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A method for determining the overburden failure height of coal mining based on the change of drilling speed and the leakage of sectional water injection in underground upward bolehole

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Abstract. A coal mine in Xinjiang was taken as research site in this paper, it is proposed to determine the overburden failure height based on both the drilling speed of upward bolehole and sectional water injection methods. The results show that the overburden failure height of borehole CH01 is 44.80m based on the drilling speed and 44.32m based on the sectional water injection method respectively, with the difference 0.48m; also the results of borehole CH02 is 42.58m and 40.59m respectively, with the difference 1.99m.The overburden failure height determined based on the drilling speed is basically the same as the results aquired by the sectional water injection method. The latter validates the former's accuracy. So the overburden failure height of mining based on the drilling speed in underground upward borehole has good accuracy, also the height of caving zone can be aquired by this method. Both of the methods verified each other, and provides a new way for field measurement of overburden failure height in coal mines.

Keywords: component; drilling speed; sectional water injection; overburden failure; field measurement

1. Introduction

When the coal seam was extracted, the roof strata breaks and loses stability, forming mining cracks. The development range of mining cracks that are vertically connected and have water conductivity is called the water flowing fractured zone. The vertical height of the water flowing fractured zone is also called overburden failure height [1]. The original water impermeability of the rock stratum within the water flowing fractured zone changes, and the mining cracks become the channel for water inrush from aquifer to the mining space. Accurate determination of the height of water flowing fractured zone is of great significance for roof water disaster control, mining parameter optimization and water conservation mining[2]. Domestic scholars have made fruitful achievements in the research on the determination method of the height of the water flowing fractured zone. According to different research methods, it can be divided into theoretical prediction, simulation analysis and field measurement, and field measurement is the most direct and reliable method to obtain the height of the water flowing fractured zone[3]. According to the different ways of measurement and research, it can be divided into geophysical exploration[4] and borehole measurement. Ground borehole measurement is widely used in major mining areas because of its mature method and intuitive and reliable data acquisition[5-7]. Relevant scholars also explored various theoretical prediction methods of overburden failure height under different mining thickness and mining depth through measured data and theoretical analysis[8-11]. Other scholars have monitored and analyzed the occurrence and development process of overburden failure through modern means and studied the visualization of fracture development morphology[12-14]. However, as the mining depth of coal mines in China increases year by year, the quantities of ground survey boreholes increase correspondingly, and the engineering cost increases significantly. At the same time, when mining under large surface water bodies, the quantities of ground survey boreholes are also limited. Some scholars try to detect the development range of overburden failure by underground boreholes with upward borehole, and determine the vertex position of water flowing

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fractured zone by sectional water injection in the hole, which provides a new way for measuring the height of water flowing fractured zone[15-16].

At present, the method to detect overburden failure height in underground upward borehole is to block the borehole by sections and inject water through the double end water plugging device with its own inflatable capsule. Because the consumption of the hole wall in the fracture development section increases, the apex of the water flowing fractured zone can be determined. When the author measured the height of the water flowing fractured zone underground through the double ended water plugging device, it was found that due to the collapse of the roof rock layer and the disordered accumulation of rock blocks after fracture, the irregular development of fractures and the poor integrity of the hole wall, the double ended water plugging device is easy to get stuck when passing through the hole section with relatively developed fractures, and the observation of deep hole data is difficult.

During the underground upward borehole drilling, generally speaking, with the same drilling tools and feed pressure, the harder and complete the rock stratum, the slower the drilling footage, the looser and broken the rock stratum, and the faster the drilling footage. For the underground survey boreholes in the "water flowing fractured zone", the drilling trajectory is usually "complete rock stratum - mining damaged rock stratum - complete rock stratum". Due to the development of mining damaged rock stratum cracks and poor rock stratum integrity, when drilling, it generally shows abnormal conditions such as fast footage, small water return or even complete leakage, skip drilling, idling, etc. based on the above analysis, the above characteristics can be combined to determine the height of overburden failure.

The author proposes a method to comprehensively determine the overburden failure height of mining based on drilling speed and sectional water injection in underground upward borehole. The results aquired by sectional water injection method verifies the analysis results based on drilling speed, and provides a new idea for predicting the overburden failure height of mining.

