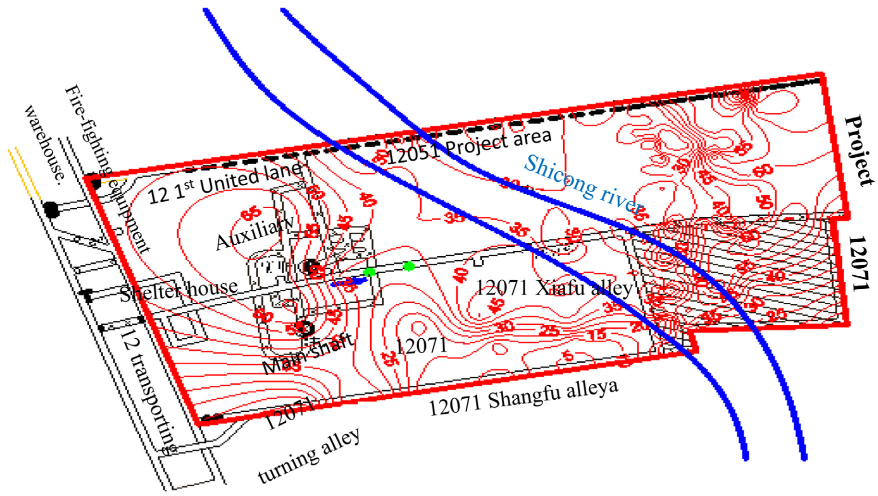
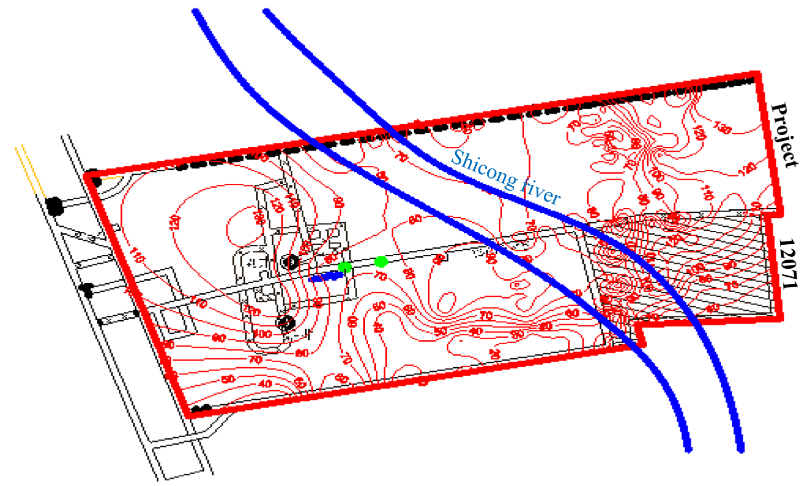
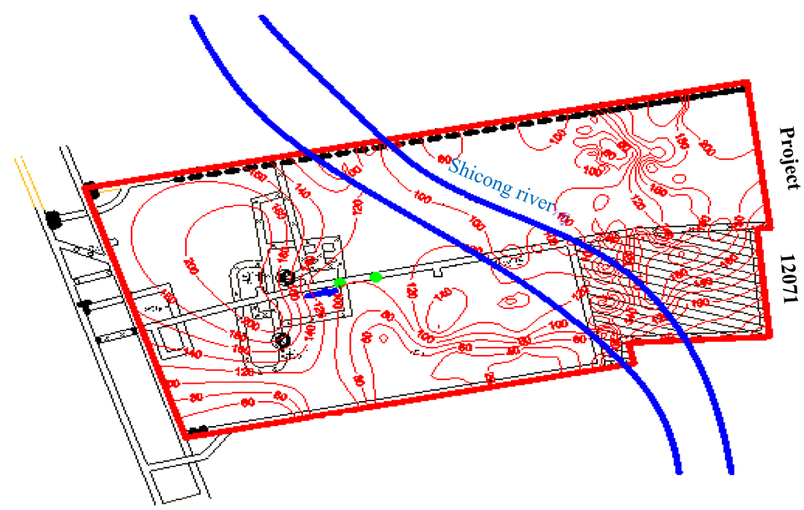


Figure 4. Contour map of cavitation zone height.



(a)



(b)

Figure 5. Contour map of water-conducting fracture zone height. (a) Calculation result of formula 4-3; (b) Calculation result of formula 4-4.

Table 5. Calculation formula of caving zone height for top coal caving mining in thick seam.

lithology	hard	medium hard	weak
Calculation formula/m	$H_k = 7M + 5$	$H_k = 6M + 5$	$H_k = 5M + 5$

Note: 1) M is the mining thickness. 2) Scope of application of the formula: mining thickness 3.0 - 10 m.

Table 6. Calculation formula for height of water-conducting fracture zone for top coal caving mining in thick seam.

Lithology	One of the formulas	One of the formulas
Hard	$H_{li} = \frac{100\sum M}{0.15\sum M + 3.12} \pm 11.18$	$H_{li} = 30M + 10$
Medium hard	$H_{li} = \frac{100\sum M}{0.23\sum M + 6.10} \pm 10.42$	$H_{li} = 20M + 10$
Weak	$H_{li} = \frac{100\sum M}{0.31\sum M + 8.81} \pm 8.21$	$H_{li} = 10M + 10$

Note: M is the mining thickness.

Figure 4 is a straight line diagram of the height of the caving zone above the working face obtained by calculating according to the calculation formula of the caving zone in the top coal mining of thick seam caving under medium-hard lithology conditions in the "Guide". In most areas above the surface, the development height of the caving zone is between 25 m and 65 m.

Figure 5(a) is the contour map of the height of the water-conducting fracture zone in the mining face obtained according to formula 4-3. It can be seen from the figure that the height of the water-conducting fracture zone caused by the mining of the working face is in the range of 50 - 130 m. The height of the water-conducting fracture zone in the local area has exceeded the minimum burial depth of 120 m in the coal seam of the 12071 working face, which proves that the overlying rock is affected by mining, and the local area of the water-conducting fracture zone will directly develop to the surface.

Figure 5(b) is the contour map of the height of the water-conducting fracture zone in the mining face obtained according to the formula 4-4. It can be seen from the figure that the height of the water-conducting fracture zone caused by the mining of the working face is 80 in most areas. Within the range of −200 m, the local area has exceeded the burial depth of the 12071 working face, so the water-conducting fracture zone will develop to the surface at the shallower burial depth [12].

The Shicong River is one of the underground water sources for Xingyun Coal Industry. Whether the mining cracks below the river can lead to the influx of river water into the well is the main factor that will determine the safe production of the working face. Therefore, an accurate analysis is made on the development height of water-conducting fractures under the river. According to the field measurement, the elevation of the riverbed in the study area is 270.1 - 274.0 m, the elevation of the working face under the river is 138.7 - 151.8 m, and the buried depth of the working face in the river area is 118 - 132 m. In **Figure 5(b)**, it can be seen that the development height of the water-conducting fracture zone caused by the mining of the working face in the channel area is 100 - 140 m, and the local area is 118 - 132 m greater than the working depth. To sum up, the water-conducting fracture zone caused by the mining of the working face will develop directly to the bottom of the river bed, forming the water-filled channel of the working face.

5. Field Measurement of the Height of the Water-Conducting Fracture Zone

Xingyun Coal has the conditions for on-site observation of the water-conducting fracture zone, in order to provide certain technical guidance for mine safety production as soon as possible, to meet the requirements of the standardization of coal mine quality construction, and based on the actual situation of mine production, after research and decision by both parties: above the working face The development height of the water-conducting fracture zone in the overlying rock is detected, so as to realize the improvement of the basic data for the research on the development law of the water-conducting fracture zone in the mine.

5.1. On-Site Observation Methods and Instruments

Observation Method of Water-Conducting Fracture Zone Height

The measurement of the development height of the water-conducting fracture zone on a site involves various observation methods, including underground drilling, surface drilling, geophysics, direct working face observation, and inner roadway observation of overburden damage zones. Ground borehole observation measures flushing fluid leakage, water level changes, and abnormal phenomena to analyze and determine rock failure height. TV probes in drilling TV method directly observe rock mass cracking and water leakage. Electromagnetic or magnetotelluric methods judge "two zones" based on rock mass resistivity changes, detecting water-conducting fracture zone and caving zone height. Downhole drilling near goaf measures water injection loss, determining caving zone and fracture zone height. Working faces being mined are selected for observation using ground drilling fluid loss and drilling video methods. Ground drilling fluid loss measures flushing fluid leakage to determine water-conducting fracture zone height reliably. Borehole TV method observes crack distribution in rock layers, determining the development height of the overlying fissure zone in the working face.

1) Observation instrument for ground borehole leakage

Mainly including DPP100-4 drilling rig for on-site construction. The instruments for observing the leakage of flushing fluid mainly include: stopwatch, measuring ruler and drill pipe. The water level measuring instruments in the hole mainly include: measuring clock, measuring rope, stopwatch and tape measure. The field measurement is shown in Figure 6.

2) Drilling TV detector

It mainly includes intelligent drilling image (GD3Q-GM and CXK12(B)) host, drilling probe, depth detector, extension rod (signal line), and a set of wire racks. During the detection, the camera is pushed into the borehole through the connecting rod, and the distribution of fissures in different rock layers in the borehole is observed through the imager, and photos and videos are taken at the same time. Figure 7 shows two sets of borehole television observation systems.

5.2. Observation Plan and Implementation Steps

5.2.1. Number, Structure and Location of Drilling Holes

To determine the position and orientation of the drilling hole (drilling hole), it is

Figure 6. Ground drilling instruments and water level measuring instruments.

① Extension signal wire
② Extension connecting rod
③ Camera
④ Borehole imager
⑤ Depth detector

Figure 7. GD3Q-GM and CXK12(B) borehole TV observation system.

necessary to first consider the development of fissures in the overlying rock after mining, as well as the integrity and stability of the surrounding rock at the construction position of the drilling hole (drilling hole), so as to ensure the observation The integrity of the drilled hole and the hole sealing after observation should also be considered, and the convenience of pedestrians and construction space should also be considered.

1) Number of drilling holes

After the working face is mined for a period of time, to measure the maximum damage height of overlying strata in coal seam mining, the number of drilling holes is determined based on the progression of overburden fissures. After mining, the overlying fissures gradually close, so boreholes are strategically placed as close as possible to the working face and goaf. In this case, two observation holes are set above the 12th mining area, considering factors like the mining situation and proximity to the goaf. The specific distances from the boreholes to the Shicong River bed and surface are provided: 23 m and 43.5 m for the 1# borehole, and 45 m and 65.8 m for the 2# borehole, respectively.

2) Drilling structure

According to the geological mining conditions of the working face and the calculation results of the development height of the water-conducting fracture zone, the actual construction depth of borehole 1# is 77 m., the borehole diameter is 108 mm, and the casing is not installed; the actual construction depth of borehole 2# is 51.5 m, the final hole layer is within the predicted range of the water-conducting fracture zone, and the distance from the coal seam roof is 87.8 m, of which the observation section is designed to be 37 m, and the borehole diameter The diameter of the borehole is 108 mm within the range of 14.4 m above the observation section, and a casing with a diameter of 108 mm is installed. The specific structure of the drilling is shown in **Figure 8**.

3) Drilling position

Considering the development of fissures in the overlying rock after mining, the integrity and stability of the surrounding rock at the construction location of the borehole (drilling hole), and the convenience of the construction space, the

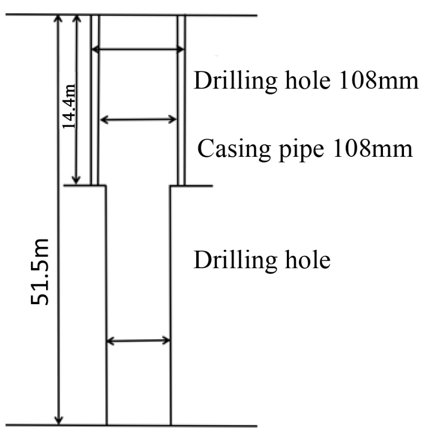


Figure 8. 2# Drilling structure diagram.

drilling site should be selected as close as possible to the working face after mining 1. At the position in February, combined with the mining situation of the working face, the position of the construction drilling site can be selected within a certain range behind the working face. According to the above analysis, the design drilling construction elements for detecting the height of the water-conducting fracture zone in the mining face are shown in Table 7.

In addition, in order to achieve the expected purpose of on-site detection research and obtain more accurate and reliable observation data, according to requirements, on-site detection should be carried out as soon as possible after drilling construction to prevent hole collapse and other phenomena.

5.2.2. Specific Implementation Steps

The development height of the water-conducting fracture zone is measured by the borehole fluid loss method and the borehole TV method, as shown in Figure 9 and Figure 10, respectively. The drilling steps are as follows:

Table 7. Drilling construction elements.

hole number	hole depth	Drill level	drop from the riverbed	distance from the river	Buried depth
1#	77 m	282.9 m	12.9 m	43.5 m	143.4 m
2#	51.5 m	283.3 m	13.3 m	65.8 m	144 m

Figure 9. Field measurement of drilling leakage.

Figure 10. On-site measurement of drilling TV.

