The effect on river and earth dam caused by large height mining in underground coal mine — a case in Inner Mongolia

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Abstract. Some coal seams located in the shallow area belong to Jurassic system strata in Inner Mongolia, China. There may be some effect on the rivers and earth dam on the earth surface of coal field after large height mining. Hydraulic connection was analyzed according to the hydrogeological condition and additional exploration results in Wotugou coal mine. Empirical formulas were used to predict overburden failure height after analyzing the strength type of overlying rocks. The deformation of earth dam was predicted through probability integral method under large height mining. The final research results include: (1) Quaternary system aquifer belongs to the type of weak to strong watery property and has an intimate hydraulic connection with the Youfang River. (2) The overlying rocks of 2-2 coal seam belong to medium hard type for the average uniaxial compressive strength of 25.52 MPa. The maximum height of fissure zone is 92.40 m, there was no effect on Youfang River after large height mining under the depth of 251.46 m. (3) The maximum surface subsidence reached 1.7 m and the horizontal deformation reached the allowable maximum value 4.0mm/m, there would be some effect on the earth dam, so some safety measures were put forward and needed to be done.

1 Introduction

Coal distributes widely, but the hydrogeological condition is very complex in China. Many coal mines are threatened by different aquifers and surface water bodies [1, 2]. 1950s, a great deal of experimental investigations about the mining under water bodies were carried out. Experimental study and production practice indicated coal was mined safely under rivers, lakes, seas and different aquifers [3, 4]. However, in 1980s, large mining height and full-mechanized caving mining methods were used widely with the development of the level of mechanization. Then the mine pressure appeared acutely and the extent of overburden failure brought new problems caused by the advanced technology [5-7]. In the 21st century, with the development of large mining height method and computer technology, the characteristics of caving zone and fissure zone have been known specifically under High-strength underground mining. The empirical formulas of caving zone and fissure zone heights have also been formed and scientifically instructed the safety mining under water bodies [8-10].

Taking Wotugou coal mine as an example, hydraulic connection was researched through analyzing the hydrogeological condition and additional exploration results. Empirical formulas were used to predict overburden failure height after analyzing the strength type of overlying rocks and the effect on the Youfang River was evaluated under large height mining. The deformation of earth dam was predicted through probability integral method and under the effect on the earth dam was evaluated under high strength mining, then some safety measures were put forward.

2 General situation of research area

2.1 Mining status

Wotugou coal mine has the production scale of 0.9 Mt/a, and excavates from +850 m to +1070 m (above sea level) in Inner Mongolia. The mine excavates 2-2 coal seam of first panel, with the thickness of 3.47 m to 4.12 m, and average thickness is 3.84 m. The average depth of 2-2 coal seam is 251.46 m and the average dip angle is 1.5 °, which belongs to nearly flat seam. The mining method of strike long-wall comprehensive mechanization of a full mining height and the management of all caving the roof are used. Neighborhood coal mines are shown in Fig. 1.
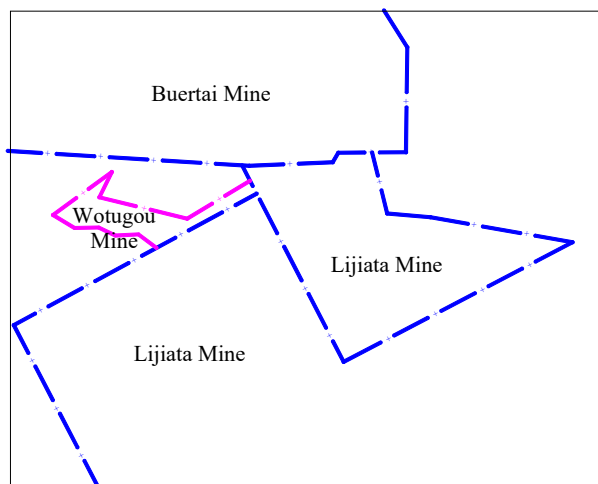
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Fig. 1. Neighborhood coal mines of Wotugou mine

