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Research on the Numerical Simulation of Steep Coal Seam Mining under Water Body

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Abstract: The steep coal seam mining under water body is a technical difficult problem. Because it will bring many mining hazards such as ground subsidence, roof water inrush and water body destruction. To solve these problems in Tongjiaowan mine, the method combining with strip mining and backfilled mining is proposed. First the coal seam is divided into several strips along the trend and the width between two strips is ten meters. Then the coal seam of every strip is caved in turn from up to down. After mining every strip, the mined-out area is filled with filling materials immediately. The example simulation results show that the strip mining method is feasible and the filling effect of high strength filling material is the best. This research may be a better suggestion on resolving the problem of the steep coal seam mining under water body. The study method would also be a reference for other kinds of mining conditions including mining beneath buildings or railways.

Key words: Steep coal seam, under water body, numerical simulation, strip mining, backfilled mining

INTRODUCTION

According to the statistics, the quantity of coal under water body is about 25 billions in China. But the mining quantity is only ten percent of the total quantity now. To meet the need of the economic development, it is important to mine the coal under water body. However, mining under water body is affected by the upper aquifers and the surface water body including the rivers, the reservoirs and the faults. And it will bring many mining hazards such as ground subsidence, roof water inrush, fault activating and water body destruction and so on. Therefore it is a technical difficult problem to mine under water body in practice. In present, the methods of mining under water body are strip mining (Zhang, 2012), backfilled mining (Liu *et al*., 2004; Li *et al*., 2010) and roof and fully mechanized mining (Li *et al*., 2003). Some scholars propose green mining technology, that is mining the coal under water body and protecting the water resource at the same time (Miao and Qian, 2009). The problems introduced in previous paper aren't solved effectively yet. The researches about the steep coal mining are focused on the mining beneath buildings or railways mostly (Chai *et al*., 2008; Ding *et al*., 2010; Huang *et al*., 2010; Zhai *et al*., 2012) and it is few under water body. Therefore it has important theoretical significance and practical value to study the mining method of the steep coal seam under water body.

Tongjiaowan mine lies in Xiangyong mine area of Hunan province in China. The coal production of Tongjiaowan mine is about 0.3 million tons per year. The main mining coal seam is the 6th seam and its average thickness is 3.69 m. The average angle of the coal seam is 50°C, which belongs to the high angle steep coal seam. There are two main effect factors of mining the coal seam, one is the Lei river, the other is the F_3 fault near the coal seam. The Lei river is the branch of Xiang River, which is flowing from the east to the west in the middle of Tongjiaowan mine. And its discharge is 26.9-473 m^3sec^{-1}. If the mining method is not suitable, the large number of water in Lei river will flow into the working face. Thus, mine water inrush accident will happen. The F_3 fault is a main effect fault of mining under Lei river. Though the water conductivity of F_3 fault is weak, it will active and lead to water inrush under the condition of mining. So it is necessary to apply reasonable mining method avoiding the effects of Lei river and F3 fault. To ensure the safe product of Tongjiaowan mine, the method combining with strip mining and backfilled mining is proposed. And its feasibility is analyzed with the simulation of finite element method.

MATERIALS AND METHODS

Method combining with strip mining and backfilled mining: The method of strip mining is usually used to

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Table 1: Mechanical and seepage parameters of rock stratus in calculation model

Llithology	Modulus (GPa)	Strength (MPa)	Poisson ratio	Internal friction angle (°)	Bulk density ($KN \cdot m^{-3}$)	Permeability coefficient ($m \cdot d^{-d}$)	Pore pressure coefficient
1	15	15	0.25	200	30	0.20	0.99
2	10	20	0.25	100	32	0.01	0.1
3	20	25	0.25	21	35	0.1	0.1
4	14	18	0.28	20	28	0.2	0.2
5	12	10	0.3	20	30	0.3	0.2
6	25	30	0.25	24	34	0.01	0.1
7	7	4	0.35	16	25	0.3	0.3
9	26	35	0.25	26	37	0.01	0.1
F_1, F_3	4	5	0.4	19	20	0.1	0.2
10	30	50	0.25	26	38	0.01	0.1