1) Implementation steps for the observation of fluid loss in ground boreholes

a) After drilling, when the flushing liquid forms a circulation, measure the water level of the water source tank once, and record the drilling time and drilling depth. Each time you add water, measure and record it again. When the leakage fluid changes greatly, it needs to be measured and recorded once. And use a meter ruler to measure the actual drilling footage for this time.

b) When drilling in the observation section, the water level in the hole is measured every time before drilling and tripping. When the drilling time is long, observe the water level every 5 - 10 min.

c) When the flushing fluid circulation is interrupted, the hole depth and time are recorded in time. The hole depth and time were also recorded when the rinsing fluid resumed circulation.

d) When drilling into the crack, after each trip, if there is any phenomenon such as suction into the borehole, the depth of the borehole at that time should be recorded, and the abnormal phenomenon should be recorded.

e) The core of the observation section should accurately judge the horizon, lithology, dip angle of the rock formation and describe the broken state of the core.

f) When the circulation of the flushing fluid in the borehole is interrupted, the drilling tool should be pulled out of the hole, and then the water pump should be directly injected into the hole, and then the water leakage should be measured through the water source tank. During the test, the injection volume of clean water is required to be greater than the leakage volume

2) Implementation steps of borehole TV observation

Before working, assemble and connect all parts of the equipment to ensure that all interfaces work normally.

When working, connect the push rods one by one, push them in, and observe whether the image on the screen and the depth indication on the cable are displayed normally.

During observation, when the image on the screen shows obvious cracks, you can record or take pictures until there are no cracks or obvious mining cracks in the image on the screen.

After the test is completed, the device should be turned off first, and then the connecting rod should be gradually retracted and removed to store the device.

According to the degree of fracture development in the photos taken, the situation of the fractures generated by the overlying rock layer can be judged, and then the development height of the water-conducting fracture zone can be determined [13].

5.3. Field Measurement Results and Analysis

5.3.1. On-Site Measurement Time and Process

1) Ground Borehole Fluid Loss Observation: According to the above-mentioned design plan for the observation, the Construction of the designed borehole for

fluid loss observation began on October 9, 2021, at the Xingyun Coal Industry site above the working face. The Henan University of Technology research team arrived at the construction site at the start to monitor and record real-time fluid loss data.

2) TV Observation of Boreholes: Xingyun Coal Mining completed the construction of the designated 1# borehole above the working face on October 22, 2021. To prevent collapse, the research team immediately collected drilling images after completion. The 1# borehole collapsed at 34.67 m. The construction of the 2# borehole concluded on October 28, 2021, and subsequent probing analyzed the height of the water-conducting fracture zone in the overlying rock mining at the working face [6].

3) Drill Core Analysis: Following the design and construction plan for the 1# and 2# drilling holes, the Henan University of Technology research team was present at the construction site from the beginning. They photographed and numbered the drilling cores, and the results are organized in Table 8 and Table 9.

5.3.2. Analysis of the Observation Results of Fluid Loss from Ground Boreholes

1) Observation results of flushing fluid leakage

According to the recorded data of the field measurement, when the drilling depth is 0 - 14.4 m, the casing needs to be installed due to the existence of the surface topsoil, and the leakage data is not recorded. The relationship between the leakage of flushing fluid and the depth of drilling in drilling hole 2. It can be seen from Figure 11 that when the drilling depth is 20.5 - 21.5 m, the leakage of drilling flushing fluid does not change much, and it is maintained at about 5.3 - 5.4 L·min^{-1}; the drilling depth is 22.5 - 28.5 m When the drilling fluid loss is

Table 8. 1# drilling and coring results.

Lithology	Hole depth/m	Thickness/m	Lithological description
Loess layer + gravel	11.5	11.5	Loess mixed with gravel
sandy mudstone	22.1	10.6	Gray-yellow, with star-like muscovite, broken core, loose weathered, with iron interlayers
fine-grained sandstone	35.5	13.4	Gray-yellow feldspar quartz sandstone with dark minerals and horizontal bedding
sandy mudstone	39	3.5	Gray-yellow, with argillaceous inclusions, broken core
mudstone	44	5.0	Contains calcite filler
medium-grained sandstone	58.9	14.9	Main ingredient Quartz
sandy mudstone	60.9	2	grey, medium siltstone
mudstone	67.9	7.0	grey or light grey
fine-grained sandstone	70.4	2.5	grey with oblique bedding
mudstone	77	6.6	dark grey with wavy bedding

Table 9. 2# Drilling and coring results.

Lithology	Hole depth/m	Thickness/m	Lithological description
Loess layer + gravel	13.5	13.5	Loess mixed with sand and gravel
sandy mudstone	17.5	4	Gray-yellow, with star-like muscovite, broken core, loose weathered, with iron interlayers
fine-grained sandstone	19	1.5	Gray-yellow feldspar quartz sandstone with dark minerals and horizontal bedding
sandy mudstone	23.5	4.5	Gray-yellow, with argillaceous inclusions, broken core
fine-grained sandstone	37	13.5	Gray-yellow feldspar quartz sandstone with dark minerals and horizontal bedding
sandy mudstone	41	4	Gray-yellow, with argillaceous inclusions, broken core
mudstone	46.5	5.5	Contains calcite filler
medium-grained sandstone	5 0	3.5	Main ingredient Quartz

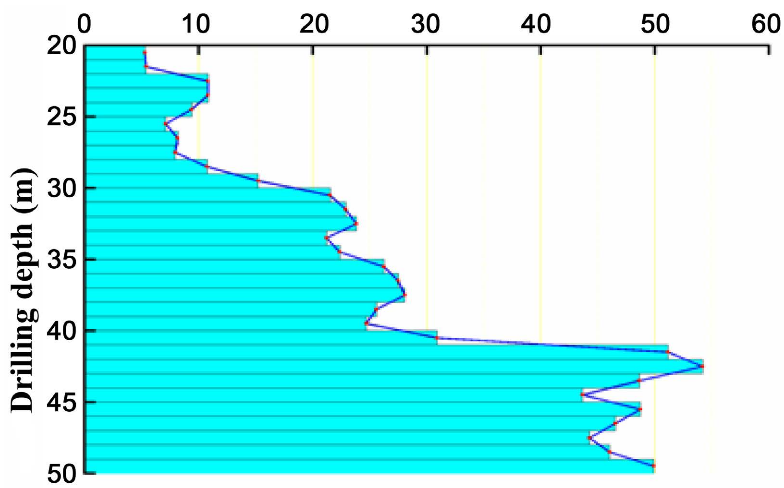


Figure 11. The relationship between the loss of drilling hole 2 and the drilling depth.

about 10 L·min^{-1} compared with the previous section, it remains basically stable after that, and the change range is about 3 L·min^{-1}; when the drilling depth is 28.5 - 29.5 m, the flushing The amount of fluid leakage continued to increase, with an increase rate of about 5 L·min^{-1}; when the drilling depth was 29.5 - 30.5 m, the amount of flushing fluid leakage further increased, with an increase rate of about 6 L·min^{-1}; the drilling depth was From 30.5 m to 34.5 m, the leakage of flushing fluid reaches about 22 L·min^{-1}, and the amount of fluid loss changes little; when the drilling depth is 35.5 m to 40.5 m, the loss of flushing fluid further increases, reaching a maximum of 30.9 L·min^{-1}; when the drilling depth is 41.5 m - 49.5 m, the leakage of flushing fluid has a huge increase compared with the previous section, and the increase rate reaches 20 L·min^{-1}.

2) Analysis of observations

The analysis of observations regarding the water-conducting fracture zone apex is based on two main principles:

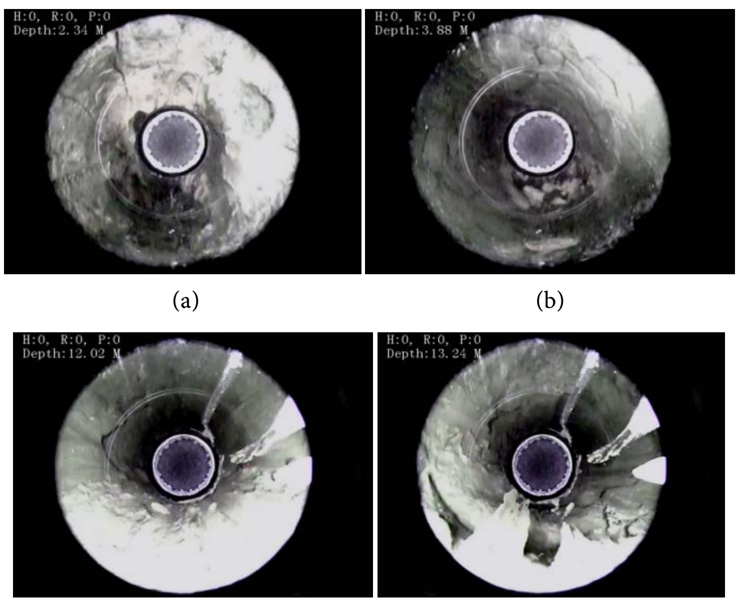
a) Significant increases in drilling flushing fluid leakage, showing a general upward trend with drilling depth;

b) Substantial decreases in drilling water level, with an accelerated descent, even in the absence of water in the hole.

Examining **Figure 11**, key findings include a 5 L/min increase in fluid leakage at 22.5 - 28.5 m, a rapid rise from 10.75 L/min to 21.52 L/min at 28.0 - 30.0 m, and relatively small changes between 30.5 - 34.5 m (21.52 - 23.83 L/min). At 40.5 - 41.5 m, there's a rapid increase from 30.9 L/min to 51.14 L/min, with a significant rise of 20.24 L/min, indicating an upward trend with drilling depth. The analysis concludes that at drilling depths of 28.0 - 30.0 m and 40.5 - 41.5 m, there are sudden and substantial increases in flushing fluid leakage by 10.77 L/min and 20.24 L/min, respectively. Considering geological and mining conditions, it is recommended to choose a larger value as the development height of the water-conducting fracture zone. Therefore, it is determined that the water-conducting fracture zone extends to 28.0 - 30.0 m below the surface, indicating a maximum height of 114 - 116 m.

5.3.3. Analysis of the Results of Borehole TV Observation of Fractures

The 1# and 2# post-mining boreholes were observed by using the GD3Q-GM and CXK12(B) borehole video detection systems, respectively. When transverse cracks appear in the borehole, it indicates that the cracks exist in the rock layer, and when there are longitudinal cracks in the hole, it indicates that the rock layer is broken under the influence of mining. There are cracks on the hole wall in some positions in the 1# hole. The TV result of the 1# hole drilling is shown in **Figure 12** below.



(a) (b)

(c) (d)

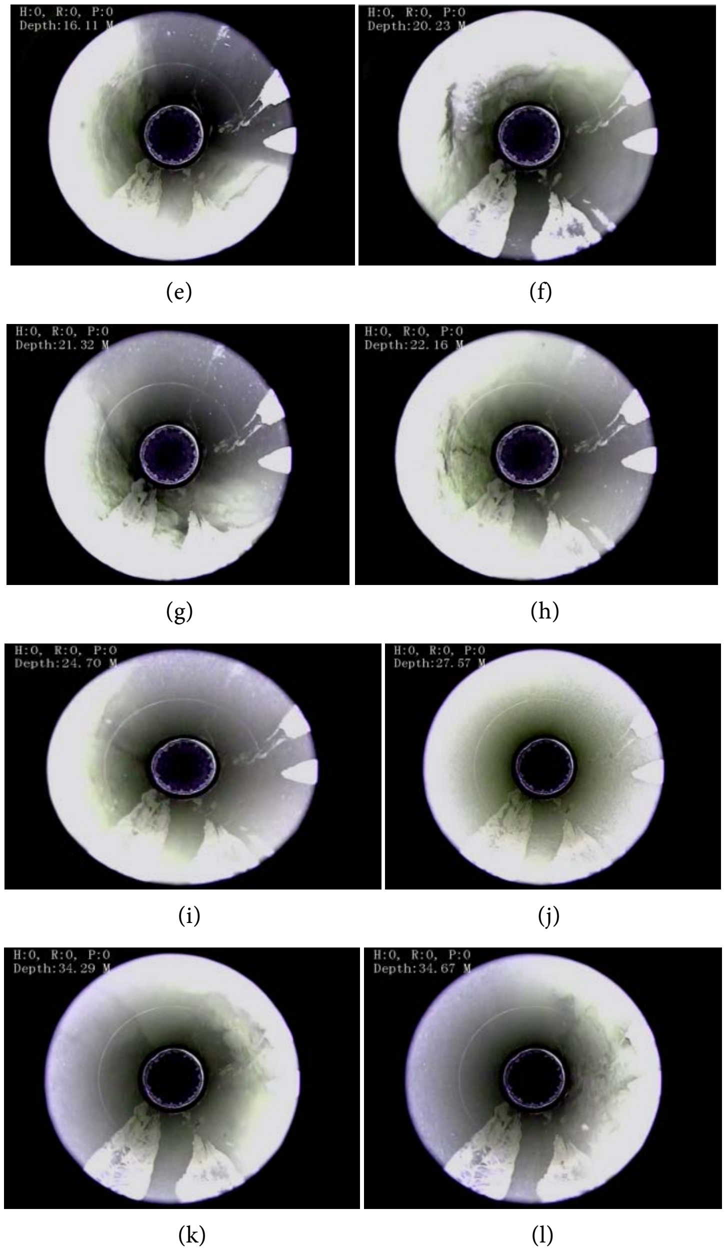


Figure 12. Photographs of overburden fissures at different positions in the 1# borehole after mining. (a) The distance between the prob hole and the ground is 2.34 m; (b) The distance between the probe hole and the ground is 3.88 m; (c) The distance between the probe hole and the ground is 12.02 m; (d) The distance between the probe hole and the ground is 13.24 m; (e) The distance between the probe hole and the ground is 16.11 m; (f) The distance between the probe hole and the ground is 20.23 m; (g) The distance between the probe hole and the ground is 21.32 m; (h) The distance between the probe hole and the ground is 22.16 m; (i) The distance between the probe hole and the ground is 24.70 m; (j) The distance between the probe hole and the ground is 27.57 m; (k) The distance between the probe hole and the ground is 34.29 m; (l) The distance between the probe hole and the ground is 3 4.67 m.