The terrain in this area is badly cut. Youfang River is a north-south ravine on the surface of mining area and the flow direction is from south to north. An earth dam with the top width of 5.0 m, bottom width of 20.0 m and height of 3～6 m was constructed on the river. There are two ponds in the north and south of earth dam (as shown in Fig. 1). The mining faces near the Youfang River are shown in Fig. 2, the reality images of river and earth dam are shown in Fig. 3.
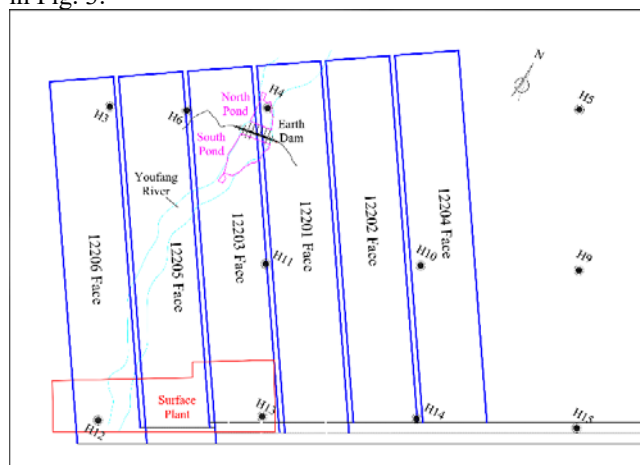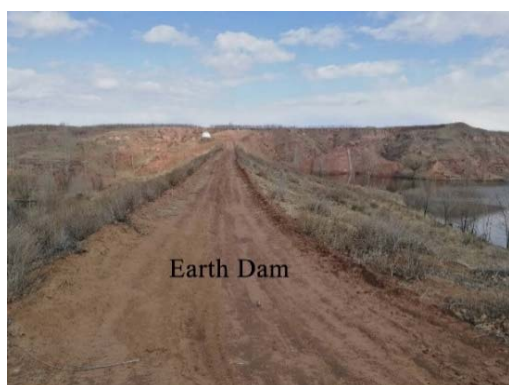

Fig. 2. The mining faces near Youfang River

Fig. 3. Reality images of river and earth dam

2.2 Hydrogeological condition

According to the hydrogeological condition and additional exploration results, the hydraulic connection of aquifers are as follows:

(1) Quaternary system aquifer

The unit flow rate of water-bearing strata is 0.09-1.29 L/(m.s) and the permeability coefficient is 16.54-90.27 m/d of pore phreatic aquifer in Quaternary system strata, so it belongs to the type of weak to strong watery property. The thickness of aquifer is usually less than 10m, and the permeability performance is strong. Phreatic aquifer has very close hydraulic connections with atmospheric precipitation and surface water body.

(2) Cretaceous system aquifer

The unit flow rate of water-bearing strata is 0.02-0.03 L/(m.s) and the permeability coefficient is 0.02-0.05 m/d of clastic rocks pore and fissure aquifer with the thickness of about 100m, it belongs to the type of weak watery property in Cretaceous system strata. Red sandstone and glutenite are the main lithology of the pore and fracture confined aquifer. The Quaternary system aquifer and Cretaceous system aquifer have some hydraulic connection because of the lack of water-resisting layer.

(3) Jurassic system aquifer

Jurassic system strata with the thickness of about 127 m are composed of mudstone, sandy mudstone and fine sandstone. The unit flow rate of water-bearing strata is 0.0016～0.0045 L/(m.s) and the permeability coefficient is 0.0046～0.013 m/d of pore and fissure aquifer, so it has weak watery property in Jurassic system strata. The water permeability and conductivity performance are also weak. So the Jurassic system aquifer has bad hydraulic connection with upper aquifers.

3 The effect on river under large height mining

3.1 Physical-mechanical properties of rocks

The overlying strata of 2-2 coal seam are composed of sandstone, glutenite, mudstone, sandy mudstone and fine sandstone. According to the geology supplement exploration, the test results of physical-mechanical properties for overlying rock are shown in Table 1. The average uniaxial compressive strength of sandstone is 25.9 MPa and the softening coefficient is 0.77. The average uniaxial compressive strength of siltstone is 14.19 MPa and the softening coefficient is 0.60. The average uniaxial compressive strength of sandy mudstone is 30.24 MPa and the softening coefficient is 0.33. The average uniaxial compressive strength of mudstone is 25.17 MPa and the softening coefficient is 0.28.

