An evaluation on coal mining safety above high pressure confined aquifers in a deep coalmine

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Abstract

The Gedian Coalmine in Chinese Henan Province is geologically a graben structure. In both eastern and western boundary of the area, there are normal faults with a drop of 130-550 m and a dip angle of 60-70º, which causes the interaction between the aquifers in the Taiyuan Formation floor and the Ordovician. The Seam 2 in the Taiyuan Formation overlies limestone aquifers with a hydraulic pressure of 5 to 9 MPa, resulting in a groundwater inrushing coefficient of 0.13-0.22 MPa/m, which indicates a high risk of groundwater inrush. The former characterization of the hydrogeological conditions cannot satisfy the need of mine design and production; therefore, it is meaningful to figure out the hydrogeological condition to mining safety assessment and feasibility analysis of mining the Seam 2. Through the analysis of geological and hydrogeological conditions in the Gedian Coalmine, a quick, economic and feasible prospecting plan for hydrogeological condition was carried out; by drilling, outflow test and in situ stresses measurement, the hydrogeological condition and geostress distribution related to mining Seam 2 in an extended area have been characterized. Then, the composed hydrogeological conditions with graben and high pressure confining aquifers were assessed; the mine flow rate was calculated. Finally, a drainage plan of underground water inrush prevention and control from the Taiyuan Formation limestone were given, which provides a basis for the excavation of the Seam 2.

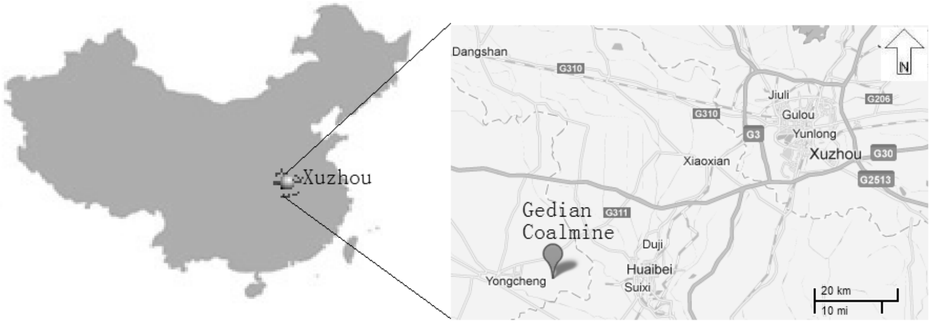
Keywords: graben, aquifer with high pressure, deep coalmine, in situ stress, evaluation of hydrogeological condition

Introduction

Many coalmines in China encounter limestone confined aquifers with high pressure underlie coal seams. During coal mining from these mines, groundwater inrushes occur frequently, which always cause disastrous consequences (Sui, 2011). It is reported that the total coal resource threatened by limestone confined aquifers is over 25 billion tons in China. Therefore, it is significant to ensure the safety for coal mining above the limestone confined aquifers (Peng, 2007). Various researches have been conducted in this area for decades in China (Zhang 1989, Zheng et al. 2000, Peng and Wang 2001, Peng and Meng 2002, Li and Guan 2002, Wang et al. 2002, Li and Gao 2003, Yang et al. 2003, Zhang 2005, Yin and Zhang 2005).

The Gedian Coalmine in Chinese Henan Province is geologically a graben structure, where the Taiyuan Formation limestone has a hydraulic pressure of 5 to 9 MPa under the Seam 2 with a depth of 600-1000 m, resulting in a groundwater inrushing coefficient of 0.13-0.22 MPa/m, which indicates a high risk of groundwater inrush. The east to west distance in the Gedian Coalmine is about 1.5

km, and the north to south distance is 6 km. Figure 1 shows the location of the Gedian Coalmine which is located at about 100 km southwest of Xuzhou city in



eastern China. This paper presents an evaluation on coal mining safety above high pressure confined aquifers in the Gedian Coalmine.

Figure 1 *Location of the Gedian Coalmine*

Geology and hydrogeology

The Gedian Coalmine belongs to North China Stratum District. The bedrock of the whole coal filed is covered by the Cenozoic alluvial layers. Table 1 shows the main characteristics of stratum and hydrogeology of the Gedian Coalmine.

The Gedian coalmine is located between the Yongcheng Anticline and the Gedian Anticline. Both the Shuangmiao Fault and the Wangzhuang Fault are normal faults with a drop of 130-550 m and about a dip angle of 60-70º, forming the east and west boundary of the Gedian Coalmine (Figure 2).