2. Implementation site and survey boreholes

The research site of this paper is a coal mine in Xinjiang,which located in Hutubi County, Urumqi City, and the Jurassic B42 coal seam was mined. In order to obtain the height of water flowing fractured zone for the B42 coal seam, three upward observation boreholes are implemented in workface 141. Being the first mining face in the mine， the 141 workface is located in the upper west wing of No. 1 mining area，B42 coal seam. The dip angle of B42 coal seam is 12° - 15°, and the average thickness is 3.13 m. The strike longwall comprehensive mechanized coal mining method is adopted in 141 workface, and the roof is managed by fully caving methods. The strike length of 141 workface is 1138 m, and the dip length is 159.5 m。

In order to detect the maximum value of overburden failure height as far as possible, the borehole design principle is:

(1) To ensure the observation quality and facilitate the construction, the opening positions of the three observation boreholes should be arranged in the air return roadway of 143 workface, the drilling trajectory should be in the area where the overburden failure is fully developed, and the final hole positions should fall within the mining influence range of 141 workface;

(2) Three observation boreholes should be on a profile perpendicular to the strike direction of 141 workface. The azimuth angles of the three boreholes are the same, and the dip angles are different, which can reflect a complete development pattern of mining fractures, and strive to control the highest point of mining fractures.The borehole parameters are shown in Table 1. The borehole inclination profile is shown in Fig. 1.

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Table 1. Borehole parameters of the overburden failure height surveying for B42 coal seam

Borehole name	Azimuth(°)	Dip angle(°)	Depth(m)
CH01	184	72	96.9
CH02		63	100.8
CH03		38	66

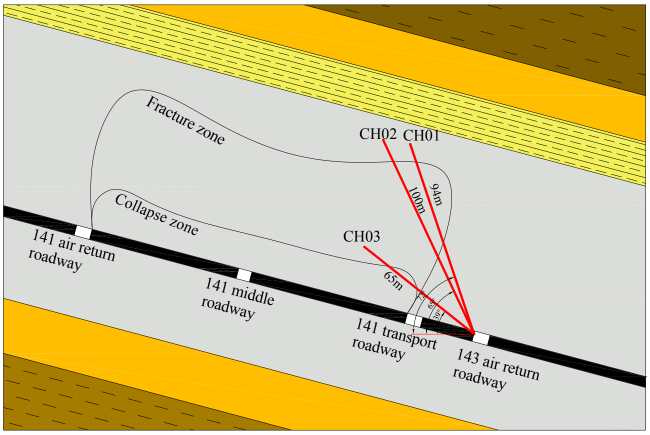

Figure 1. Profile of underground observation boreholes in workface 141

Referring to the nearby geological boreholes, the lithology of B42 coal seam roof within the range of drilling vertical height (about 82m) was determined and analyzed through the collection of rock slag produced during drilling, also the backwater condition, drilling speed and other data exposed by three boreholes were taken into consideration. The lithology of B42 coal seam roof at the drilling site was mainly sandstone rock strata, and thin sandstone with different particle sizes was deposited alternately, as shown in Table 2.

Table 2. Borehole columnar of B42 coal seam roof

Lithology	Thickness(m)	Cumulative height(m)
Siltstone	3.2	3.2
Coarse sandstone	1.9	5.1
Siltstone	1.6	6.7
Mudstone	2.5	9.2
Siltstone	4.4	13.6.
Gravelly coarse sandstone	20.1	33.7
Carbonaceous mudstone	1.1	34.8
Pelitic siltstone	6.7	41.5
Coarse sandstone	9.0	50.5
Silty mudstone	2.1	52.6
Siltstone	6.8	59.4
Coarse sandstone	4.9	64.3
Fine sandstone	3.8	68.1
Coarse sandstone	4.0	72.1
Fine sandstone	2.7	74.8
Medium sandstone	2.1	76.9
Siltstone	3.7	80.6
Fine sandstone	1.5	82.0

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3. Analysis of overburden failure height based on drilling speed

3.1 Analysis of borehole CH01

The borehole CH01 is designed to detect the damage height of overburden, and there are no phenomena of no return of water, sticking, skipping and empty area during drilling. Figure 2 shows the drilling speed change curve of borehole CH01.

