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Study on Water Disaster Prevention and Control Technology under Condition of Extra-thick Coal Seam with Slicing Full-mechanized Caving Mining

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Abstract: Some coal seams belong to cretaceous strata in the east of Inner Mongolia, China. There are obvious differences of rock characteristics and mechanical properties between Cretaceous and Carboniferous-Permian strata. The overburden failure characteristics of extra-thick coal seam with slicing full-mechanized caving mining are studied through rock mechanics experiment, field observation and theoretical analysis and so on. Water disaster prevention and control method of roof and goaf is put forward under the condition of extra-thick coal seam with slicing full-mechanized caving mining. The final research results include: (1) The rock of cretaceous strata has low strength and soft characteristic, its stability is very poor, cretaceous rock belongs to weak type; (2) Under the condition of extra-thick coal seam with slicing full-mechanized caving mining, the ratio between caving zone and mining height of field observation result is 4.58～4.74, the observation results of two boreholes are close; (3) It is significantly effective to prevent and control water disaster from goaf through roof hole drainage method, coal and rock safety pillar remain method is used to limit mining height under the Tertiary gravel aquifer, which makes the working face exploit safely.

1 Introduction

The coal mine hydrogeological condition of China is very complex and rarely seen in the word [1,2]. Loose aquifers generally exist in the flat area in north, northeast and east of China, where coal field shallow possesses the problem of mining under aquifers. Coal mines are under the threat of aquifers during exploitation process [3]. At present, safety mining technology under quaternary and ternary loose aquifers has obtained significant progress and applied in many coal mines with the deeper and more extensive research of domestic and foreign scholars [4]. However, some thick and extra-thick coal seams reserves in cretaceous strata in the east of Inner Mongolia. Mining power could make the roof strata rupture greatly and bring bad influence to safety production, when the fissure zone connects the aquifers.

The key to prevent and control water disasters is mastering the overburden failure rules and state distribution characteristics. The height of caving zone and fissure zone are the important basis of water disaster forecast and waterproof safety coal and rock pillar design [5-7]. The research on overburden failure characteristics acquires breakthrough with the rapid expansion of fully mechanized mining technology [8]. However, the previous research on overburden failure rules focuses on Carboniferous-Permian and Jurassic strata and is short of Cretaceous strata, especially for the extra-thick coal seam with slicing full-mechanized caving mining [9]. Take Duolun coal mine as an example, the height of No.7 coal seam is 15.8m, using the method of slicing full-mechanized caving mining. There are ternary loose aquifer and higher slice goaf water upon the working face of lower slice coal seam. This paper researches overburden failure characteristics of extra-thick coal seam with slicing full-mechanized caving mining through rock mechanics experiment, field observation and theoretical analysis. Water disaster prevention and control methods of roof and goaf are put forward, which provides guarantee for safety mining.

2 Mine profile

Duolun mine has the designed production capacity of 1.20Mt/a, and exploits No.7 coal seam with average thickness of 15.80m located in cretaceous strata. Coal-bearing stratum of the well field locates in a faulted synclinal basin with north-south extension, length of 6000m and width of 300～1400m. Part of No.7 coal seam suboutcrop is integrated into ternary strata and locates

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under ternary aquifer.

All of the ten working faces (1700^{-1}～1709^{-1}) of top slice No.7 coal seam has been exploited until 4/18, 2017. At parent, the mine is exploiting 1704^{-2} working face with length of 528m, width of 130m, located in lower slice of No.7 coal seam, the north of No.1 mining area. Open-off cut of 1704^{-2} working face closes to north of mine boundary, mining from north to south. Boreholes reveal the thickness of No. 7 coal seam is 5.42～15.35m and the thickness of bed rock is 55.0～74.9m in 1704^{-2} working face. The goaf waterlogged areas of 1702^{-1} and 1704^{-1} working faces and ternary aquifer have an influence on 1704^{-2} working face. According to pumping test results and “detailed rule of coal mine water control and prevention”, the tertiary gravel aquifer belongs to weak watery with unit inflow of 0.0146 ~ 0.0517 L/s·m [10].