In this interval, noticeable mining fissures are evident in the strata, indicating their clear impact from mining activities. Figures (j)-(l) illustrate overburden strata mining between depths of 27.57 m and 34.67 m, with heights from the coal seam top ranging from 111.56 m to 104.03 m. Detection results reveal variations in strata within this layer concerning the distance from the coal seam. As roof distance decreases, the development of overlying fissures increases, demonstrating a positive correlation. The 1# borehole's proximity to the riverbed, at a distance of 43.5 m from the river surface flow with a drop of 12.9 m, leads to a rapid rise in water levels due to the riverbed aquifer. The probe enters the water at 14.5 m, reaching 34.67 m depth, where observation becomes challenging. Further probing is hindered by hole collapse, potentially caused by a small geological structure or the cobblestone layer of the riverbed, rendering borehole detection impossible. Overall, a comprehensive view suggests that the water-conducting fracture zone in the overlying rock at the mining area's working face will emerge at shallower burial depths.

Analysis of 2# drilling results

The water-conducting fracture zone in the overlying rock on the roof in more detail, 2# was constructed 21 m away from the 1# hole drilling. Use CXK12(B)) borehole TV system for observation, and then use professional software to stitch the video images. The results are shown in **Table 8** above.

Water-conducting fracture zone in the mining face, the overburden fissures at different positions in the 2# borehole are shown in **Table 10**, and the left side of the photo in the table corresponds to the Drilling depth. In order to prevent hole collapse caused by topsoil rocks, casing was installed at 0 - 14.4 m of the borehole.

Figure (a) shows the situation of mining overburden when the drilling depth is in the range of 12.9 - 15.4 m. Above 14.4 m, the steel casing wall interferes with the magnetic field of the compass. Drill image.

In Figure (b), we can see the development of clear fractures. Compared with the core and geological drilling histogram, this section is sandy mudstone with softer texture, and the core is relatively broken, and the primary structural bedding fractures are more obvious;

Figure (b) in (c), according to the fine-grained sandstone in this section of the core, the 19.5 - 19.7 m hole wall has obvious broken rocks, and water flow is constantly gushing out from the broken place; among them, the drilled holes in the layers of (d)-(f). The depth is 20.6 - 33.3 m, and the rock stratum is broken at 21.5 - 21.9 m in Figure (d), especially at 28.3 - 29.3 m in Figure (e), the rock wall is broken and large vertical cracks and transverse cracks are connected, accompanied by water flow; 30.0 - 30.4 m in the phenomenon of borehole enlargement, combined with the video data of the borehole, here is the gravel layer.

Figures (g)-(h) show the overburden mining in the drilling depth range of 33.4 - 38.5 m. Obvious sandstone fillings can be observed in the strata in this interval. The rock formations in the range of 36.8 m and 37.5 to 37.6 m all appear layer separation. Figures (i)-(l) show the overburden mining in the drilling depth range of 41.2 - 50.2 m, of which 40.3 - 40.4 m, 41.6 - 41.7 m and 42.2 - 42 m. Large fissures or separation layers appear at 3 m.

Table 10. TV observation results of hole 2#.

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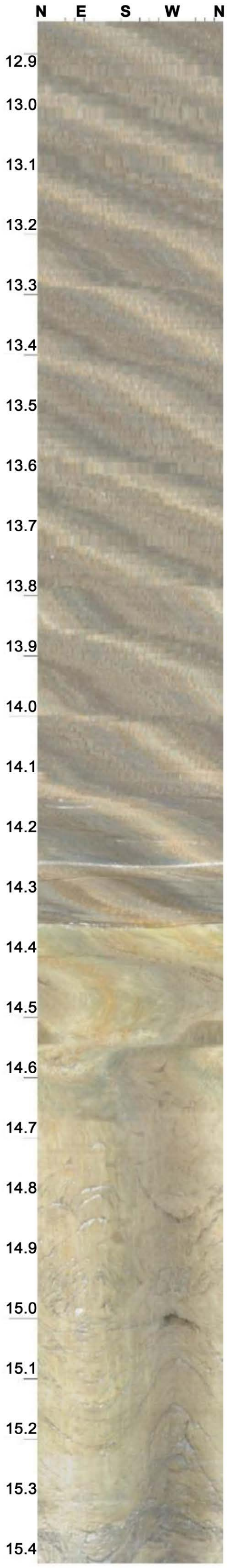

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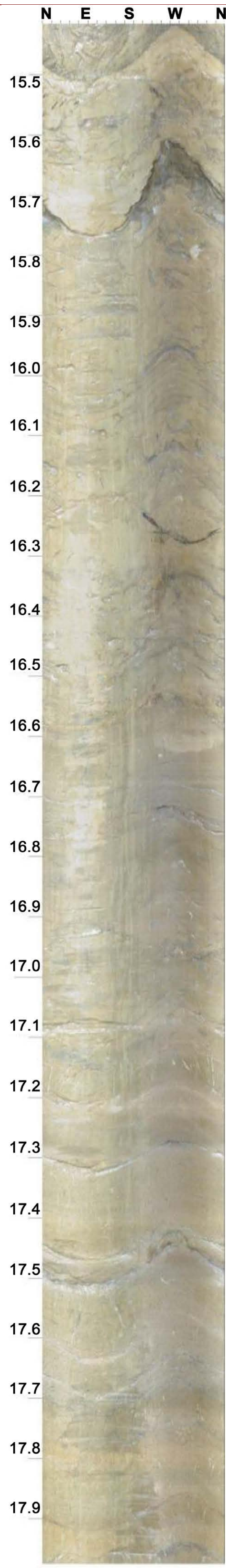

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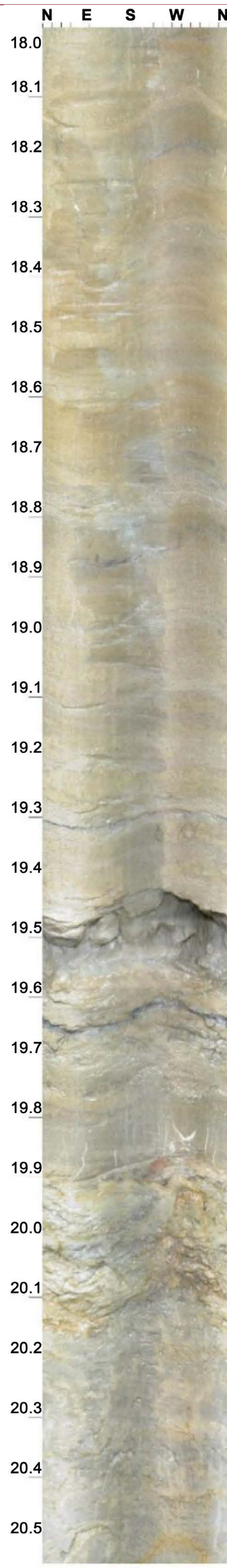

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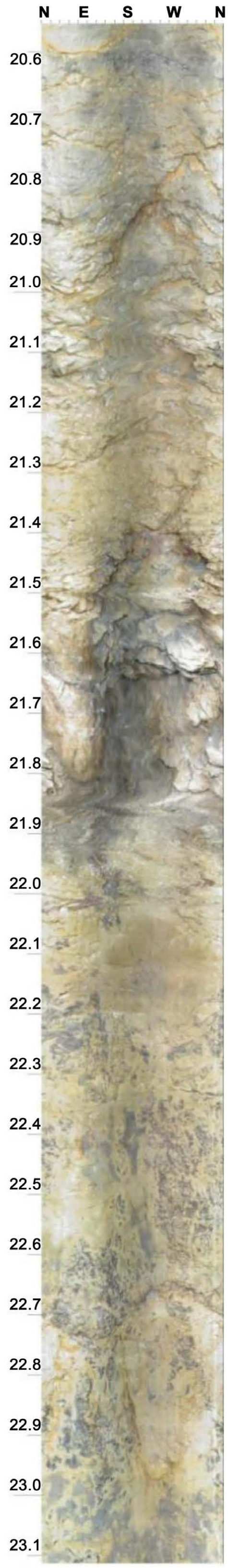

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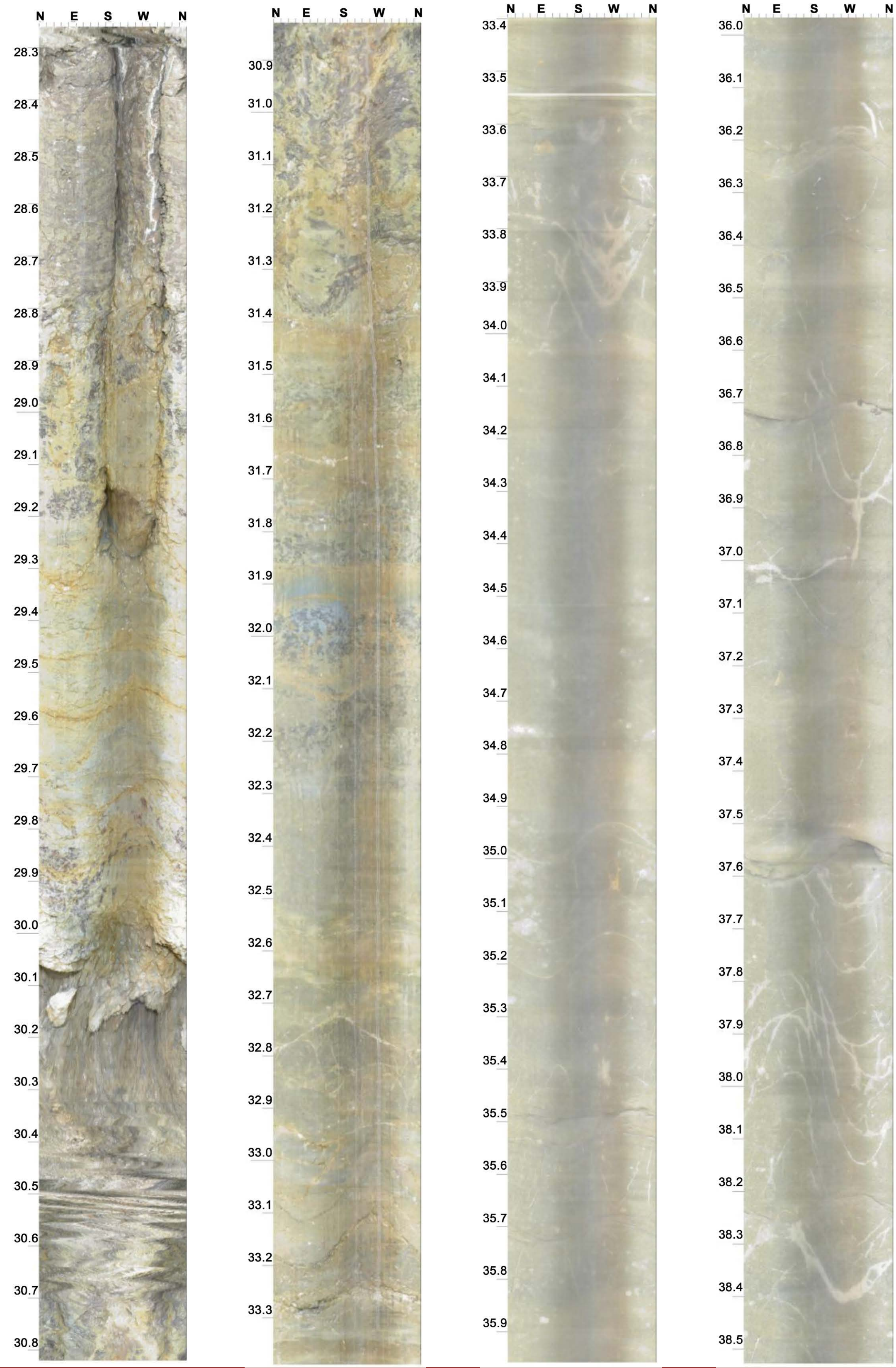
e	f	g	h