***Table 1** Stratum and hydrogeology of the Gedian Coalmine*

Stratum	Total thick-ness (m)	Thickness of Stratum (m)	Lithology	Hydrogeology
Quaternary (Q)	139.6	139.6	Clay, fine sand	Specific capacity Top: *q*=0.136-6.713 L/s·m Middle: *q*= 0.698 L/s·m Bottom: *q*=0.00298 L/s·m
Neogene (N)	183.5	43.9	Clay, sandy clay, sand	
Shiqianfeng Formation (P_2^3)	301.9	118.4	Mudstone, siltstone	
	415.5	113.6		
	498.7	83.2	Mudstone, silty mudstone	
Shanshihezi Formation (P2S1)	505.1	6.4	Mainly sandy mudstone, sandstone, siltstone	
	712.2	207.1	Coarse sandstone	
	845.0	132.8	siltstone, sandy Mudstone containing non-coal seam	
Xiashihezi Formation (P_{1x})	929.2	84.2	Mudstone, siltstone, coal seams, Interbedded shale and siltstone	*q*=0.036 L/s·m
Shanxi Formation (P1S)	1020.2	91.0	Mudstone and silty sandstone, Coal seam 2, Fine sandstone	q=0.047 L/s·m
	1065.4	45.	Mainly limestone, Fine-grained sandstone	q=0.000461-3.69 L/s·m
Taiyuan Group (C3t)	1120.6	55.127	Mudstone, Limestone	
	1141.6	21.0	Limestone and Mudstone	q=1.216 L/s·m Sodium calcium sulfate type water
Benxi Formation (C2b)	1155.3	13.7	Aluminum Mudstone	
Majiagou Formation (O2m)		206.56-423.32	Limestone	q=0.633 L/s·m, Sodium sulphate calcium type water, Salinity =3.5 g/L

Method

Because geological prospecting is urgent for the Gedian Coalmine, a quick, economic and feasible prospecting plan should be carried out. Underground drilling, geochemical water test, the in-situ stress test and laboratory test methods were adopted with a full use of existing underground roadways.

Aquifer test

In order to characterize the hydrogeology of the Taiyuan Formation, five boreholes into limestone aquifers L7 – L13 were designed. Among them, one borehole was outflow well, the others were observation wells. The depth of the boreholes varies from 165 to 193 m from tunnels at an elevation of -600 m. The boreholes have an initial diameter of 190 mm and a final diameter of 75 mm.

The outflow test started on May 19, 2011, 10 AM. The flow rate was around 70 m³/h. The test finished on May 25, 2011, 16 PM, lasting for 150 hours. After the closure of valve, there was an observation of water level recovery. Figure 3 shows the results of aquifer tests in pumping borehole and 4 observation boreholes, and their locations are illustrated in Figure 4.