At the initial stage of drilling in Borehole CH01 (depth 0 ~ 17.4m), the drilling return water is normal, the water volume is stable, the drilling speed is basically within 0.15m/min, the drilling in local hard coarse sandstone section is slow, and the drilling footage is fast at the depth of 8.4m ~ 9.9m. The drilling slag core is identified as a mudstone layer with low hardness, and it is determined that the depth of 0 ~ 17.4m is a complete rock layer; At the depth of 17.4 ~ 53.4m, the drilling water return was not interrupted, but the water return was significantly reduced. The analysis shows that the rock stratum in this section was significantly damaged by mining, and the mining cracks changed the original integrity of the rock stratum and increased the permeability of the rock stratum. After the drilling revealed the mining cracks, the water return was reduced due to the leakage consumption of the mining cracks, and the drilling speed in this section was between 0.078 ~ 0.233m/min, The lithology is judged as siltstone and coarse sandstone with high hardness, which further indicates that the integrity of the rock stratum is poor, and the water flowing fractured zone has been exposed in the borehole; At the depth of 53.4 ~ 96.9m, the drilling return water increased slightly, and then the return water has been relatively stable, but the drilling speed has decreased significantly, and the drilling speed of this section has returned to within 0.15m/min. The lithology judgment is mostly siltstone and medium and coarse sandstone. It is inferred that this section has passed through the mining fracture development area and entered the complete rock stratum.

The dip angle of borehole CH01 is 72 °. According to the analysis and calculation of drilling speed and abnormal drilling conditions, the overburden failure height of B42 coal seam observed by borehole CH01 is 44.79m.

3.2 Analysis of borehole CH02

The borehole CH02 is designed to detect the fractured zone of overburden. During the drilling of borehole CH02, there was no circulation fluid loss, sticking, skipping and empty area. Figure 3 shows the drilling speed change curve of hole CH02.

At the initial stage of CH02 drilling (depth 0 ~ 21.3m), the drilling return water is normal, the water volume is stable, and the drilling speed is basically within 0.3m/min. Therefore, it is determined that the rock stratum is complete between 0 ~ 21.3m. At the depth of 21 ~ 57.3m, the footage is fast. Although the drilling return water has not been interrupted, the return water has been significantly reduced, and has been significantly affected by mining destruction. The drilling speed of this section is between 0.094 ~ 0.5m/min. The lithology is judged as siltstone and coarse sandstone with high hardness, and the integrity of the rock stratum is poor. The borehole has exposed the water flowing fractured zone; In the section with depth of 57.3 ~ 100.8m, the drilling return water increased slightly, and then the return water has been relatively stable, but the drilling speed decreased significantly, and the drilling speed of this section returned to within 0.3m/min. The lithology judgment is mostly siltstone and medium and coarse sandstone. It is inferred that this section has passed through the mining fracture development area and entered the complete rock section.

The inclination of borehole CH02 is 63 °. According to the analysis and calculation of drilling speed and abnormal drilling conditions, the overburden failure height of B42 coal seam observed in Borehole CH02 is 42.58m.

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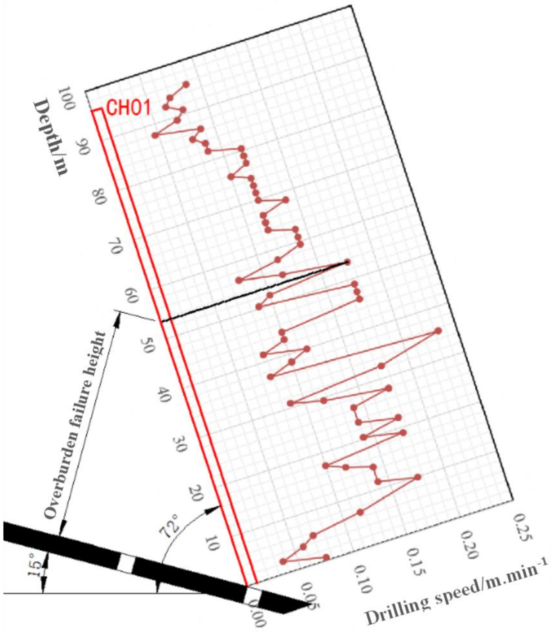