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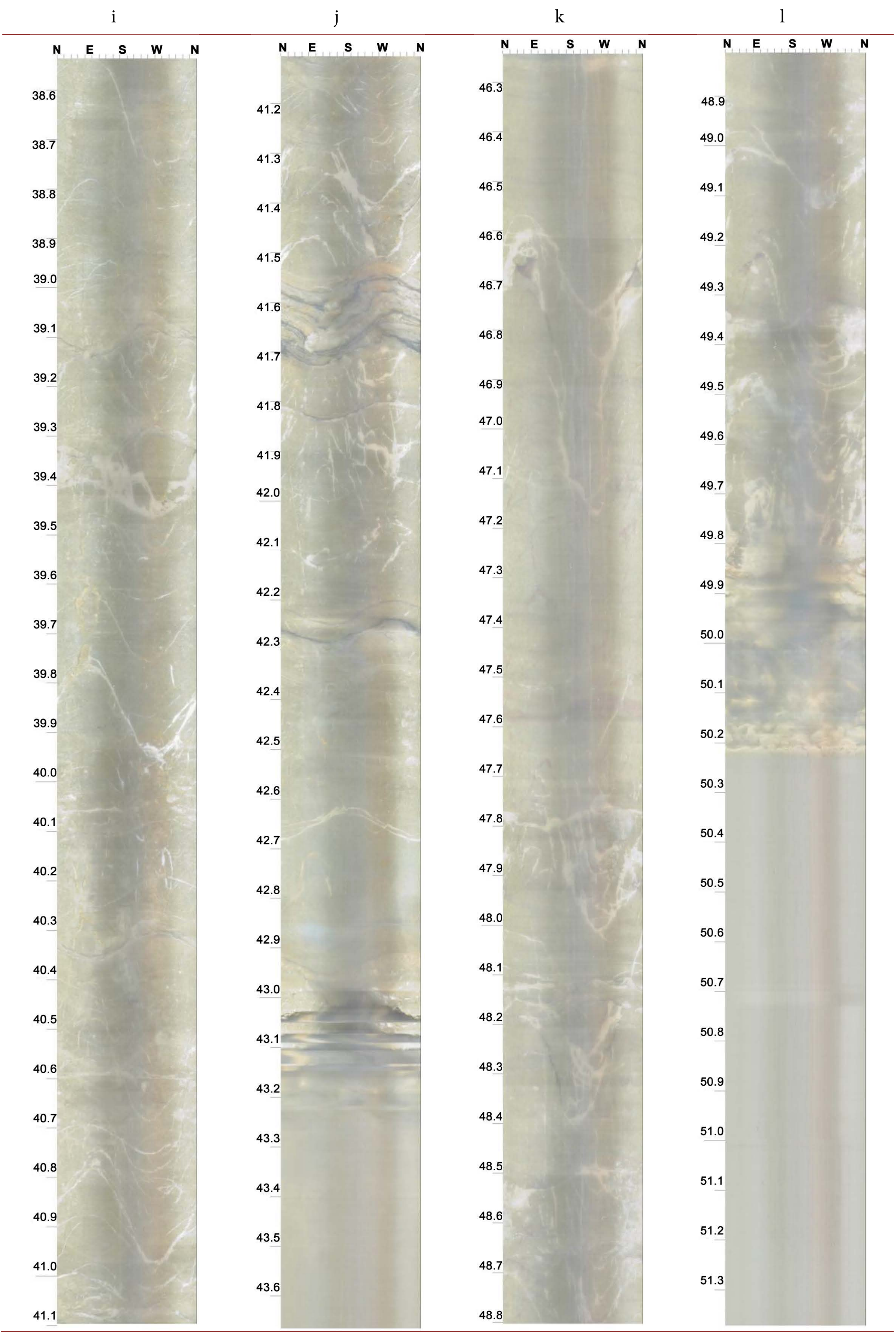
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49.6
49.7
49.8
49.9
50.0
50.1
50.2
50.3
50.4
50.5
50.6
50.7
50.8
50.9
51.0
51.1
51.2
51.3

According to the detection results, as the distance from the coal seam roof decreases in the overlying strata on the working face, the degree of development of fissures in the overlying stratum increases, and there are many separation layers and large fissures. The distance and the development of fissures show a positive correlation. The mining influence increases with the decrease of the distance from the coal seam roof within the range.

It can be seen comprehensively that under the influence of mining disturbance, the bedrock with shallower burial depth appears cracks, and the bedrock with deeper burial depth appears to bend and sink. There are many obvious rock fissures and layer separation phenomena in the 2# hole, accompanied by water flow. The fissures are relatively densely distributed, and the longitudinal and lateral fissures at 28.3 - 29.3 m are connected (as shown in **Figure 13** below), so that the water flow can penetrate the rock layer through the fissures. It should be noted that there are obvious cracks and separation layers in the bedrock below the casing, and the soft topsoil layer is covered by the casing. No image was observed due to the existence of the casing. Therefore, by analyzing the TV measured data of the 2# borehole, it can be obtained that the water-conducting fracture zone of the overlying rock developed in the working face is 28.3 - 29.3 m below the surface, that is, the height of the water-conducting fracture zone detected by the 2# borehole is 115.7 m.

5.4. Summary

1) The ground borehole leakage method and borehole TV method were used to observe the development height of the water-conducting fracture zone caused by the mining of the working face. A total of 2 post-mining boreholes (1# and 2# boreholes) were constructed. In order to facilitate the construction, the drilling should be selected at a suitable position above the working surface. Among them, the 1# hole (the distance from the ground river is 43.5 m), the depth of the hole is 77 m; the 2# hole (the distance from the ground river is 65.8 m), the depth of the hole is 51.5 m.

2) According to the data of 2# borehole flushing fluid loss and borehole TV data, the measured heights of water-conducting fracture zones are 114 - 116 m and 115.7 m, respectively. Combining two kinds of data analysis, it can be concluded that the leakage of flushing fluid has a sudden change at 28 - 30 m, and

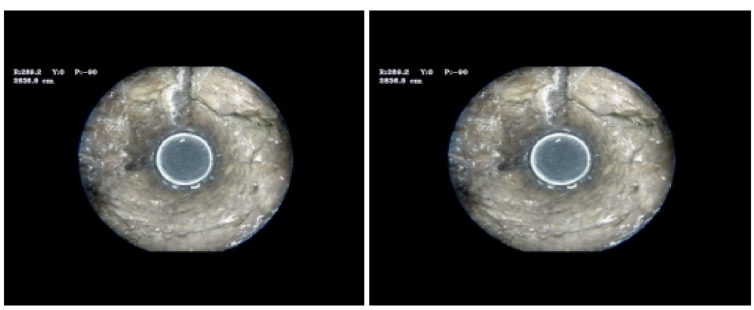

Figure 13. Details of the water-conducting fracture zone.

the drilling TV data shows vertical cracks and transverse cracks in the rock stratum at 28.3 - 29.3 m. The interval of fissure bands observed in TV matches. Combined with the TV images of the 1# and 2# boreholes and the fluid loss changes of the 2# borehole, the research results show that the development height of the water-conducting fracture zone is 115.7 m, and the water-conducting fracture zone will develop to the surface in the shallower buried depth.

6. Prediction of Surface Movement and Deformation and Surface Cracks

6.1. Computational Model and Scheme

6.1.1. Computational Model

To analyze ground surface movement and deformation resulting from underground coal mining at Xingyun Coal Industry and ensure safe mining under a water body, surface movement and deformation calculations are essential. Currently, common methods include the typical curve, negative exponential function, and probability integral methods. This study adopts the probability integral method.

Based on the discrete random medium theory, the probability integral method was developed by Chinese scholars Liu Baochen and Liao Guohua in 1965 [14]. Academicians like Liu Tianquan refined its practical application, making it widely used in China. This method utilizes the normal distribution function as the influence function to express rock formation and subsidence basin with an integral formula. Known for its ease of use, adaptability, and high prediction accuracy, the probability integral method has a solid theoretical foundation. Predicted parameters, derived from measured data, remain stable within a mining area and follow a certain law of change. Hence, this method is extensively employed in China, emerging as a primary calculation approach for coal mining-induced surface movement and deformation.

Analyzing geological mining data provided by Xingyun Coal Industry, it is evident that the surface subsidence in this area aligns with the principles of the probability integral method.

The mathematical model and calculation formula for the probability integral method are as follows:

1) Subsidence of any point on the surface

$$\begin{aligned} W(x,y) &= \int_{-m_0}^{m_0}\int_{-s_0}^{s_0}\int_{-t_0}^{t_0}\frac{1}{r^2}\mathrm{e}^{-\frac{\pi}{r^2}\left[(x-s)^2+(y-q)^2\right]}\mathrm{d}s\mathrm{d}m\mathrm{d}q \\ &= \frac{1}{W_0}W^0(x)W^0(y) = W_0\cdot C(x)\cdot C(y) \end{aligned} \tag{6-1}$$

In the formula, $C(x)$ and $C(y)$ are called subsidence distribution coefficients in the main section.

2) Inclination of any point on the surface

At any point (x,y) and in any direction that $i(x,y)_\phi$ intersects the x-coordinate axis at an angle, the slope of the earth's surface ϕ is:

$$i(x,y)_{\varphi} = \frac{\partial W(x,y)}{\partial x}\cos\varphi + \frac{\partial W(x,y)}{\partial y}\sin\varphi \tag{6-2}$$

The main inclination direction ϕ_k and main inclination values are:

$$\varphi_k = \operatorname{arctg}\frac{C(x)i(y)}{C(y)i(x)} \tag{6-3}$$

$$i(xy)_{\phi_k} = C(x)i(y)\cos\varphi_k + C(x)i(y)\sin\varphi_k$$

3) Curvature of any point on the surface

Curvature in any direction through any point $k(x,y)_{\phi}$ is:

$$k(x,y)_{\varphi} = C(y)k(x)\cos^2\varphi + C(x)k(y)\sin^2\varphi + C_{[x,y]}\sin 2\varphi \tag{6-4}$$

$$\text{in } C_{[x,y]} = \frac{1}{W_0 i(x)} i(x)i(y)$$

In the principal curvature directions $k(x,y)_{\phi_k}$ and principal curvature values are: ϕ_k

$$\varphi_k = \frac{1}{2}\operatorname{arctg}\frac{2C_{[x,y]}}{C(y)k(x) - C(x)k(y)} \tag{6-5}$$

$$k(x,y)_{\varphi_k} = C(y)k(x)\cos^2\varphi_k + C(x)k(y)\sin^2\varphi + C_{[x,y]}\sin 2\varphi_k$$

4) Horizontal movement of any point on the surface

The tilt in any direction through any point $U(x,y)_{\phi}$

$$U(x,y)_{\varphi} = C(y)U(x)\cos\varphi + C(x)U(y)\sin\varphi \tag{6-6}$$

The main horizontal movement direction ϕ_k and main horizontal movement value ar $U(x,y)_{\phi_k}$

$$\varphi_k = \operatorname{arctg}\frac{C(x)U(y)}{C(y)U(x)} \tag{6-7}$$

$$U(x,y)_{\varphi_k} = C(y)U(x)\cos\varphi_k + C(x)U(y)\sin\varphi_k$$

5) Horizontal deformation of any point on the surface. The horizontal deformation in any direction through any point $\varepsilon(x,y)_{\phi}$ is:

$$\varepsilon(x,y)_{\varphi} = C(y)\varepsilon(x)\cos^2\varphi + C(x)\varepsilon(y)\sin^2\varphi + \frac{1}{2}r_{[x,y]}\sin 2\varphi_k \tag{6-8}$$

$$\text{in } r_{[x,y]} = \frac{1}{W_0}\left[C(y)i(y)U(x) + C(x)i(x)U(y)\right]$$

The main horizontal deformation direction ϕ_k and the main horizontal deformation value are: $\varepsilon(x,y)_{\phi_k}$

$$\varphi_k = \frac{1}{2}\operatorname{arctg}\frac{2r_{[x,y]}}{C(y)\varepsilon(x) - C(x)\varepsilon(y)} \tag{6-9}$$

$$\varepsilon(x,y)_{\varphi_k} = C(y)\varepsilon(x)\cos^2\varphi_k + C(x)\varepsilon(y)\sin^2\varphi_k + \frac{1}{2}r_{[x,y]}\sin 2\varphi_k$$

6) The maximum surface movement and deformation and its position on the

main section

Maximum sinking value: $W_{cm} = Mq\cos a$, mm, Position: $x = \infty$

Maximum tilt value: $i_{cm} = \frac{W_{cm}}{r}$, mm/m, Position: $x = 0$

Maximum curvature value: $K_{cm} = 1.52\frac{W_{cm}}{r^2}$, $10^{-3}/\text{m}$, Position: $x = \pm 0.4r$

Maximum horizontal movement value: $U_{cm} = bW_{cm}$, mm, Position: $x = 0$

Maximum horizontal deformation value: $\varepsilon_{cm} = 1.52b\frac{W_{cm}}{r}$, mm/m, Position: $x = \pm 0.4r$

6.1.2. Calculation Parameters

When the probability integration method is used to calculate the surface movement and deformation, the selection of the calculation parameters of the probability integration method is very important. According to the basic principle of probability integral method calculation, several parameters required for calculation are: subsidence coefficient *q*, main influence angle tangent tan *b*, horizontal movement coefficient *b*, mining influence propagation angle *q* and inflection point offset, etc. In order to ensure the probability integral method The scientific nature of the calculation, comprehensive analysis and selection of the calculation parameters of the probability integral method.

The predicted parameters of the probability integration method are obtained by fitting the curve method to the measured data of each observation station in the Zhengzhou mining area, and the predicted parameters of the probability integration method for mining the "three soft" coal seams in the Zhengzhou mining area are given, as shown in Table 11.

At the same time, the project research team analyzed the calculation parameters of the probability integral method for the underground coal mining face of Baiping Coal Industry Company in the project of "Construction Plan for the Reinforcement Project of Jishan Radio and Television Signal Station in Dengfeng City", and finally determined the parameters suitable for Baiping coal mining. The parameters of the probability integral method of the coal mining face of the mining company are shown in Table 12.