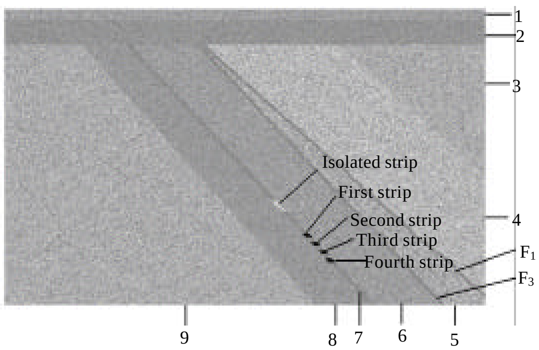

Fig. 1: Calculation model of strip mining, (1) The aquifer, which is used to simulate the Lei river, (2) The equivalent layer, which replace with the weathering zone and overburden rock strata, (3) The sandy conglomerate strata, (4) The marl strata, (5) The sandy mudstone strata, (6, 8) The siltstone strata, (7) The coal seam and (9) The sandstone strata

mine the steep coal seam beneath the surface buildings and railways. First the coal seam is divided into several strips along the trend of the steep coal seam. And certain width coal pillar will be left between two strips to control the movement of the upper rock stratus. Thus, the ground buildings and railways would be protected effectively. However, it is not suitable for the mining under water body. Because the water pressure of the water body will load on the surface of rock stratus. And the controlling of rock stratus' movement will be difficult if the upper rock stratus fracture, ground subsidence and roof water inrush will happen. To solve these problems, the method combining with strip mining and backfilled mining is proposed. After mining every strip, the mined-out area is filled with filling materials immediately. The filled tunnels can support the upper rock stratus. The effect of the method will be verified with the simulation of finite element method.

Numerical simulation model and parameters of strip mining method

Numerical simulation model: The strip mining model of the steep coal seam under Lei river is established with RFTA-FLOW^{2D} software (Pu and Zhang, 2010). It is two-dimensional plane strain model shown in Fig. 1. The size of the model is three hundred and sixty millimeters multiplies two hundred and fifty millimeters. They express the length and height of the model respectively. And the total number of calculating element is ninety thousands. The mechanical and seepage parameters of each rock strata are shown in Table 1. The F_3 fault is set as water conductivity one. The weathering zone and overburden are replaced by equivalent layer which thickness is 30 m.

Mechanical and seepage boundaries: The left and right boundaries of the model are supposed as displacement constraints and their values are zeros. While there is unconstrained on the vertical direction. The flow of the upper boundary is 1 MPa which is used to simulate the water pressure of Lei river. And the lower boundary is water-resisting. Also, the water pressure of both sides in the model is zero. The managing method of roof is caving method. The drawing pace is four meters and the coal pillar width is ten meters.

Where 1, 2, 3, 4, 5, 6, 7, 9 are introduced in Fig. 1. The isolated strip, F_1 and F_3 are the main effect faults.

Numerical simulation model and parameters of backfilled mining method: The simulation steps of backfilled mining method are as follows. The first strip coal seam is caved firstly. After finished this calculating step, the parameters of filling material are set in the area of the caved first strip. Then the second strip is caved. The same step is done as the former until the fourth strip is caved lastly.

The key problem of the backfilled mining method is the selection of filling material. To compare the filling effect of different materials, three kinds of materials are chosen to simulate the backfilled mining. The parameter values of the three materials are shown in Table 2. The calculating model of the backfilled mining method is the same as that of the strip mining method. Mechanical and seepage parameters of rock stratus in calculation model are shown in Table 1. The mechanical and seepage boundary conditions are also consistent with those of the strip mining method.