Figure 2. Drilling speed of borehole CH01

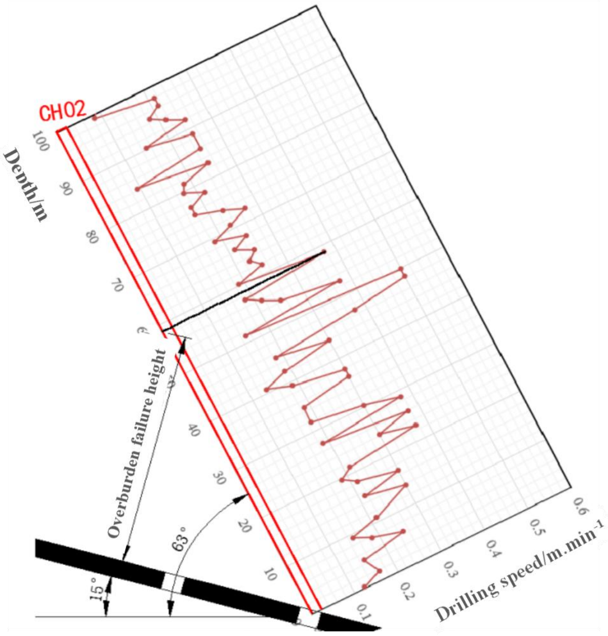

Figure 3. Drilling speed of borehole CH02

3.3 Analysis of borehole CH03

The borehole CH03 is designed to detect the height of the collapse zone. During drilling, there were many phenomena such as water return interruption, non drilling, skip drilling and empty area. Figure 4 shows the drilling speed change curve of borehole CH03.

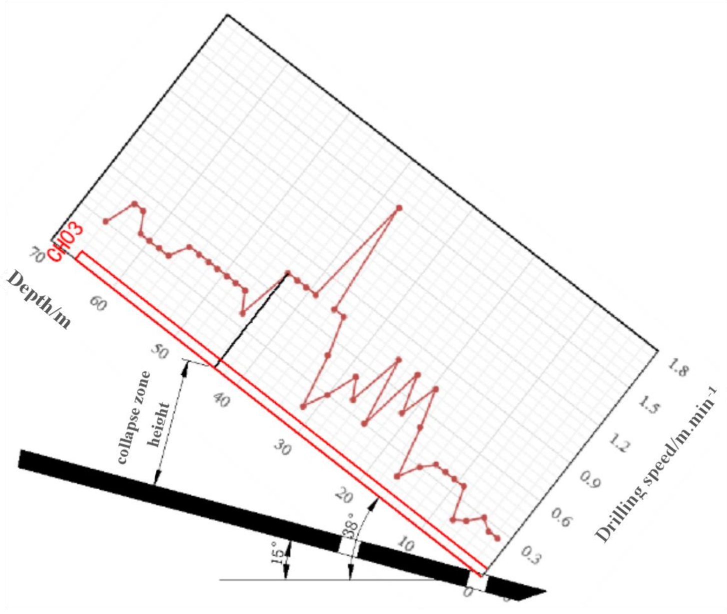

Figure 4. Drilling speed of borehole CH03

At the initial stage of drilling of CH03 borehole (depth 0 ~ 16.5m), the drilling return water is normal, the water volume is stable, and the drilling speed is basically within 0.4m/min. Therefore, it is determined that the depth 0 ~ 16.5m is a complete rock stratum; At the depth of 16.5 ~ 19.5m, although the drilling return water has not been interrupted, the return water has decreased significantly. The analysis shows that the rock stratum in this section has been significantly affected by mining destruction. The drilling speed in this section is between 0.3 ~ 0.5m/min, and the lithology is judged as siltstone and coarse sandstone, which further indicates that the integrity of the rock stratum is poor, and the water flowing fractured zone has been exposed in the borehole; After drilling to the depth of 19.5m, the backwater of the drill hole is greatly reduced, and the outlet water