3 Physical and mechanical properties of cretaceous rock

3.1 Rock mechanical parameter test

Rock cores are gathered from roof strata of No.7 coal seam in surface borehole and processed into standard rock samples in the rock mechanical laboratory. Rock samples can be used for uniaxial compressive strength test, apparent density test and softening coefficient test. The stress-strain curve of rock uniaxial compressive strength is shown in Figure1 and the test results of rock mechanical parameter are shown in Table 1.

The uniaxial compressive strength of roof rock of No.7 coal seam is 1.4 ～ 11.6MPa, softening coefficient is 0.20～0.60, which indicate the rock of cretaceous strata has low strength, and soft characteristic, poor stability.

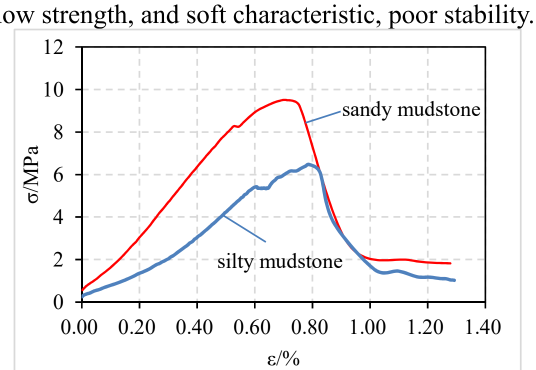

Fig. 1. Stress-strain curve of uniaxial compressive strength

Table 1. Physical and mechanical parameters of rock

Lithology	apparent density ($kg \cdot m^{-3}$)	Compressive strength (MPa)	Softening coefficient	Elasticity modulus (GPa)	Poisson ratio
Fine sandstone	1855～2620 2238	3.8～7.2 6.8	0.41～0.48 0.46	0.92～1.83 1.52	0.24～0.30 0.28
Mudstone	1625～2200 1753	1.4～11.6 5.8	0.24～0.60 0.34	3.28～7.44 5.36	0.19～0.29 0.24
Sandy mudstone	1801～1936 1860	4.9～9.0 7.0	0.60	0.52～1.63 1.03	0.30～0.34 0.32
Silty mudstone	1963～2031 1999	4.5～6.4 5.3	0.20～0.43 0.30	0.67～1.32 0.96	0.30～0.33 0.32
Carbon mudstone	1816～1922 1846	3.6～7.1 5.6	/	1.22	0.31

3.2 Overburden type

The roof rock strata of No.7 coal seam is composed of mud rock and sandstone through analyzing 50 geological drills’ data from coal field. The bedrock is divided into four sections which are 0 ~ 20 m, 20 ~ 40 m, 40 ~ 60 m and >60 m from No. 7 coal seam to the top of bedrock. The mud rock proportion of each section is 54.10%, 53.50%, 53.80% and 49.59%, each section closes to 50% (as shown in Table 2). So mud rock of overburden rock strata belongs to moderate proportion. However, due to the low strength of cretaceous rock and the late diagenesis of cretaceous strata, the roof rock is classified as weak type.

Table 2. Lithology combined characters of overlying strata

Subsection of roof	Sandstone thickness (m)	Sandstone percentage (%)	Mudstone thickness (m)	Mudstone percentage (%)
0-20m	9.18	45.90	10.82	54.10
20-40m	9.30	46.50	10.70	53.50
40-60m	9.24	46.20	10.76	53.80
>60m	31.69	50.41	31.17	49.59

4 The caving zone height of extra-thick coal seam with slicing full-mechanized caving mining

4.1 Observation results of caving zone

The depth of No.7 coal seam in Duolun coal mine is less than 400m, relatively shallow. It is feasible and rational for technology and economy to observe the height of caving zone through ground borehole [11,12]. The diagrammatic sketch of caving zone observation is shown in Figure 2.