Table 2: Mechanical parameters of the three material

Material	Modulus (Gpa)	Strength (Mpa)	Poisson ratio	Internal friction angle (°)	Bulk density (KN•m^{-3})	Permeability coefficient (m•d^{-d})	Pore pressure coefficient
A	15	50	0.25	2.6	38	0.01	0.1
B	14	40	0.25	2.4	36	0.01	0.1
C	13	30	0.25	2.2	35	0.01	0.1

Where A, B and C are the names of the different filling materials

EXAMPLE AND RESULTS

Simulation result analysis of strip mining method

Analysis of surface vertical displacement: The surface vertical displacements of strip mining method are shown in Table 3. After caving the first strip and the second strip, the surface vertical displacements are only twenty millimeters and fifty millimeters respectively. It shows that the strip mining method can control the surface movement in mining the steep coal seam. However, when caving the first strip, the surface vertical displacement is reach to 200 mm. It will cause ground subsidence and other mining hazards in future. It proves that the method can't ensure the safe product completely.

Analysis of maximum principal stress: The maximum principal stress distributions of strip mining method are shown in Fig. 2. When caving the third strip, the maximum principal stress near the mined-out area adds 1.29 million Pa. That is the mining pressure has been larger than before with the growing of mining depth. From the Fig. 2c, there are some failure zones in the proof and floor of coal seam and near the faults. It shows that mining destruction has formed and the faults of F_1 and F_3 have activated. If the failure zones continue to involve and reach to the upper aquifers, the water inrush and ground subsidence will happen. Therefore, some methods should be used to avoid the happening of these mining hazards.

Simulation result analysis of backfilled mining method

Failure zone analysis: The failure zones caused by backfilled mining are shown in Fig. 3. In figure a, there are no obvious failure zones in the roof or floor of coal seam. It shows that mining the fourth strip is safe after the three caved strips filled with the filling material A. In figure b and c, the failure zones exist in the roof and floor of coal seam or near fault F_1 and F_3. After the caved strips filled with material B and C, the mining hazards have formed when mining the fourth strip. The results show that the filling effect of material A is the best.

Roof displacement analysis: After filling the three materials, the roof displacements are 60.3, 1480 and 2847 mm, respectively. It shows that the roof displacement caused by material A is far smaller than the others. And it can control the movement of rock stratus efficiently. But

Table 3: Surface vertical displacements when caving every strip

Strip name	First strip	Second strip	Third strip
Surface vertical displacement (mm)	20	50	200