Table 11. Estimated parameters of the "three soft" coal seam mining probability integral method in Zhengzhou mining area.

Mine name	Observatory	Probabilistic Integral Method Predicted Parameters							
		q	$\tan\beta$	θ	b	S_1/H_1	S_2/H_2	S_3/H_0	S_4/H_0
zhaojiazhai	11206	0.93	2.38	87.4	0.3	0.04	0.08	0.1	0.1
superficial	11051	0.79	2.1	83.2	0.34	0.09	0.12		
Daping	13091	0.82	2.1	78	0.3			0.05	0.05
rice village	260061	0.82	2.46	84				0.05	0.05
	1302	0.85	2.2		0.24	0.1	0.14		
Pei Gou	31071	0.78	2.2	80	0.34	0.05	0.06	0.08	0.08
Golden Dragon	21081	0.79							

Table 12. Calculation parameters of probability integral method of coal mining face of Baiping coal company.

q	$\tan\beta$	θ	b
0.88	2.1	87.8	0.3

Xingyun Coal and the above-mentioned mines both belong to the Zhengzhou mining area. The mines are geographically close to each other, and the geological mining conditions of the underground coal mining face are basically the same as those of the above-mentioned mines. After comprehensive analysis and calculation, the calculation parameters of probability integral method suitable for the coal mining face of Xingyun Coal Industry are finally determined, as shown in Table 13.

6.1.3. Calculation Scheme of Surface Movement and Deformation

According to the above analysis of the calculation parameters of the probability integral method, combined with the mining situation of the underground working face of Xingyun Coal Industry, two schemes are proposed for the calculation and analysis of the working face mining.

Option 1: Calculate the surface movement and deformation caused by the mining of the 12071 working face until the time of the investigation;

Option 2: Calculate the movement and deformation of the ground surface after all mining in the future working face is completed.

6.2. Calculation Results and Analysis of Surface Movement and Deformation

6.2.1. Calculation Results of Plan 1

The contour map of surface movement and deformation calculated according to Scheme 1 is as follows:

The surface subsidence contour map is shown in Figure 14;

The contour map of surface inclination along the strike is shown in Figure 15;

The slope contour map along the inclined surface is shown in Figure 16;

The contour map of horizontal movement of the surface along the strike is shown in Figure 17;

The contour map of horizontal movement along the inclined surface is shown in Figure 18;

The contour map of horizontal deformation of the surface along the strike is shown in Figure 19;

The contour map of horizontal deformation along the inclined surface is shown in Figure 20.

6.2.2. Calculation Results of Option 2

The contour map of surface movement and deformation calculated according to Scheme 2 is as follows:

The surface subsidence contour map is shown in Figure 21;

Table 13. Calculation parameters of Xingyun coal mining face probability integral method.

face name	Mining thickness/mm	coal seam Inclination/˚	sink coefficient	main influence tangent	Mining influence propagation angle/˚	Average burial depth/m	b
12051 Planning Surface	5000	5 to 8	0.85	2.1	88.3	154.4	0.3
12071	2400 - 3000	5 to 8	0.85	2.1	88.3	146.7	0.3

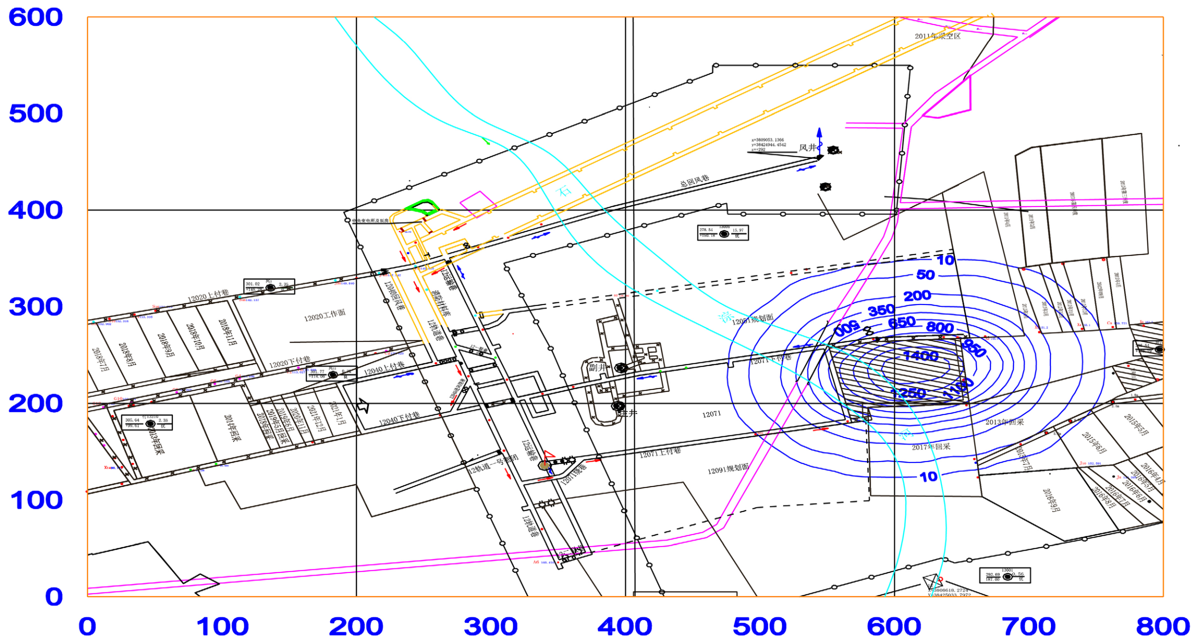

Figure 14. Contour map of surface subsidence.

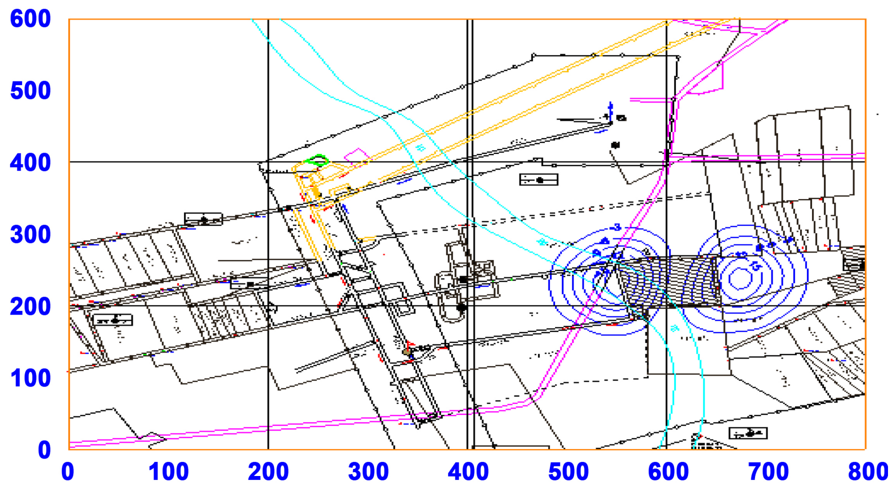

Figure 15. Contour map of surface inclination along strike.

The contour map of surface inclination along the strike is shown in **Figure 22**;

The slope contour map along the inclined surface is shown in **Figure 23**;

The contour map of horizontal movement of the surface along the strike is shown in **Figure 24**;

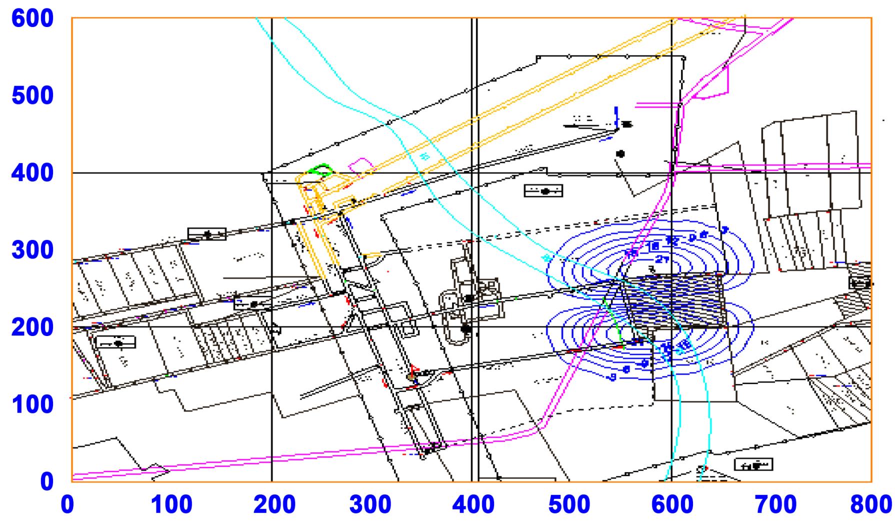

Figure 16. Contour map of slope along the inclined surface.

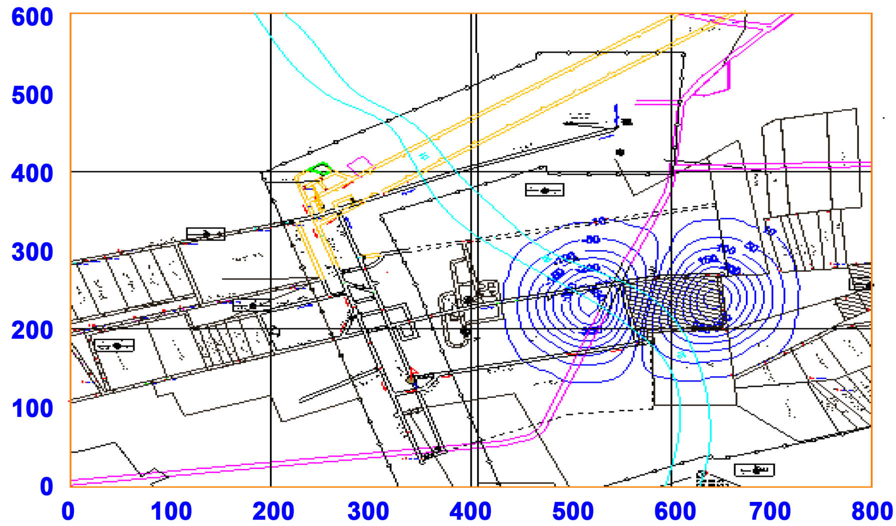

Figure 17. Contour map of horizontal movement of the surface along strike.

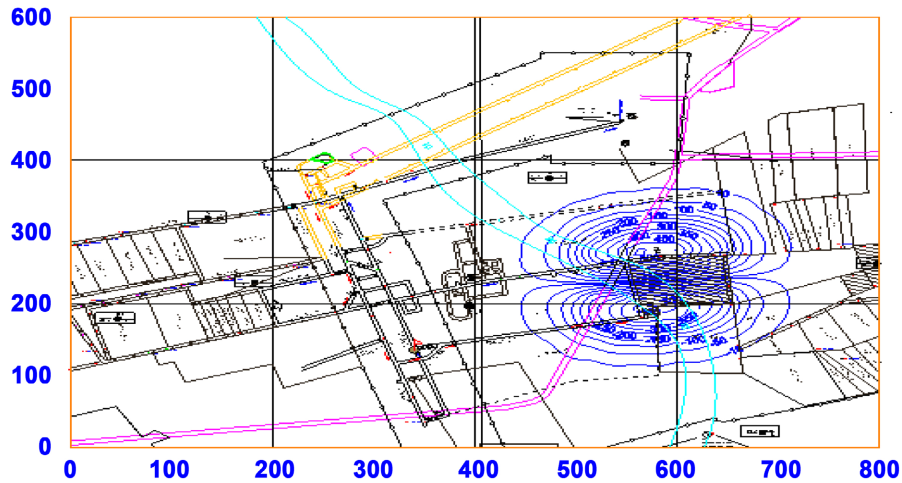

Figure 18. Contour map of horizontal movement along the inclined surface.

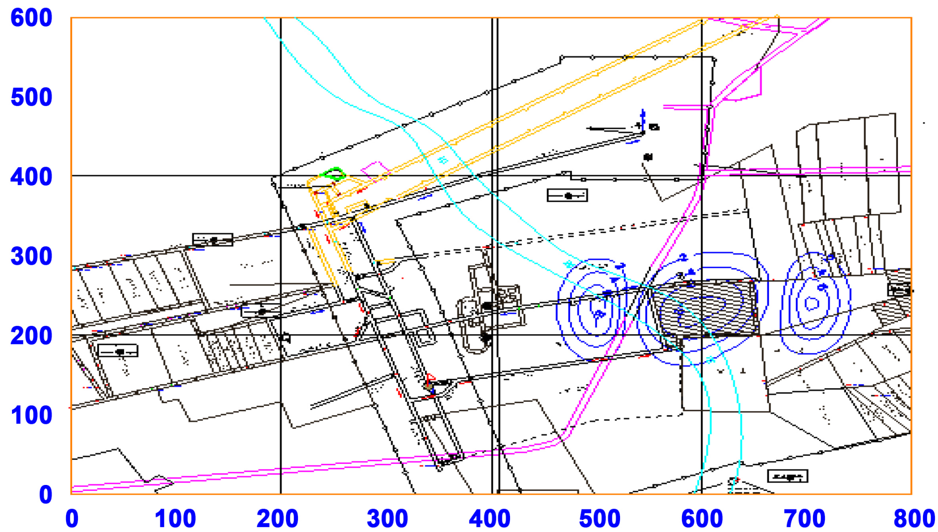

Figure 19. Contour map of horizontal surface deformation along strike.