Tectonic structures

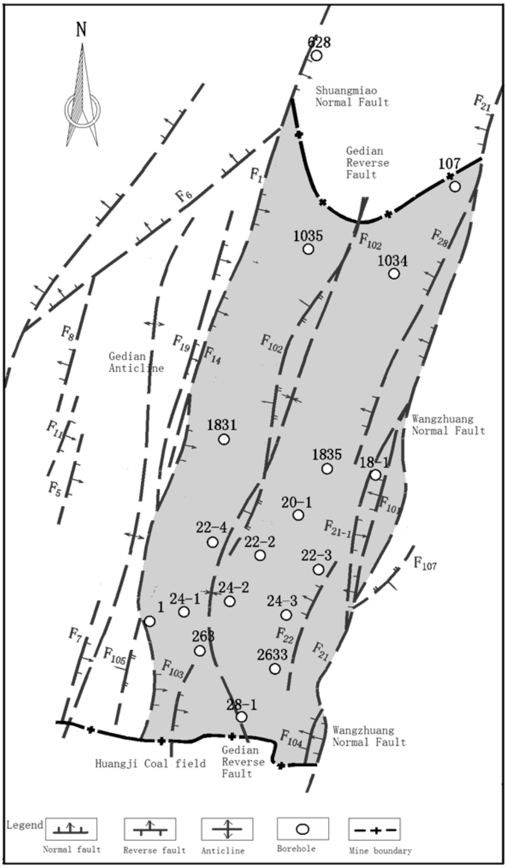


***Figure 2** Tectonic structures of the Gedian Coalmine*

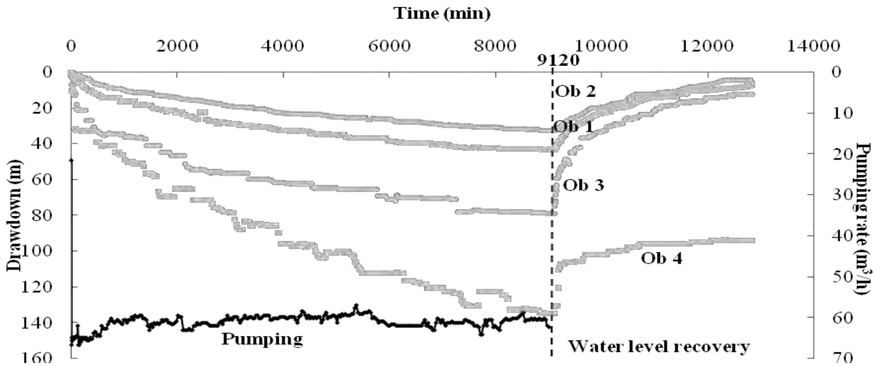


Figure 3 *The results of Aquifer test*

Measurement of in situ *stress*

The boreholes for aquifer test were also used to investigate in situ stresses for saving time and costs. The hydraulic fracturing method was applied to measure geostress in two observation boreholes. Each of the fracturing sections must be fractured four or five times to obtain reliable fracturing parameters. Table 2 shows geostress test results.

Table 2 *Geostress tests results in two boreholes*

Depth (m)	Lithology	Geostress in Ob 1 (MPa)			Geostress in Ob 2 (MPa)			S_H Direction
		P	S_H	S_h	P	S_H	S_h	
109.85-110.55	Coarse-grained sandstone	2.00	13.23	9.29	2.20	12.84	9.10	—
117.55-118.25	Fine-grained sandstone	1.80	13.45	9.45	2.00	13.42	9.48	N62.43°E
123.75-124.45	Sandy mudstone	1.90	13.69	9.65	1.70	15.28	10.54	—
128.1-128.85	Mudstone	2.60	14.33	9.97	0.00	13.62	9.58	N56.78°E

The geostress test is mainly carried out within 30 m deep from the coal seam floor. Geostress tests were measured on 11 test sections, and in situ stresses were successfully gained in 9 sections. The results show that maximum horizontal principal stress is 12.84-15.28 MPa and the minimum horizontal stress is 9.10-10.54 MPa. The vertical principal stress S_V is calculated to be 19 MPa according to a depth of 730m and a rock unit weight of 26.0 kN/m^3. It indicates that the vertical stress is larger than the horizontal stress in the study area. Pressure and time relation curves show that rock mass with different structure has different response to water pressure, and the following three criterions were proposed for floor safety assessment:

$I_1 = P_W/S_h < 1, I_2 = P_W/P_r < 1, I_3 = P_W/P_b < 1$

where I_1 is the coefficient factor for fractured rock mass; I_2 for fissured rock mass; and I_3 for integral rock mass; P_W is water pressure; S_h is the minimum horizontal stress; P_r is reopening pressure; P_b is fracture pressure of rock mass.

Calculation of hydrogeological parameters

Unsteady flow theory was used for calculating the hydrogeololgical parameters. An *s*-lg(*t*) line diagram method which also called Jacob approximate formula is described as follows (Samuel and Jha, 2003).

(1) Draw an *s*-lg(*t*) line diagram on logarithm scale.

(2) Intercept a logarithm period on the logarithm coordinate axis to make sure Δlg(*t*)=1,and the Δ*s* is the slope of the line

$$\Delta s = \frac{2.30Q}{4\pi T}$$

Where *Q* is outlet flow, *T* is transmissivity.

(3) Measure the intercept t_0 on the coordinate axis (*s*=0) of the line, then

$$\lg \frac{2.25Tt_0}{r^2 S} = 0$$

Where *S* means storage coefficient, and can be calculated.

(4) According to the formula

$$T = K * M$$

K can be got

$$K = T / M$$

There were four observation boreholes in the water outflow test. The outlet flow *Q*=70 m^3/h, and the mean thickness of aquifer *M*=11 m. Table 3 shows the results.

Hydrogological delineation and drainage prediction

Hydrogeological division for the Taiyuan Formation limestone aquifers is based on tectonic line direction (Figure 2), water level isotropic line and the pumping test data (Figure 3 and Table 2). Figure 4 shows the hydrogeololgical division of the Gedian Coalmine.