The bed rock thickness of 1703^{-2} working face is more than 140 m. According to “*Preliminary design of Duolun coal mine*”, working face 1703^{-2} can be mined with slicing full-mechanized caving mining. So on the earth's surface of working face 1703^{-2}, two observation holes (17-SD1 and 17-SD2) are designed in the ‘saddle’ peak area of caving zone. The location of observation holes is shown in Figure 3. To obtain the maximum height of caving zone, the location of observation holes should have been exploited about one month before drilling to the peak of caving zone.

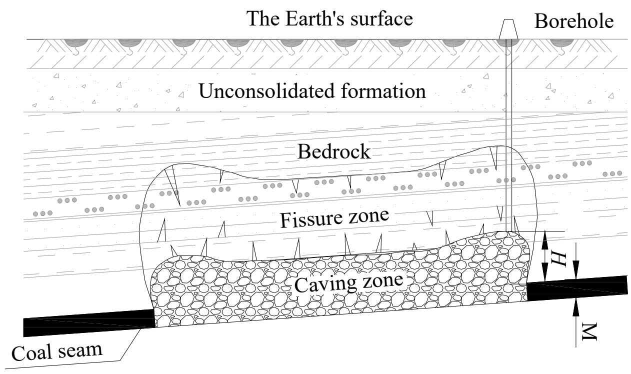

Fig. 2. Diagrammatic sketch of caving zone observation

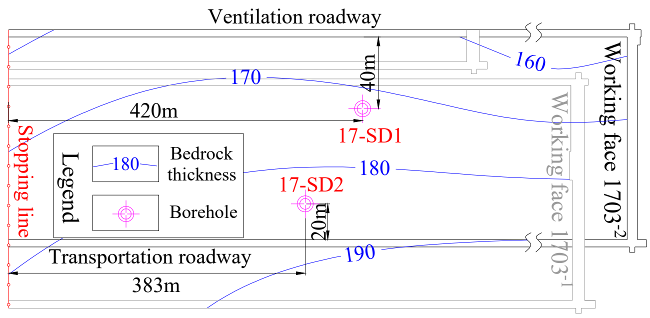

Fig. 3. Sketch map of observation borehole location

Water level variation of borehole is shown in Figure 4. The bedrock section of caving zone borehole is drilled with clear water. Water level of both boreholes drops significantly when drilling depth reaches 222.72m and 234.43m each one. The phenomenon of "drill bit falling" happens in the depth of 226.72m and 238.43m each borehole. Drilling speed sometimes is fast, sometimes is slow, drilling tool shook more intensively, and "falling and sticking drills" phenomenon occurred. Borehole has distinct suction phenomenon, and the core had high fragmentation degree, low extraction ratio, many stagger cracks, and disorganized stratification and angles (as shown in Figure 5). On the basis of above analysis, it is regarded that this position is the peak of caving zone.

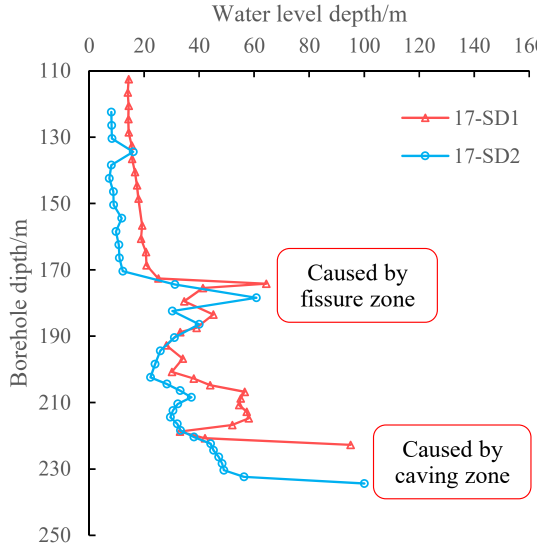

Fig. 4. Water level variation of boreholes

Fig. 5. Rock core of caving zone

4.2 Calculation of caving zone height

Based on the statistics of mining height of 17-SD1 and 17-SD2, the accumulative total mining height is 15.72m and 15.08m respectively. The calculation formula of caving zone height as follow:

$$H_k = Z_k - Z_d - M_z - h_k$$

Where H_k is caving zone height; Z_k is borehole initial elevation; Z_d is the coal floor elevation; H_k is the peak depth of caving zone; Mz is the total of mining thickness.