Table 1. Test results of physical-mechanical properties for overlying rock

Sample No.	Depth (m)	Lithology	Uniaxial compressive strength (MPa)	Softening coefficient
1	213.16-225.03	Siltstone	23.84	0.27
2	226.12-230.66	Sandy mudstone	20.84	0.22
3	231.10-232.96	Siltstone	34.73	0.35
4	233.75-236.81	Mudstone	13.89	0.29
5	237.01-241.36	Fine sandstone	19.26	0.74
6	221.34-229.27	Siltstone	3.97	0.73
7	230.52-239.29	Fine sandstone	5.18	0.53
8	244.23-247.39	Siltstone	14.77	0.81
9	247.58-253.40	Mudstone	36.45	0.27
10	217.79-225.12	Sandy mudstone	35.49	0.21
11	227.15-230.16	Fine sandstone	19.10	0.89
12	231.30-234.22	Sandy mudstone	46.58	0.23
13	241.80-243.12	Fine sandstone	29.39	0.70
14	243.75-244.60	Sandy mudstone	33.13	0.34
15	245.25-246.25	Gritstone	56.57	0.97
16	247.09-247.59	Sandy mudstone	15.16	0.55
Average			25.52	0.48

The average uniaxial compressive strength of overlying rock is 25.52 MPa and most of overlying rock is less than 30 MPa, the strength of overlying rock is relatively low. The average softening coefficient is 0.48 and most samples are less than 0.75, so the rocks are easily softened. Based on the partitioning method of rock strength [11] (as shown in Table 2), the overlying rocks of 2-2 coal seam belong to medium hard type.

Table 2. Partitioning method of overlying rock

Types	Uniaxial compressive strength （MPa）	Main rocks
Hard	40～80	quartz sandstone, limestone, sandy shale, conglomerate
Medium hard	20～40	sandstone, argillaceous limestone, sandy shale, shale
Weak	10～20	Mudstone, argillaceous sandstone
Very weak	<10	bauxite, weathered mudstone, clay, sandy clay

3.2 Impact assessment to the river after mining

From 1950s to now, many research about the mining method under water body. For the research of caving zone and fissure zone (as shown in Fig.4), field observation is the main method coupled with model test, numerical analysis, and physical simulation and so on. Based on a large number of in si-tu observations, empirical formulas for the heights of caving zone and fissure zone are summarized. In the 21st century, with the development of large mining height method and computer technology, the growth characteristics of caving zone and fissure zone have been known specifically. The empirical formulas of caving zone and fissure zone for the large mining heights have also been formed (as shown in Table 3) and scientifically instructed the safety mining under water bodies [12].
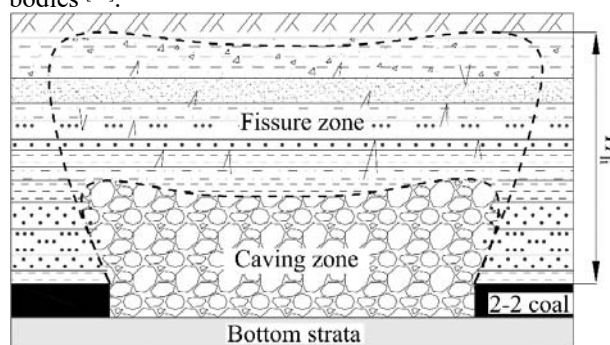

Fig.4. Characteristics of overburden failure

Table 3. Empirical formulas of "two zones"

Overlying rock types		Empirical formulas （m）
Caving zone height	Hard	$H_k = 7M + 5$
	Medium hard	$H_k = 6M + 5$
	Weak	$H_k = 5M + 5$

Fissure zone height	Hard	$H_{li} = \dfrac{100M}{0.15M + 3.12} \pm 11.18$	$H_{li} = 30M + 10$
	Medium hard	$H_{li} = \dfrac{100M}{0.23M + 6.10} \pm 10.42$	$H_{li} = 20M + 10$
	Weak	$H_{li} = \dfrac{100M}{0.31M + 8.81} \pm 8.21$	$H_{li} = 10M + 10$

Where M is mining height, m.