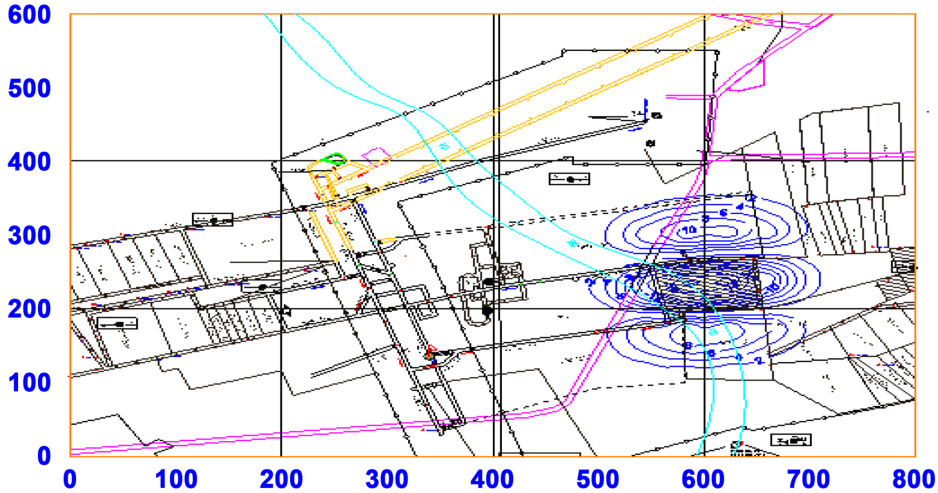

Figure 20. Contour map of horizontal deformation along the inclined surface.

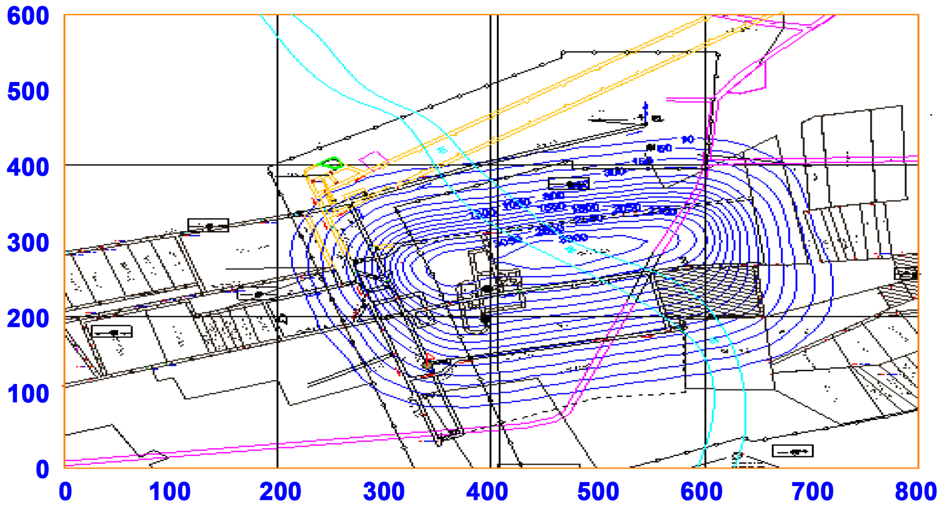

Figure 21. Contour map of surface subsidence.

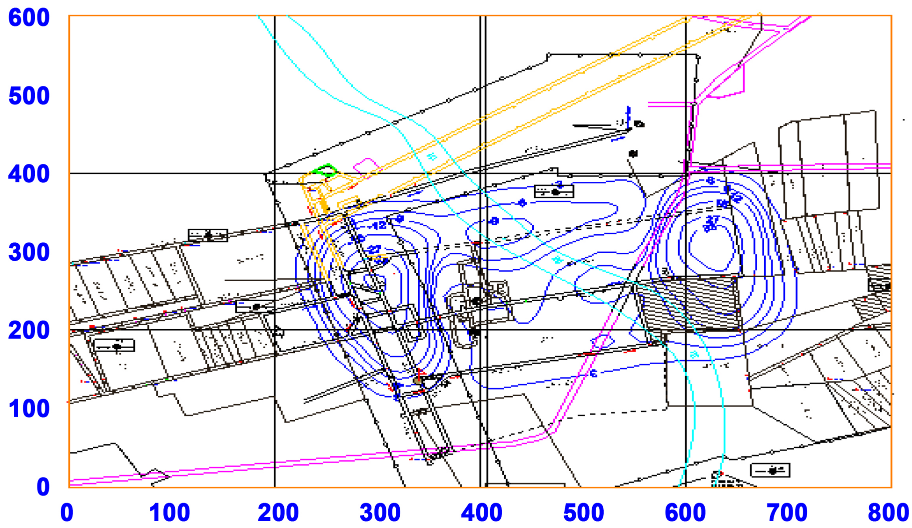

Figure 22. Contour map of surface inclination along strike.

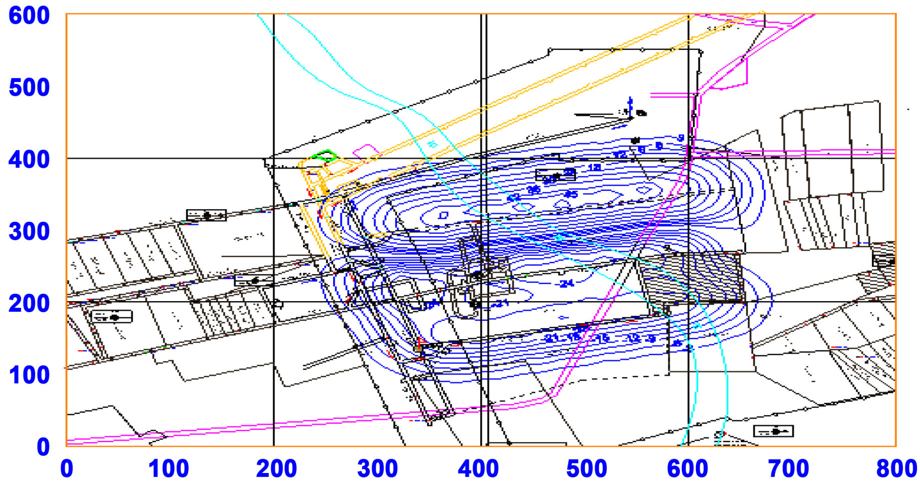

Figure 23. Contour map of slope along the inclined surface.

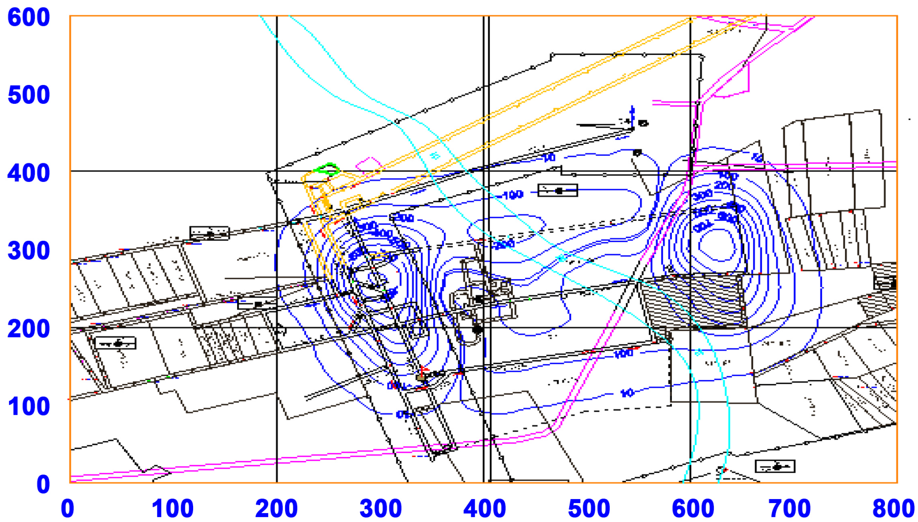

Figure 24. Contour map of horizontal movement of the surface along strike.

The contour map of horizontal movement along the inclined surface is shown in Figure 25;

The contour map of horizontal deformation along the strike surface is shown in Figure 26;

The contour map of horizontal deformation along the inclined surface is shown in Figure 27.

6.2.3. Analysis of Calculation Results of Surface Movement and Deformation

According to the above calculation results, the calculation results of Plan 1 show that, as of the time of the investigation, the maximum subsidence value of the surface in the area caused by the mining of the 12071 working face of Xingyun Coal Industry is 1506.9 mm, the maximum surface inclination value is 24.9 mm/m, and the maximum horizontal movement of the surface The value is 583.7 mm, the maximum horizontal tensile deformation of the ground surface is 12 mm/m, and the maximum horizontal compressive deformation is 21.9 mm/m.

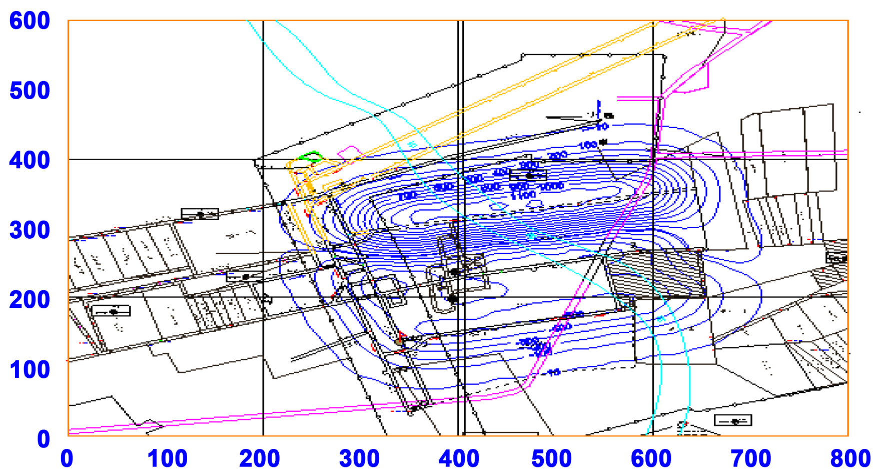

Figure 25. Contour map of horizontal movement along the inclined surface.

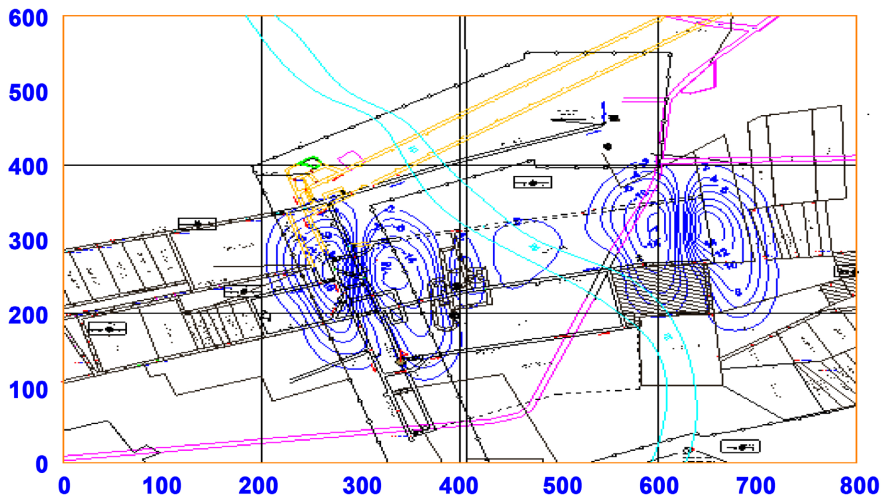

Figure 26. Contour map of horizontal surface deformation along strike.

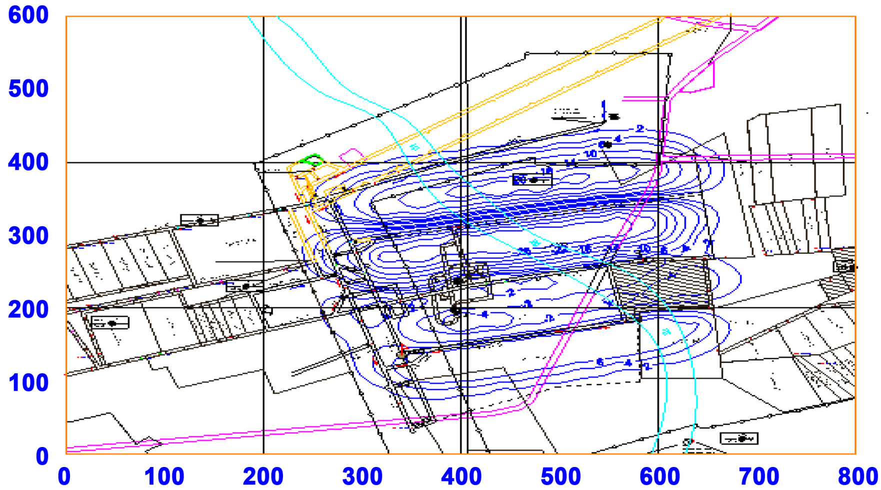

Figure 27. Contour map of horizontal deformation along the inclined surface.