Under the condition of slicing full-mechanized caving mining, calculation results of caving zone height are shown in Table 3. The ratio between caving zone height and mining height is 4.58～4.74, observation results of two boreholes have good consistency.

Table 3. Measure value of caving zones

Borehole no.	17-SD1	17-SD2
***Z_k* (m)**	1254.20	1255.64
***Z_d* (m)**	943.79	935.13
***H_k* (m)**	222.72	234.43
***H_k* (m)**	71.976	71.468
***Mz* (m)**	15.72	15.08
H_k/Mz	4.58	4.74

5 Water disaster prevention and control of working face 1704^{-2}

5.1 Goaf water control and prevention

The working face 1704^{-2} is located in the bottom of 1702^{-1} and 1704^{-1}. The mining fissure of roof rock will conduct the goaf of working face 1702^{-1} and 1704^{-1} when mining working face 1704^{-2}. The goaf water may inrush stope instantaneously and induce catastrophic accident, which threats safety production of working face.

In order to eliminate the hidden danger of goaf water and guarantee safety mining, 2 drill sites and 7 boreholes are designed in the transportation roadway, 3 drill sites and 10 boreholes are designed in the open-off cut and 3 drill sites and 21 boreholes are designed in the ventilation roadway during the period of ventilation roadway. All of the final location of boreholes reach the bottom of goaf. The total of boreholes are 38 and total footage is 1830.5m. Boreholes in the area near open-off cut is shown in Figure 6. The total of water inrush boreholes is 6 and the maximum water inflow is 12.5m^3/h (as shown in Table 4). The total water inflow is less than 3m^3/h after one month's dewatering.

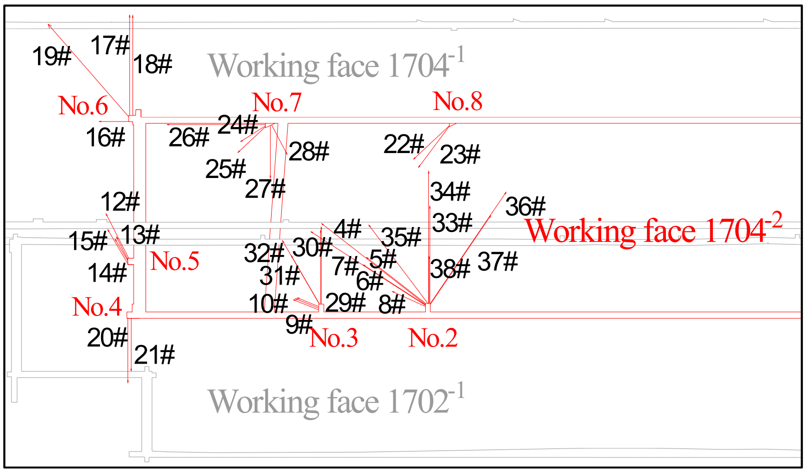

Figure. 6. Boreholes in the area near open-off cut

Table 4. Records of water inrush boreholes

Borehole site location	Borehole no.	Azimuth angle (°)	Dip angle (°)	Depth (m)	Water inrush location (m)	Water inflow (m^3/h)
NO.2	6#	30°	15°	52.5	46	1
	8#	22°	8°	25.5	19	1
NO.8	22#	320°	15°	38	36 and 38	5 and 12.5
	23#	310°	15°	39	37 and 39	1 and 2
NO.7	27#	270°	10°	34	21 and 34	3 and 3
	28#	240°	10°	23	17 and 23	3 and 3