According to the data of 11 boreholes in the research area, the thickness of 2-2 coal seam is from 3.47 m-4.12 m, with average thickness of 3.84 m. Based on above analysis, the overlying rocks belong to medium hard type. The fissure zone heights of different boreholes are shown in Table 4. The maximum height of fissure zone is 92.40 m in borehole H5.

Through above analysis, Quaternary system aquifer has an intimate hydraulic connection with the Youfang River. The average depth of 2-2 coal seam is 251.46 m and the minimum depth is 211.49 m. The maximum fissure zone height only is 92.40 m, which can't reach the Quaternary system aquifer. That is, Youfang River won't be affected through the large height mining in Wotugou coal mine.

Table 4. Fissure zone height of research area

Boreholes	Coal depth (m)	Thickness of coal (m)	Fissure zone height 1 (m)	Fissure zone height 2 (m)
H3	244.63	3.96	66.90	89.20
H4	230.35	3.66	63.14	83.20
H5	211.49	4.12	68.88	92.40
H6	271.47	4.11	68.76	92.20
H9	234.38	3.95	66.78	89.00
H10	232.64	3.52	61.36	80.40
H11	265.45	4.04	67.89	90.80
H12	262.52	3.6	62.38	82.00
H13	291.44	3.47	60.72	79.40
H14	224.17	3.73	64.03	84.60
H15	260.16	4.08	68.39	91.60
Average	**251.46**	**3.84**	65.41	86.80

4 The effect on earth dam under large height mining

4.1 Impact assessment to the river after mining

For the prediction of surface movement and deformation, many experts from domestic and overseas have put forward different methods. After systematic research and practice for more than 40 years, the law of surface movement and deformation have been mastered. Probability integral method, negative exponential method, Weibull function method and typical curve method are usually used to predict surface movement and deformation

in China [13]. Parameters are easily determined and practicability is high for the probability integral method, so it is used widely. For that reason, probability integral method was used to predict the deformation of earth dam under large height mining.

Subsidence and horizontal deformation formulas of every point and every direction in the surface subsidence trough are as follows:

(1) Surface subsidence computation

$$W(x,\ y) = W_{cm} \iint_D \frac{1}{r^2} e^{-\pi \frac{(\eta-x)^2 + (\varepsilon-y)^2}{r^2}} d\eta d\xi$$

(2) Horizontal deformation computation

$$\varepsilon_x(x,y) = U_{cm} \iint_D \frac{2\pi}{r^3} \left(\frac{2\pi(\eta-x)^2}{r^2} - 1\right) e^{-\pi \frac{(\eta-x)^2 + (\xi-y)^2}{r^2}} d\eta d\xi$$

$$\xi_y(x,\ y) = \frac{\partial U_y(x,\ y)}{\partial y} = U_{cm} \iint_D \frac{2\pi}{r^3}\left(\frac{2\pi(\xi-y)^2}{r^2} - 1\right)$$
$$\bullet e^{-\pi \frac{(\eta-x)^2 + (\varepsilon-y)^2}{r^2}} d\eta d\xi + i_y(x,\ y)ctg\theta$$

Where r is major influence radius, is related to mining depth and the main influence angle, m; D is the mining area; x, y is relative coordinates of point, m; W_{cm} is the maximum subsidence value, mm; U_{cm} is the maximum horizontal movement value, mm.

The ranges of surface movement computation parameters for different overlying strata in different areas have been summarized in China. The applicability of these parameters is very high because of the long-term monitoring. Wotugou coal mine near to Bulianta coal mine (as shown in Fig. 1) has the similar geological condition, mining method and mining scale, so the parameters of Bulianta coal mine can be used to compute the earth dam deformation. Deformation contour line can be drawn after computation when the parameters and mining information are imported the probabilistic integration method software. The relevant parameters are shown in Table 5.