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of the orifice is streamlined. After the depth of 21m, there are many intermittent backwater interruptions, and the drilling tool jumps in the empty area, indicating that the drill hole has entered the scope of the collapse zone; At the depth of 19.5 ~ 43.5m, the drilling speed sometimes fast and sometimes slow, the return water of the borehole is very unstable, sometimes large and sometimes small, and the return water at the orifice is mostly streamlined. At the depth of 28.5 ~ 30m and 37.5 ~ 40.5m, the drilling circulating fluid is completely lost, and the return water is interrupted; When drilling at the depth of 30 ~ 31.5m, the drilling time was prolonged and the average drilling speed was reduced due to the phenomenon of different drilling; After passing through the depth of 40.5m, there is a very small amount of backwater at the orifice. Between the depth of 19.5 ~ 43.5m, the drilling speed is very fast, basically between 0.5 ~ 1.5m/min. After drilling to 43.5m, the drilling speed decreases significantly, and the backwater at the orifice gradually increases until the final depth of 66m, and the drilling speed is stable at 0.3 ~ 0.5m/min. By analyzing the above phenomena, it can be determined that the 19.5 ~ 40.5m section of borehole CH03 is the collapse zone of B42 coal seam. The dip angle of borehole CH03 is 38 °, and the height of the B42 coal seam collapse zone observed is 15.82m.

4. Sectional water injection method for verification

Sectional water injection in borehole is to use drilling tools to send the double end water plugging device into the borehole to complete the observation after borehole is formed. The divice can block the hole by sections, inject water into the enclosed space, and the water injection pressure of each enclosed space is controlled by the console to be a fixed value (generally 0.1MPa). Through observation and analysis of the water injection leakage at different depths, determine whether the mining fractures are developed and damage degree. The measurement principle is shown in Figure 5. Due to the high degree of rock fragmentation within the collapse zone and the intense development of mining fractures, the underground observation instrument is prone to jam, probe fall off and other abnormalities after entering the collapse zone, and the height of the collapse zone cannot be determined by segmented water injection. Therefore, the reliability of the judgment results based on drilling speed is verified and analyzed by using the observation results of sectional water injection leakage in boreholes CH01 and CH02.

4.1 Leakage analysis of sectional water injection in borehole CH01

Figure 6 shows the change curve of sectional water injection leakage of borehole CH01. At the depth of 24.35 ~ 37.85m, the leakage of segmented water injection in the borehole is stable at 1.0 ~ 1.8 L/min. Although there is leakage consumption after water injection in the plugging section, the leakage is at a low level. It is judged that this section belongs to the development range of primary micro fractures; At the depth of 37.85 ~ 39.35m, the water injection leakage of the section suddenly increased to 9.4 L/min. Continue to observe, and the leakage is stable. At the depth of 39.35 ~ 42.35m, the water injection leakage of the drilling section reaches 11.6 ~ 12 L/min. it is determined that this section has entered the mining fracture development range of the roof of the working face; At the depth of 42.35 ~ 52.85m, the leakage of sectional water injection in the borehole gradually decreases to 3.6 L / min; At the depth of 52.85m ~ 78.35m, the water injection leakage of the borehole section is stable within 2 L / min. it is judged that this section has passed through the mining fracture development area and entered the complete rock section with primary micro fracture development.