The calculation results of Plan 2 show that after all mining of the future working face is completed, themaximum surface subsidence value in this area will be 3480.3 mm, the maximum surface inclination value will be 51.2 mm/m, the maximum surface horizontal movement value will be 1273.2 mm, and the maximum surface horizontal tensile deformation will be is 24.3 mm/m, and the maximum horizontal compression deformation of the ground surface is 33.8 mm/m. The maximum values of surface movement and deformation in the goaf calculated based on the above two schemes are shown in Table 14.

According to the above calculation results of surface movement and deformation, after the mining of the two working faces, the maximum subsidence value of the surface reaches about 3.5 m. Because the river is located directly above the working face, the riverbed of this section will sink, so there will be a certain degree of water accumulation in this section. However, according to the topography of the area and the depth of the riverbed, it will not cause flooding.

In addition, after the working face is mined, the maximum tensile horizontal deformation of the ground surface can reach 24.3 mm /m. Therefore, ground fissures will inevitably appear on the ground surface. A few meters to tens of meters. According to the calculation results of the development height of the water-conducting fracture zone, it can be seen that the ground fractures and the water-conducting fracture zone are highly connected, which will cause the leakage of surface water to the downhole. During the on-site investigation, some surface fissures were seen, and the phenomenon that the river water leaked downward from the fissures (as shown in Figure 28 below). According to the mine, the amount of water inflow at the underground working face has increased significantly recently. It can be seen that the above calculation results are consistent with the actual situation.

6.3. Analysis of the Development Characteristics of Surface Fractures

Members of the project team conducted a field survey on the study area on

Table 14. The maximum surface movement and deformation caused by the mining of each plan.

mining plan	Subsidence value (mm)	Tilt (mm/m)	Level move (mm)	Level Deformation (mm/m)		curvature (10^{-3}/m)
Option I	1506.9	24.9	583.7	+12	−21.9	<0.05
Option II	3480.3	51.2	1273.2	+24.3	−33.8	<0.05

Figure 28. River infiltration and river bed cracks.

October 8, 2021, mainly investigating the impact of mining on the surface near the 12071 working face. Through investigation, obvious mining damage cracks were found on the surface near the 12071 working face.

According to the on-site investigation and the geological mining information provided by the mine, there is a Shicong River and a road obliquely passing through the surface of the 12071 working face, as well as an earth-rock dam., the highway bridge has been prohibited from opening to traffic, and mining cracks were found on the bridge deck, and the bridge deck was relatively broken (see Figure 29). Figure 30), on October 28, it was found that the crack development degree was further increased, and the bridge deck at this position was directly arched (see Figure 31), with obvious mining damage characteristics. According to "Buildings, water bodies, railways and main shafts and roadways" are specified in the Specification for Coal Pillar Retention and Pressed Coal Mining, that this place has reached level IV damage. The compression deformation value is greater than 12 mm/m.

Secondly, according to the mine staff, the earth-rock dam was washed away during the flood season in July 2021. During the investigation, it was found that the damaged dam still had obvious vertical mining deformation cracks (see Figure 32), and the crack width exceeded 30 mm. According to the calculation results of surface movement and deformation, the maximum horizontal deformation value of the surface here exceeds 12 mm/m. During the investigation, it was also found that the sluice in the upper reaches of the Shicong River has been closed, and the water flow in the river bed has decreased. A bedrock outcrop was found in the riverbed above, and there were obvious cracks in the outcrop, and water flowed into the cracks. The reliability of the calculation of surface movement and deformation is verified by comparing and analyzing the results of the above-mentioned on-site investigation of surface cracks and the calculation results

Figure 29. Crack in the bridge deck of the highway bridge.

Figure 30. Extrusion crack at the bridge head on the south side of the 7th highway bridge.

Figure 31. Extrusion cracks at the bridge the south side of the 8th Highway bridge.

Figure 32. Cracks in the remaining dam head on the body of Shigong River.

of surface movement and deformation. In addition, relatively obvious mining deformation cracks were also found in the road near the surface of the goaf of the 12071 working face (see **Figure 33**).

Figure 33. Road pavement affected by mining cracks.

To sum up, the surface movement and deformation damage caused by the mining of the 12071 working face is relatively serious [6]-[13]. The surface movement and deformation results calculated according to the second scheme show that the degree and scope of the surface deformation and damage will further increase after all the mining of the working face in the future.

7. Impact Assessment of Working Face Recovery and Water Filling and Comprehensive Water Control Measures

7.1. Evaluation of the Influence of Surface River Water on the Mining and Filling of the Working Face

7.1.1. The Main Factors Restricting the Surface Rivers to Fill the Working Face with Water

1) Filling water source

a) Surface river water: The precipitation in this area is mostly concentrated in July to September. At this time, the mine water inflow is generally 1 to 2 times larger than usual, indicating that atmospheric precipitation has a direct impact on the mine water filling. On March 29, 2021, the Dengfeng Municipal Water Resources Bureau issued Dengshuizi [2021] No.53 to approve the abandonment of the Xi Liubei Reservoir [6]. The sections that the river passes through are mostly Quaternary loess and sand and mudstone of the Upper Shihezi Formation, with weak water permeability, but the sand-gravel skylight in the northwest corner and the open pit in the northeast have extremely strong water permeability. 21 Near the coal seam outcrop and the Shicong River, where the water-conducting fracture zone connects to the surface, the precipitation and flood during the wet season will fill the well with water through the water-conducting fracture zone.

b) River bed aquifer: widely distributed on the surface and in river valleys, mainly the lower sand and gravel layer. There are still gravel skylights on the Shicong River and its two sides in the northwest corner of the well field. Water richness is extremely uneven. It mainly receives precipitation recharge, and its water level and water volume vary greatly with the seasons. Under normal circumstances, the sand and gravel water has little effect on the mining of the No. 1 coal seam, because the thick sand and mudstone of the Upper Shihezi Formation can be regarded as a good water barrier. However, in and near the sand and gravel skylights and coal seam outcrops, it can infiltrate or infiltrate downhole directly or through fissures and fissures.

2) Water filling channel

The water-conducting fracture zone is one of the main water-conducting channels for mine water inrush. If the height of the water-conducting fracture zone reaches the aquifer (or river bed), it will cause a sharp increase in mine water inflow. According to part 4: The development height of the water-conducting fracture zone caused by the mining of the working face in the river area is 100 - 140 m, and the buried depth of the local area is 118 - 132 m greater than that of the working face of the river channel. The water-conducting fracture zone caused by the mining of the working face will directly develop to the river bed. At the bottom, a water-filled channel for the working surface is formed. Based on this analysis, it is believed that the water in the aquifer above the roof of the Er1 coal seam in the mine field may directly enter the mine along the water conducting fracture zone, which will increase the mine water inflow. Both atmospheric precipitation and surface water may enter the mine directly along the water-conducting fracture zone. Therefore, in mine production, roof management and underground hydrological monitoring should be strengthened.

3) Characteristics of coal seams and overlying strata

According to the production geological report of Xingyun Coal Industry and drilling cores, it can be seen that the 21 coal seam occurs at the bottom of the Shanxi Formation, which is the main mineable coal seam in the area, with a coal thickness of 0.20 - 15.96 m and an average of 5.29 m. The roof of the coal seam is dominated by the sliding structural fracture zone, which is mostly mixed sandstone, sandy mudstone and mudstone, and local fault breccia and fault gouge. The roof is very broken, weak in strength, and difficult to maintain and manage. And the direct roof aquifer of No.1 coal seam is composed of Dazhan sandstone and fragrant charcoal sandstone [2]-[10]. According to the calculation of the water-conducting fracture zone, the confined water of the sandstone fissures on the roof of the No.1 coal seam can enter the mine through the water-conducting fracture zone and become the direct water-filling water source for mine water-filling.

4) Faults and collapse columns

a) There are 2 faults with a drop greater than 60 m in the mining area: F1 and F2. Among them, the Shiconghe normal fault (F2) is located in Xiliubei Village, with an extension length of more than 2 km, strikes N66˚E, dips N24˚W, and dips 68˚. It is far away and has no impact on coal mining under the river.

b) Falling column: According to the production geological report of Xingyun Coal Industry, there is no falling column in the mining area.

7.1.2. Comprehensive Evaluation of Surface River Water for Mining Safety of Working Face

According to the information provided by the mine, the Shigong River is a seasonal river. Affected by the "7.20" heavy precipitation disaster and the flood discharge of the upstream Zhifang Reservoir and Chaoyanggou Reservoir during the flood season, the flow of the river has increased., the underground water inflow has increased from 10 m^3/h before the flood season to 75 m^3/h. of the characteristics of the overlying strata, the variation of the leakage of the drilling flushing fluid, and the theoretically calculated height and the measured height of the water-conducting fracture zone, it is concluded that the damage of the overlying stratum caused by the mining of the working face is more serious, and the water-conducting fracture zone is more likely to develop to the river bed. At the bottom, the surface river water poses a water-filled threat to the mining face. For coal mining under rivers, certain measures must be taken to prevent the river water from penetrating into the well through the cracks in the damaged rock formations. Its main basis is as follows:

1) Influence of water-conducting fracture zone on water-filling of working face

Water-conducting fracture zones are formed inside the overlying rock. When the water-conducting fracture zones develop to the bottom of the river bed, the river water will collapse into the well through the mining fractures. According to the theoretical calculation of the height of the water-conducting fracture zone in part 4 the height of the water-conducting fracture zone caused by the mining of the working face in the channel area is within the range of 100 - 140 m, and the height of the water-conducting fracture zone in the local area has exceeded the minimum burial depth of the coal seam in the channel working face. It is proved that the overlying rock is affected by mining, and the water-conducting fracture zone will develop directly to the surface or the bottom of the river bed in local areas. Combined with the data on the loss of flushing fluid in the 2# borehole and the TV measured data in the 1# and 2# boreholes, the results show that the overlying fracture zones above the working face are densely distributed, the calculations match.

In order to understand the damage of rock formations affected by mining in 12 mining areas. According to the "Dengfeng Xingyun Coal Industry Co., Ltd. CAN-type Magnetotelluric Geophysical Prospecting Report" in the 12 mining areas, there are 8 exploration lines: L, M, N, O, P, Q, R and S lines. Among them, the L survey line has one structural fracture surface and shows the phenomenon of multiple structural fractures; some areas on the L, M, N, O, P, and S lines are obviously affected by mining; L, M, N, O, There are four survey lines, and there is an anomaly of weak and rich water in the goaf in the southwest of the exploration area. The geophysical prospecting results of mining area 12 show that the rock stratum above the working face affected by mining is damaged, and water-conducting fracture zones are easily formed, which is consistent with the measured results of the water-conducting fracture zones. In addition, the buried depth of the working face under the river is 118 - 132 m, and the maximum drop between the borehole and the river water surface is 13.3 m, and the water-conducting fracture zone is more likely to develop to the river bed, so the river water poses a certain threat to the safe mining of the working face.

2) Influence of overburden stratum characteristics on water filling of working face

Working face of the mining area is a low mountain and hilly area, and the overlying rock layers are Permian and Quaternary. The Quaternary system is widely distributed in the working face, and there are sand and gravel skylights in the Shicong River and its two sides. Surface water can infiltrate or infiltrate into the well directly or through fissures in the sand and gravel skylights and coal seam outcrops and their vicinity. According to the 13005 borehole histogram and the coal mine production geological report, it is found that there is only one layer of aquifer in the overlying rock above the working face [9]. In addition, the roof of the coal seam is dominated by the sliding structural fracture zone, which is mostly mixed sandstone, sandy mudstone and mudstone, and local breccia and fault gouge. The strength of the overlying rock is weak and prone to cracks.

7.1.3. Evaluation of the Impact of Other Water Bodies on the Mining and Filling of the Working Face

1) Groundwater

a) Fissure diving in bedrock weathering zone

The lithology of the aquifer varies from place to place, and the thickness of the weathered zone is affected by the topographic relief, and the depth is generally 10 to 50 m. In the shallow buried section of the coal seam, when the water-conducting fracture zone generated by the coal seam mining and falling roof communicates with the aquifer, the deposit is filled with water.

b) 21 Coal seam roof sandstone and fractured pore confined water aquifer in the fractured zone of sliding structure

Since the aquifer is the direct roof of the Er 1 coal seam, the roof caving zone and its failure fissures are combined with the sliding structural fissure zone after excavation to communicate with the overlying clastic rock aquifer, resulting in water inrush. The distribution and development intensity of water inrush channels are related to the lithology of the overlying strata, the development and distribution of sliding structural fissures and mining fissures. In mine production, water is mostly filled into the pit in the form of seepage and drenching, and the amount of water is small, which is easy to drain during production.

c) Confined water in limestone karst fissures in the upper Carboniferous Taiyuan Formation

7-8 limestone in the upper Taiyuan Formation is dense and hard, with well-developed karst caves and fissures, with an average thickness of 9.52 m, medium water-rich, uneven, and small static reserves. The average thickness of the effective water-retaining layer of the second 1 coal seam floor is 9.89 m, which is less than the thickness of the mining failure, and it is easy to intrude water into the well. Especially under the action of the fault structure, when it is hydraulically connected with the lower strong aquifer, the water inrush will increase accordingly.

d) Confined water in limestone karst fissures in the lower Carboniferous Taiyuan Formation

1-4 limestone in the lower section of the Taiyuan Formation is dense and hard, with well-developed karst caves and fissures, strong water-richness and medium static reserves. The coal seam floor is indirectly filled with water source. The sand-mudstone section in the middle of Taiyuan Formation is 23.27 - 36.12 m thick, with an average thickness of 29.93 m. Under normal circumstances, the water from this aquifer cannot enter the Er 1 coal seam deposit, but if it encounters faults and other structures, it is often associated with the lower Cambrian Ordovician ash. At the same time, the rock water intrudes into the mine through the L7-8 limestone aquifer, threatening the safety of the mine.

e) Confined water in karst fissures of Cambrian Ordovician limestone

The Cambrian Ordovician limestone has huge thickness, developed karst fissures, strong water content and huge static reserves. It is 64.54 m away from the 2-1 coal seam, which is the indirect water-filled aquifer of the 2-1 coal seam, and the direct water-filled aquifer on the floor of the 1-2 and 1-3 coal seams. Under normal circumstances, there is little threat to the mining of the second 1coal seam, but the threat to the mining of the one 1 and one 3 coal seams is relatively large.