Table 5. Parameters for surface deformation prediction

Subsidence coefficient	Horizontal movement coefficient	Propagation angle (°)	Tangent of main influencing Angle
0.55	0.20	89	2.2

4.2 Earth dam deformation computation

The relevant working faces for the earth dam deformation computation are shown in Table 6. Subsidence value was computed through working faces mined one by one. Subsidence contour maps for 3 working faces (12201, 12202 and 12203) and 6 working faces (12201 to 12206) mined are shown in Fig. 5 and Fig. 6 respectively. Subsidence of 10 mm was taken as the boundary of influence range caused by mining. The surface subsidence increased with the expansion of mining range. The maximum surface subsidence reached 1.7 m after 3 working faces mined and the maximum value tended to be

stable after 6 working faces mined. The earth dam didn't be affected because of the uniform subsidence.

Table 6. Working faces in the research area

Working faces	Length （m）	Width（m）	Mining thickness （m）
12201	1700	300	3.84
12202	1700	300	3.84
12203	1400	300	3.84
12204	1700	300	3.84
12205	1435	300	3.84
12206	1435	300	3.84
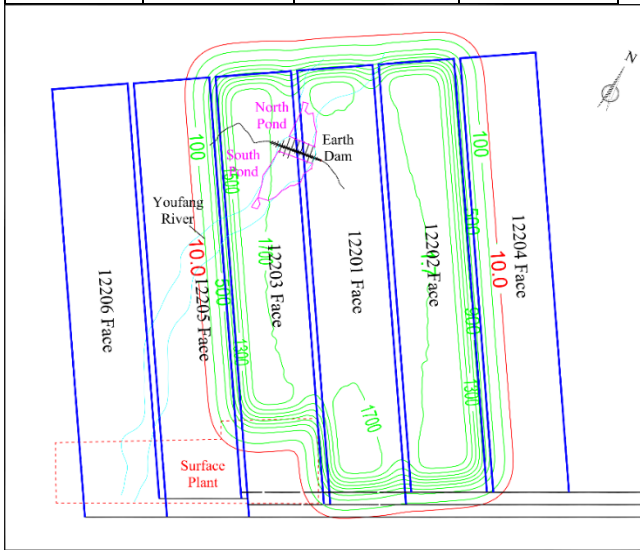
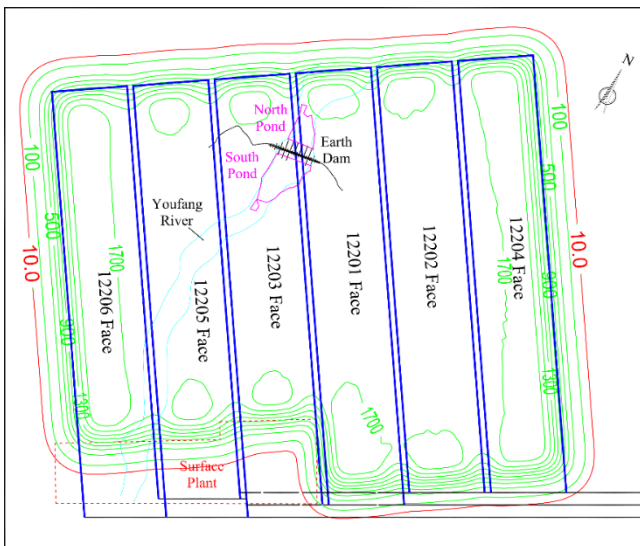**Fig. 5.** Subsidence contour map for 3 working faces mined