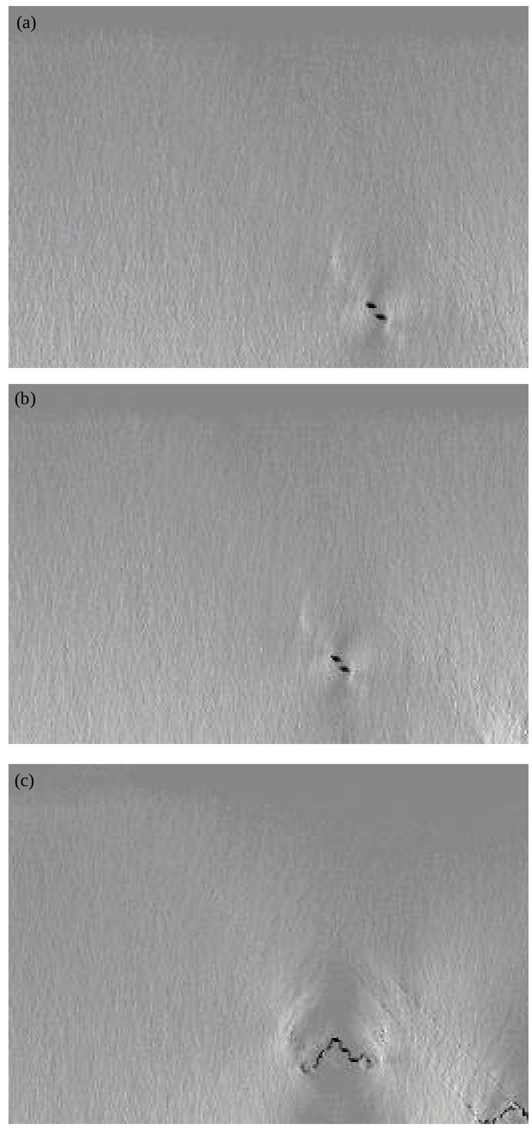

Fig. 2(a-c): Maximum principal stress distributions when caving the strips, (a) Maximum principal stress figure when caving the first strip, (b) Maximum principal stress figure when caving the second strip (c) Maximum principal stress figure when caving the third strip

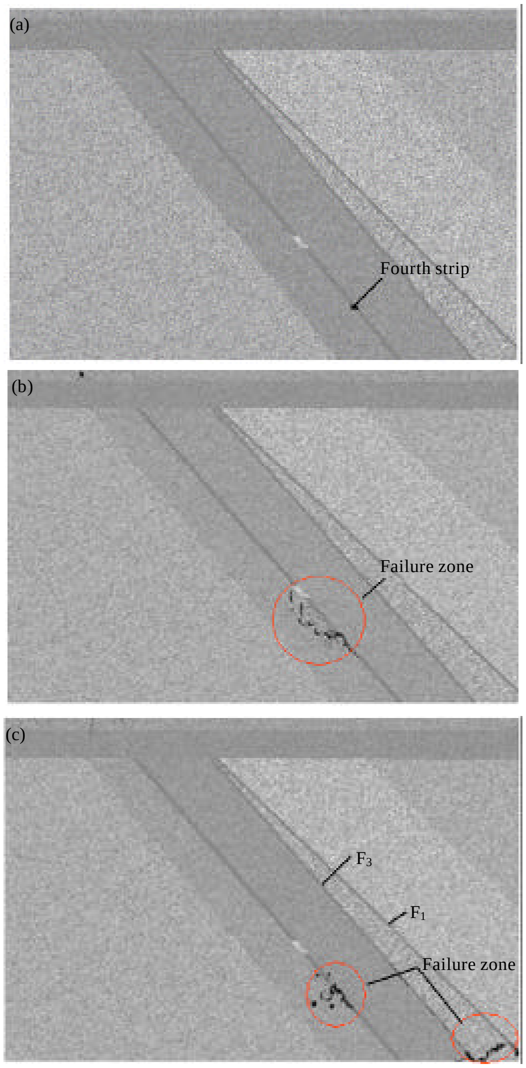

Fig. 3(a-c): Failure zone contributions filled with different materials, (a) Failure zone filled with material A, (b) Failure zone filled with material B and (c) Failure zone filled with material C

the coal seam filled with material B and C can't support the upper rock stratus. And it will cause the ground subsidence.

Maximum water inrush quantity of the roof: The maximum water inrush quantities of the roof are 5.4 and 445.2 m^3 h^{-1} filled with material A and C. it shows that the coal seam filled with material A has certain water-resisting ability. Because the failure zones have formed, the caved strips filled with material C has no water-resisting ability. And it will lead to the roof water inrush hazard.

The numerical simulation results of backfilled mining show that the filling effect of high strength material is good. It is feasible to mining steep coal seam under Lei river. The minimum roof displacement is 600 mm with other method and that is only 60.3 one with the proposed method. The water inrush quantity is 150 m^3h^{-1} with using paste-like filling method (Huang *et al*., 2013). However, it is just 5.4 m^3h^{-1} with this method. The comparing results show that the filling effect of this method is better than others.

CONCLUSION

To mine the steep coal seam under Lei river in Tongjiaowan mine, the method combining with strip mining and backfilled mining is proposed. The simulation results shows that the filling effect of high strength material is good. And the method is feasible to mining steep coal seam under water body.

Comparing with others methods, the method combining with strip mining and backfilled mining can control surface subsidence and water inrush efficiently. And it would be a reference for other kinds of mining conditions including mining beneath buildings or railways.

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