Section I is in the north of the extended area of the Gedian Coalmine. The boundary is the axis of anticline line 17.

Section II is in the west of the extended area, between the exploratory lines 17 to 23. North and south boundary are anticline line 17 and 28. Observation borehole 1 is located in this section. The Liuzhuang Syncline and Anticline 28 are in this section. The relative uplift stratum results in rich groundwater and a strong runoff zone, as in the mines with similar geological conditions in North China.

***Table 3** Calculating results by linear graphic method*

Boreholes	Pumping			Water level recovery		r (m)	S (m)	K (m/h)
	Initial water level	Final water level	Drawdown	Recovery water level	Difference with initial			
Ob 1	-205.1	-248.858	43.758	-212.24	-7.14	335	0.0025	0.0732
Ob 2	-175.182	-207.414	32.232	-179.06	-3.88	315	0.0052	0.0938
Ob 3	-108.12	-186.967	78.846	-93.13	14.99	155	0.0028	0.1508
Ob 4	-140.11	-274.654	134.538	-235.89	-95.78	150	0.0108	0.1307

Section III is in the southwest of the extended area. North boundary is anticline axis line 28; its west boundary is the Fault 21 and east boundary is Shuangmiao Syncline axis. Observation borehole 2 and 4 are located in this section. The hydrogeological condition for this section is simple due to its lower groundwater level and drainage into the north western mined-out area.

Table 4 *Back analysis for hydrogeological parameters*

Divisions	Hydraulic conductivity		Storage coefficient (*S*)
	*K*x (m/h)	*K*y (m/h)	
I	0.192	0.192	9.75E-08
II	0.234	0.234	9.975E-08
III	0.228	0.228	4.75E-07
IV	0.018	0.018	5.875E-06

Section IV is in the southeast of the extended area. Its north boundary is axis of anticline line 28, west boundary is Shuangmiao Syncline axis and east boundary is Fault 21. Observation borehole 3 is located in this section. Section IV will be the first mining district for the Seam 2. Most of this section is located in the Taiyuan Formation limestone area with high groundwater level, the aquifers are recharged not only by the Ordovician limestone aquifers but also by intersection of the Fault 21, and therefore its hydrogeological condition is complex. According to a numerical simulation, hydrogeological parameters in different sections were gained (Table 4) and the inflow rate was predicted (Table 5).

Table 5 *Inflow prediction*

Mining elevation (m)	Normal (m^3/h)	Maximum (m^3/h)
-531	282	493.5
-631	390	682.5
-700	396	693.0

Figure 4 *Hydrogeological division of the Gedian Coalmine*

Conclusions and Recommendations

From the Taiyuan Formation limestone aquifer test results, it can be concluded that the water level of the Taiyuan Formation limestone aquifer in the Gedian Coalmine can be depressurized into a water level for mining safety. Due to the heterogeneity of the limestone fissures, and the hydrogeological conditions of the mine, the boreholes and water inrush points in roadways can be used for drainage.

Assessment on drainage system and ability

The sump in -600 m level is lower than mining district of Seam 2. Therefore, the mine groundwater can flow to the sump automatically. Moreover, there are four large volume pumps with a total drainage capacity of more than 1000 m^3/h, which is bigger than the expected flow rate listed in Table 5.

Drainage and depressurization

Boreholes can be drilled into limestone aquifers from roadways. Because of the high water pressure, groundwater will flow into the roadway automatically. Then, the water will be pumped to ground using the drainage system. Meanwhile, it is easy for encountering groundwater inrush when excavating roadways in the Taiyuan Formation limestone aquifers. Therefore, the inrushing points during excavation of roadways as a drainage option is an effective way for ensuring mining safety. Moreover, the mine drainage capacity is more than 1000 m^3/h which is sufficient for coping with the groundwater inrush in roadways.

The aquifer test results show that the groundwater level in the south and east of the Gedian Coalmine is higher than in the north and west. Therefore, in the north and west, the water pumping and depressurization mining is easier in the subordinate syncline position. According to the results, the water level can be reduced to lower than the safety water head with a drainage rate of 400 m^3/h in half of a month.

Acknowledgements

The authors want to acknowledge the financial support of the National Natural Science Foundation of China under Grant No.51174286 and the Specialized Research Fund for the Doctoral Program of Higher Education under Grant No.20100095110015. It is also supported by "A Project Funded by the Priority Academic Program Development of Jiangsu Higher Education Institutions". We also would like to express our acknowledgements to the reviewers for their constructive comments.

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