Fig. 6. Subsidence contour map for 6 working faces mined

Horizontal deformation contour maps for 3 working faces (12201, 12202 and 12203) and 6 working faces (12201 to 12206) mined are shown in Fig. 7 and Fig. 8 respectively. Horizontal deformation increased with the working faces mined one by one. The maximum horizontal deformation in the strike and incline directions reached 4.0 mm/m after 3 working faces mined and the maximum value tended to be stable after 6 working faces mined.
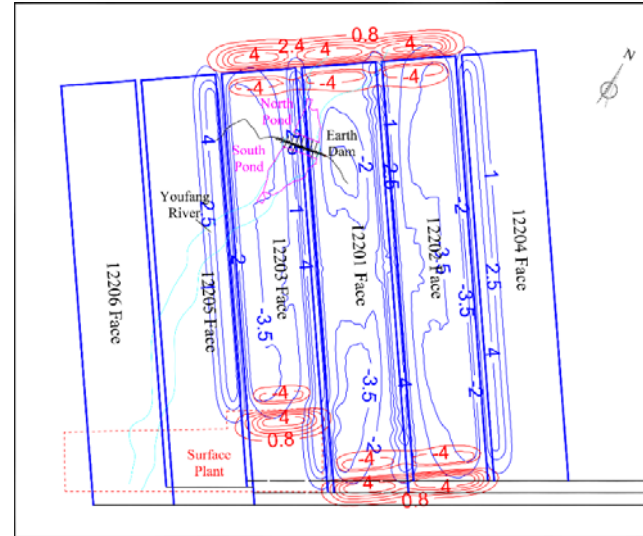

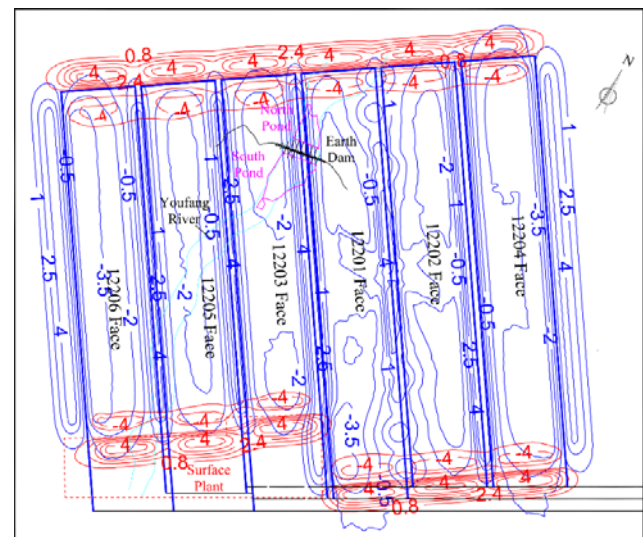**Fig. 7.** Horizontal deformation contour map for 3 working faces mined

Fig. 8. Horizontal deformation contour map for 6 working faces mined

According to 'The coal pillar design and mining standard for construction, water body, railway, main shaft and roadway', earth dam reached the allowable maximum value 4.0mm/m. To a certain extent, the earth dam was affected by the underground mining, so some safety measures needed to be done as follows:

(1) The height and width of the dam should be increased, and reinforcement measure should be used because of the earth dam subsidence;

(2) The slope of dam made a difference caused by the incline deformation, then skid-resistance decreased, the measures of decreasing the slope and increasing the width should be used to improve the anti-sliding ability.

(3) Fractures were generated in the dam because of the horizontal deformation. The fractures should be governed through backfill and grout methods.

(4) Earth dam should be monitored and maintained during mining, especially in the rainy season.

5 Conclusions

(1) Quaternary system aquifer belongs to the type of weak to strong watery property and has an intimate hydraulic connection with the Youfang River through analyzing the hydrogeological condition.

(2) The overlying strata of 2-2 coal seam are composed of sandstone, glutenite, mudstone, sandy mudstone and fine sandstone and the average uniaxial compressive strength of overlying rock is 25.52 MPa after analyzing the geological condition. The overlying rocks of 2-2 coal seam belong to medium hard type and the maximum height of fissure zone is 92.40 m. There is no effect on Youfang River after large height mining under the depth of 251.46 m.

(3) Probability integral method was used to predict the deformation of earth dam under large height mining. The maximum surface subsidence reached 1.7 m and the horizontal deformation reached the allowable maximum value 4.0mm/m, there would be some effect on the earth dam, so some safety measures are put forward and needed to be done.

Acknowledgment

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