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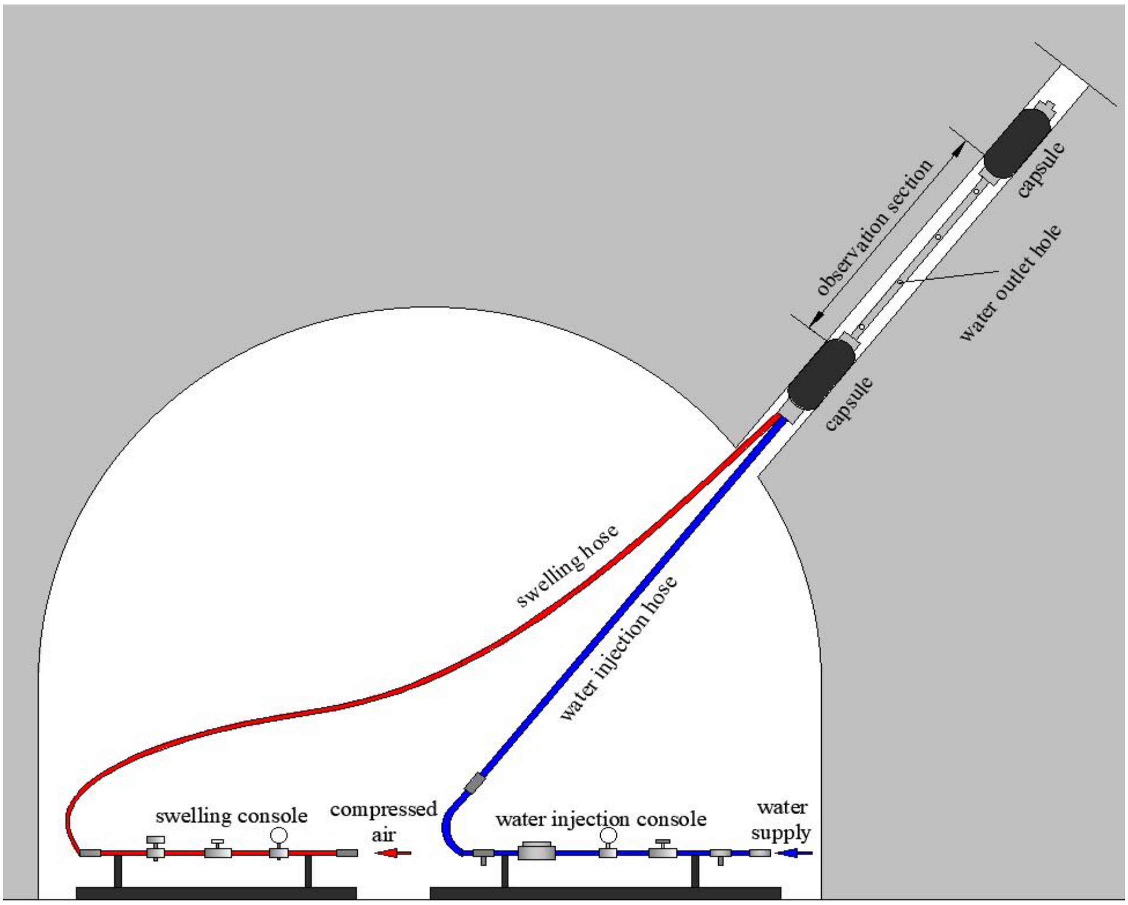

Figure 5. Schematic diagram of the double end water plugging device

According to the analysis of water injection leakage in each section, it is determined that the apex of the water flowing fractured zone of B42 coal seam exposed by Borehole CH01 is located at the depth of 52.85m, and the overburden failure height of B42 coal seam observed by Borehole CH01 is 44.32m.

4.2 Leakage analysis of sectional water injection in borehole CH02

Figure 7 shows the change curve of sectional water injection leakage of borehole CH02. At the depth of 27.35 ~ 34.85m, the leakage of segmented water injection in the borehole is stable at 0.26 ~ 1.4 L/min, and the leakage is at a low level. It is inferred that this section belongs to the development range of primary micro fractures. At the depth of 34.85 ~ 36.35m, the water injection leakage of the borehole section suddenly increased to 2.8 L/min. Continue to observe, and the leakage is stable. At the depth of 36.35 ~ 37.85m, the water injection leakage of the borehole section reaches 7 L/min, which determines that this section has entered the mining fracture development range of the roof of the working face; At the depth of 37.35 ~ 54.35m, the leakage of sectional water injection in the borehole fluctuates, but its overall trend is significantly reduced, and the leakage is basically between 1.6 ~ 4.4 L/min; At the depth of 54.35m ~ 69.35m, the sectional water injection leakage of the borehole is stable within 1.2 L/min. it is inferred that this section has passed through the mining fracture development area and entered the complete rock section with primary micro fracture development.

Judging from the sectional water injection leakage of the borehole, the apex of the water flowing fractured zone of B42 coal seam in 141 working face exposed by Borehole CH02 is located at the depth of 54.35m, and the overburden failure height of B42 coal seam observed by Borehole CH02 is 40.39m.