5.2 Gravel aquifer control and prevention

5.2.1 Designing method of safety coal and rock pillar

According to the boundary of gravel aquifer, the working face 1704^{-2} is divided into 2 areas which are clay bottom area (Area I) and gravel bottom area (Area II). The gravel aquifer is nonexistent in the clay bottom area (as shown in Figure 7). Based on the research of hydrogeological condition and "*Rules for the prevention and control of water in coal mine*", caving-proof safety coal and rock pillar can be designed in the Area I, that is, the design value of caving-proof safety coal and rock pillar should not be more than the thickness of bed rock. Sand-proof safety coal and rock pillar can be designed in the Area II, that is, the design value of sand-proof safety coal and rock pillar should not be more than the thickness of bed rock. Sand-proof safety coal and rock pillar consists of caving zone height and the thickness of protective layer. Caving height is 4.74 (choosing the maximum value of field observation) times of mining height and the thickness of protective layer is 2.8 times of mining height.

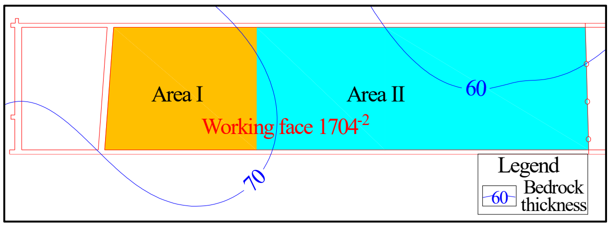

Figure. 7. Partition map of gravel aquifer

5.2.2 Design of safety coal and rock pillar

(a) Area I

According to the mining condition of working face 1702^{-1} and 1704^{-1}, the top layer of No.7 coal seam has been mined 8.1m. Based on the contour map of bed rock thickness (as shown in Figure 7), the bed rock thickness is about 70～74.9m. Safety mining thickness of working face 1704^{-2} can be calculated on the basis of the minimum value of 70 m. That is,

$$4.74(8.1+A)\leq 70\text{m}$$

Where A is the allowable mining height.

Then $A\leq 6.67$ m, so the maximum allowable thickness of mining is 3.5 m in area I.

(b) Area II

The thickness of low layer is 9m through roadway exploration. More than 5 m of low layer which will not be mined can be made as part of sand-proof safety coal and rock pillar, so the thickness of bed rock is about 60～70m. Safety mining thickness of area II can be calculated on the basis of the minimum value of 60 m. That is,

$$4.74\times(8.1+A)+2.8A\leq 60\text{m}$$

Then $A\leq 2.86$m , so the maximum allowable thickness of mining is 2.86 m in area II.

The mining heights of different areas are shown in Table 5.

Table 5. Mining heights of different areas

Area	Area I	Area II
Bedrock thickness (m)	70～74.9	60～70
Mining length (m)	0～165	165～528
Mining height (m)	6.67	2.80

6 Conclusions

(1) Based on rock mechanics experiment, the uniaxial compressive strength of roof rock of No.7 coal seam is 1.4～11.6 MPa, softening coefficient is 0.20～0.60, which indicates the rock of cretaceous strata has low strength, and soft characteristic, poor stability.

(2) Through the methods of field measurement and theoretical analysis, this paper researches the damage characteristics of overburden rock with slicing full-mechanized caving mining in cretaceous strata. It can be concluded that the ratio between caving zone height and mining height is about 4.58 ～ 4.74. Choosing the maximum value (4.74) of field observation as the design parameter of safety coal and rock pillar.

(3) Dewatering the goaf water of working face 1702^{-1} and 1704^{-1} through roof boreholes. Preventing and controlling the gravel aquifer through the method of designing reasonable safety coal and rock pillar. The two prevention and control methods of roof water disaster make the safety mining come true.

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