The Cambrian Ordovician limestone on the southern side of the southern boundary fault F2 is connected with the L7+8 and L1-4 limestones in the well field, which can directly fill the well with water.

2) Old kiln, old empty water

There are many old kilns in the north, east and south of the minefield and the goafs where the mines were produced before integration. Most of the mining scope, stoppage time, and reasons for stoppage are unknown. According to the geological report of Xingyun Coal Industry, in 2021, the results of geophysical exploration in August showed that a total of 5 abnormal areas with weak water and rich water were found in the mining area [6]. Coal mines should earnestly implement the technical measures for water safety prevention and control of "prediction and forecasting, exploration in doubt, first exploration and then excavation, first treatment and then mining". Therefore, when the excavation is approaching, the drilling should be drilled in advance, and effective measures should be taken to avoid water inrush accidents from old empty water.

3) Accumulation of water in the subsidence area

The coal seam in the area is thick, and the damage to the roof of the coal seam is more serious. The abandoned shafts and roadways of the production mines fall and collapse to form fracture and fracture zones, and subsidence depressions and ground fissures are formed on the surface. The fissures and ground fissures fill the pit with water. Therefore, in the subsidence area, the subsidence and ground fissures should be backfilled in time, and flood drainage channels or other anti-drainage infrastructure should be excavated to avoid flooding and flooding and other accidents.

7.2. Comprehensive Waterproof Measures for Coal Mining under River

Working face conditions and research conclusions of Xingyun Coal Industry in Dengfeng City, the following water control measures are proposed:

1) Dredging down the water level of the overlying rock aquifer

When mining coal under water, sometimes the water is very close to the coal seam, and it is impossible to adopt the method of setting waterproof coal pillars and changing mining measures for mining. The methods of dredging water include borehole dredging, roadway dredging, combined dredging, mining dredging and joint dredging of multi-mine subregional drainage.

a) Drilling dredging and roadway dredging is to directly pump and drain the water in the aquifer through the drilled hole and the roadway, so that the aquifer is dredged or the water level is lowered, and then the mining is carried out.

b) Combined dredging is based on the geological mining conditions and the characteristics of aquifers, using roadways and boreholes to jointly dredging water bodies. Specifically, the drainage tunnels and stone gates are first excavated, and then holes are drilled in them to discharge water through the aquifer for evacuation.

c) Recovery and dredging is to mine the working faces far away from the aquifer, so that the aquifer water slowly flows out through the mining influence of these working faces, so as to reduce the water level of the aquifer and achieve the purpose of dredging. The recovery dredging is suitable for weak aquifers and aquifers with limited recharge sources.

d) Combined drainage of multiple mines is based on the characteristics of groundwater connectivity, and the combined drainage of multiple mines is used to achieve the purpose of rapid drainage.

2) Treatment of surface water bodies

Treatment of surface water is to treat surface water by hydrogeological and engineering geological methods before recovery. According to the theoretical calculation and actual measurement results of the height of the "two belts" of the overlying rock, this time, if the coal is directly mined under the river, there will be a greater safety hazard. Therefore, according to the geographical location of the working face of Xingyun Coal Industry in Dengfeng City, this project proposes to lay plastic pipes in the river channel which will be represented in **Figure 34** below, so that the river water flowing over the working face can be discharged through the pipe instead of flowing above the working face, so as to cut off the The source of river water supply to achieve the purpose of safe mining. When this measure is implemented, it is recommended that coal mines cooperate with relevant departments such as meteorology and water conservancy to obtain early warning information of rainfall, flood discharge time, water volume and other disaster warning information in a timely manner. Determine the diameter and quantity of the laying plastic pipes and the strength of the pipes to ensure that the drainage pipes can meet the drainage requirements.

3) Block the water channel

Figure 34. Laying plastic pipes.

a) Block surface cracks. According to the calculation and analysis of surface mobile deformation cracks in Figure 35 of this report, it can be seen that after the mining face is mined, the surface cracks in the local area of the riverbed will communicate with the water-conducting fracture zone, forming a water-filled channel and threatening the safe production of the working face. Therefore, it is recommended that coal mines organize a special team for inspection of surface deformation cracks, formulate a strict inspection system, conduct regular inspection and monitoring of surface cracks in the riverbed during the mining of the working face, and timely seal the surface cracks in the riverbed. Cement, clay and other materials are injected into the surface cracks to block the channel of groundwater supply. This method is suitable for the situation where cracks have appeared on the surface and the surface water supply is small. According to the on-site geological conditions of the river where the working face of Xingyun Coal Industry in Dengfeng City is located, the bedrock is exposed in the river bed, and the river water seeps through the cracks in the outcrop rock, so cement mortar can be used to seal the cracks.

b) Drill holes that are poorly sealed, and drill holes that are close to unsealed or unqualified holes, and should be detected. At the same time, it is necessary to adhere to the principles of "exploration when in doubt" and "exploration first and then excavation" to carry out mining work. During the excavation process, if abnormal water effluent occurs, the working face should stop production. In addition to intensifying the water volume and water level observation, water samples should be taken for water quality analysis, comprehensive analysis to correctly determine the water source and channel of the effluent, and necessary measures should be taken. Production can be resumed only after the amount of water is reduced.

4) Measures for underground water control

a) Establish a complete drainage system for the working face, including temporary water silo, drainage pump or submersible pump and drainage pipeline, the drainage capacity of which is not less than 100 m^3/h, and equipped with spare and maintenance pumps to ensure that water is produced during the mining process of the working face with timely and effective excretion. Establish complete water quantity monitoring and monitoring measures, as well as analysis and testing of water quality change characteristics, so as to more accurately determine the water source.

Figure 35. On-site cracks.

b) Establish a reliable disaster avoidance route. There should be steps and lighting equipment when passing inclined lanes, and there should be signs for ascending wells at turning points and intersections. Before mining, conduct safety education for coal mining under water and conduct underground disaster avoidance drills. The mine must have a complete communication system, and report problems to the relevant departments in a timely manner so that measures can be taken to deal with them in a timely manner. Strengthen the liaison with the local meteorological, water conservancy and emergency rescue management departments, and grasp the disaster warning information such as rainfall and flood discharge. Stop production and withdraw people in time to ensure the safety of people's lives and property.

5) Other preventive measures

a) Since the thickness of coal seam in the 12 mining area varies greatly, in the production process, it is necessary to further strengthen the detection of coal seam thickness in order to study the variation law of coal thickness in the mining area and working face. Appropriately limit the thickness of coal caving, reduce the damage to the overlying rock, and ensure the safe production of the mine.

b) During the mining period of the working face, the changes, monitoring and monitoring of the underground water quantity, water quality, ground subsidence and river water quantity are carried out in real time. It is recommended to mine in the dry season and dry season when the river water volume is small to reduce the difficulty and cost of ground treatment. If there are large surface cracks on the surface, it should be backfilled and compacted with clay in time. Take relevant technical measures according to the actual situation, such as necessary grouting reinforcement, water drainage measures, etc. According to the aforementioned research, the mining of the working face will further increase the subsidence of the surface at the riverbed, and the low-lying level of this place will further increase, and it is easy to form stagnant puddles, which influences the safety of underground workers. Therefore, it is recommended that coal mines regularly control the river during the mining process of the working face, especially before the rainy season, to avoid the accumulation of water caused by large-scale subsidence pits, and to completely eliminate the potential safety hazards caused by the accumulation of water.

8. Conclusions and Recommendations

8.1. Conclusions

The project adopts the research methods of theoretical calculation analysis, field measurement and engineering analogy, etc., to demonstrate and study the development law of the water-conducting fracture zone in the overlying rock and the coal mining safety of the subsurface river in the working face of Xingyun Coal Industry. The following main conclusions are drawn as follows:

1) According to the geological mining conditions of the Xingyun coal working face, the influencing factors of the development law of the overlying rock water-conducting fracture zone caused by mining and the development height of the overlying rock caving zone and the fracture zone are analyzed [2]. Through the analysis and evaluation of the lithology of the overlying strata on the working face, according to the provisions of the "Code for the Retention and Mining of Coal Columns in Buildings, Water, Railways and Main Roadways", the calculation results of the overburden caving at the working face of Xingyun Coal Industry The line map of the belt height and the height of the water-conducting fracture zone determines the development height of the water-conducting fracture zone on the working face in the channel area.

2) According to the geological mining conditions of the mine working face and the mining situation of the underground working face, an on-site observation case of the development height of the water-conducting fracture zone in the working face mining is proposed, and the drilling water leakage method is adopted to conduct the mining of the working face of Xingyun Coal Industry [5]. Field measurement study of fracture zone development height. Two drilling holes were constructed on site, and the maximum height of the water-conducting fracture zone at this location was 114 - 116 m.

3) Using the 2 drilling holes constructed on site, the drilling video method was used to observe the damage of the overlying rock under the mining effect of the working face, and the cracks and damage images of the hole wall of the drilling holes were obtained, and the detection results were sorted out. The analysis shows that the development height of the water-conducting fracture zone is 115.7 m, which further confirms the development height of the water-conducting fracture zone in the working face.

4) Calculate and analyze the surface movement deformation and surface cracks caused by the mining of Xingyun Coal Industry working face. According to the movement law and parameters of the mining strata and the surface in this area, the deformation value of the surface movement caused by the mining of the working face is calculated and analyzed, the development characteristics of the surface cracks are analyzed, and the safety of coal mining under the river is analyzed and demonstrated. The research results show that the water-conducting fracture zone of the overlying rock in the mining area will develop to the surface locally and connect with the surface fracture to form a water-filled channel, which threatens the safety of underground production. Therefore, it is necessary

to take effective technical measures for up and down well safety.

5) The safety technical measures for underground and underground coal mining in Xingyun Coal Industry are put forward. According to the results of the safety demonstration of coal mining under rivers, coal mining under rivers has great potential safety hazards, so it is proposed to take measures to intercept the flow within the influence scope of mining at the working face, and lay water pipelines in the river channels to prevent water from flowing in the river channels and improve the Cement mortar is used to block the surface cracks. At the same time, the coal mine should further strengthen the hydrogeological work, and take measures to prevent and control water in the well, so as to completely eliminate the hidden safety hazard of surface river water to coal mining in the underground working face [1]-[13].

8.2. Recommendations

1) It is recommended that coal mines organize the establishment of a special inspection team for surface deformation cracks, formulate a strict inspection system, conduct regular inspection and monitoring of surface cracks in the riverbed during the mining of the working face, and timely seal the surface cracks in the riverbed. Block groundwater recharge channels.

2) It is suggested that coal mines should combine with relevant departments such as meteorology and water conservancy to grasp the disaster warning information such as rainfall and flood discharge time and water volume in a timely manner, and determine the laying of drainage according to factors such as the flow velocity of the river, the width of the river, the flow of the river and the surface subsidence. The diameter, quantity and strength of the pipes to ensure that the drainage pipes can meet the drainage requirements.

3) It is recommended that coal mines strengthen the observation of surface subsidence and river management during mining. The subsidence in the riverbed is closely monitored, and the river channel should be regularly treated during the mining process of the working face, especially before the rainy season, to avoid the accumulation of water caused by large-scale subsidence pits, and to relieve the potential safety hazards caused by the accumulation of water.

4) It is recommended that coal mines formulate strict emergency rescue plans for water disasters, and organize coal mine staff to conduct study and drills. The mine must have a complete communication system, so that measures can be taken in time to deal with it.

5) It is recommended that coal mines strengthen contact with local meteorological, water conservancy and emergency rescue management departments, and grasp early warning information of disasters such as rainfall and flood discharge. Under such circumstances, the coal mine should stop production and withdraw people in time to ensure the safety of people's lives and property.

6) It is recommended that the coal mine further strengthen the hydrogeological work. In this study, the height of the water-conducting fracture zone in coal

mines is mainly studied by the methods of drilling and empirical formula calculation, and there are many factors affecting the development of water-conducting fracture zones. Therefore, the coal mine should further strengthen the hydrogeological work, and report the problems to the higher authorities in time., mining activities under the Shicong River can only be carried out after the approval of the superior department.

Author Contributions

Abdoulaye Sylla: Conceptualization, methodology, formal analysis, writing, original draft preparation, Sites inspection, editing of the paper.

Pr. Guo Wenbing: review and funding acquisition.

Dr Aboubacar Soumah helped with the laboratory experiments and Drowning.

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Conflicts of Interest

The authors declare that there are no conflicts of interest.

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