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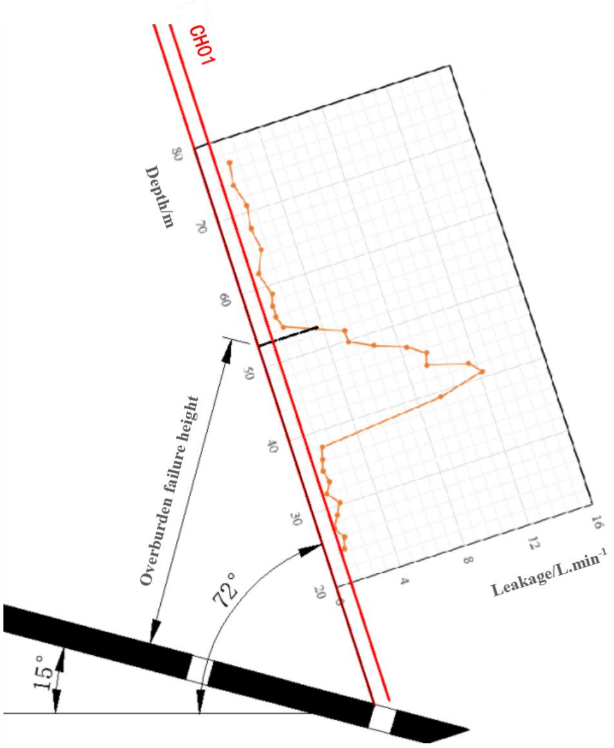

Figure 6. water leakage of borehole CH01

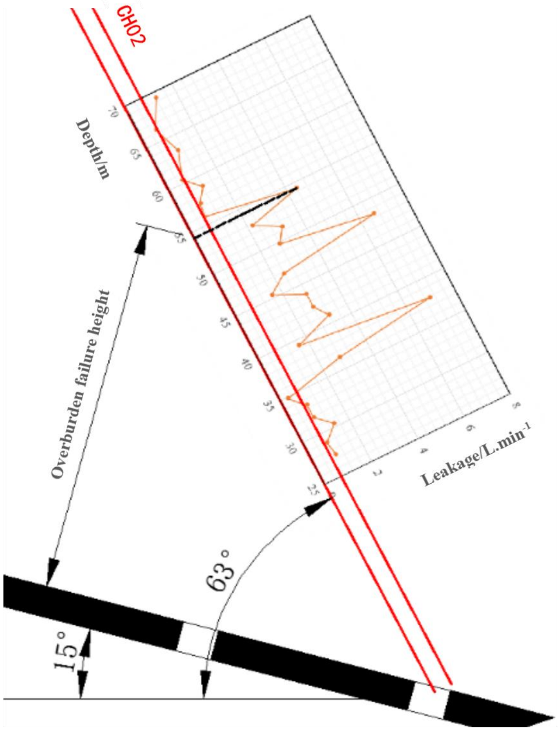

Figure 7. water leakage of borehole CH02

Based on the drilling speed and sectional water injection method, the overburden failure height of borehole CH01 is 44.8m and 44.32 respectively, with a difference of 0.48m; The overburden failure height of Borehole CH02 based on drilling speed and drilling is 42.58m and 40.59m respectively, with a difference of 1.99m, and the overburden failure height based on drilling speed is greater than that based on drilling water injection method. Therefore, it can be seen that the overburden failure height based on drilling speed has good accuracy.

5. Conclusion

In this paper, the following two conclusions were drawn:

(1) Based on the drilling speed of the upward hole and the borehole water injection method, the difference of the overburden failure height of borehole CH01 is 0.48M; Based on the drilling speed and the borehole water injection method, the difference of the overburden failure height of Borehole CH02 is 1.99m; The observation results of the two methods are close.

(2) The observation results of segmented water injection in the borehole verify the analysis results based on the drilling speed method of upward borehole, and the height of the collapse zone can be determined by analyzing the change of drilling speed. The two methods are mutually verified, which improves the accuracy of observation of water flowing fractured zone.

Acknowledgments

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