Evaluation and Depressurization of an Ordvician limestone confined aquifer in Xingcun coal mine

Sun Yajun, Sui Wanghua, Dong Guiming, Liu Shucai, Yu Jingcun

China University of Mining and Technology, 1 Daxue Road, Xuzhou, Jiangsu, 221116, China, syj@cumt.edu.cn

Abstract The maximum groundwater pressure of the Ordovician limestone aquifer is 12.97 MPa in the Xingcun coal mine. The coal mining is unavailable due to the risk of water inrush. In order to evaluate the depressurizing feasibility of the aquifer, a comprehensive method was proposed and applied. The time domain electromagnetic (TEM) exploration indicates the groundwater storage in the limestone with intensive nonhomogeneous karst development. Based on the hydrogeological test, the drawdown and its velocity were calculated. It shows the depressurizing of the aquifer is feasible. As a result of depressurization, the water pressure was finally reduced and the risk of water inrush was avoided.

Keywords depressurization, Ordovician limestone, confined aquifer, water inrush

Introduction

In the eastern part of China, the Ordovician limestone confined aquifer (OCA) is known for its intensive nonhomogeneous karst development, abundance of groundwater and high water pressure. For many coal mines, the OCA lies below the coal seam with thickness of 650-800 m (Wu 2006, Peng 2007). Generally, an aquifuge separates the aquifer and the coal seam and makes the mining available. But more than a thousand disasters of groundwater inrush into coal mines were induced because of high water pressure and insufficient aquifuge thickness. At least 35 coal mines were flooded and thousands people lost their life (Shi 2001). The maximum water inflow in a coal mine, Fangezhuang, has reached as much as 2053 m^3/min (Zhang 2005).

Dewatering and grouting are the technical choices to eliminate the possibility of water inrush and ensure the mining security, but dewatering or depressuring is generally not recommended due to expensive cost and environmental problems resulted consequently (Li 2006). In fact, it is difficult to generate effective drawdown for OCA with steady and sufficient recharge in most cases. If the aquifer is in an isolated hydrogeological unit with limited recharge, it can be achieved by dewatering OCA to depress the water level to the safe value corresponding to the aquifuge. With the practical example in Xingcun coal mine, this paper describe a comprehensive method involving geophysical exploration, hydrogeological test and calculation to evaluate the feasibility of depressurization of OCA.

Hydrogeological background

Located in Shandong, China, Xingcun coal mine is now mining the coal seam No. 3 in the lower Shanxi Group Formation of the Permian system, with thickness of 7.15 m and elevation from -1010 to -1100 m. The Ordovician limestone is below the coal seam with water level of +5.59 m. Regionally, the maximum groundwater pressure is 12.97 MPa, while the aquifuge thickness between the aquifer and the coal seam is 215.6 m.

E3206 is a work face in Xingcun coal mine, which is located in the hangingwall of fault DF39. The fault DF39 uplifts the Ordovician limestone in the footwall, making the distance between the work face and the opposite Ordovician limestone decreasing from 215.6 m to

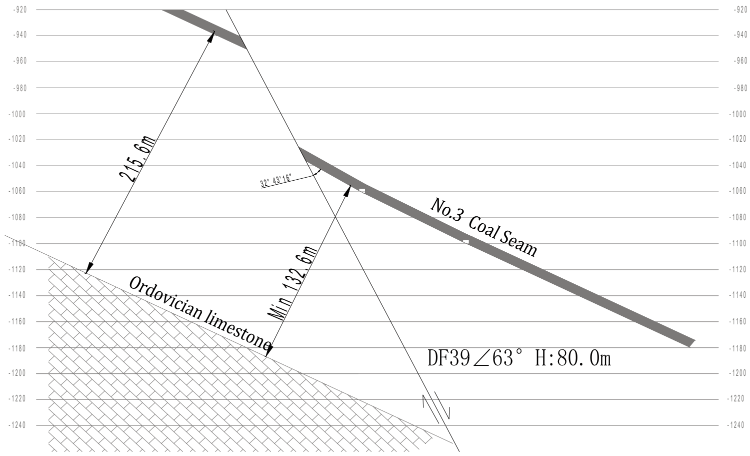

Fig. 1 *Hydrogeological profile of E3206*

132.6 m. Hydrogeological structure of the coal seam, work face, fault and the aquifer is schematically illustrated in Fig. 1. To the aquifuge of E3206, the water pressure reaches 12.97 MPa. The coal mining is under a ultra-high water pressure of confined aquifer as well as the complex tectonic conditions. The coal mining is therefore unavailable due to the risk of water inrush in this case, and the water level has to be depressed to a safe value before coal mining.

Methods and Analysis

In order to evaluate the depressurizing feasibility of the OCA with high pressure in the coal mine, we proposed and applied a comprehensive method involving geophysical exploration, hydrogeological test and calculation.

Geophysical exploration

Considering the nonhomogeneous karst development in the Ordovician limestone, the geophysical exploration of time domain electromagnetic methods was used in the E3206 to investigate the distribution of lower electrical resistance areas in the aquifer, which indicate the groundwater storage in the limestone. A total of 40 measuring points were designed by every 10 m along the E3206 track transportation tunnel. Each point investigates two directions towards floor and side. The result shows that the water stores only in the light grey area (Fig. 2).

Hydrogeological test

We conducted a hydrogeological test with a surface observation well (S5) and an under-

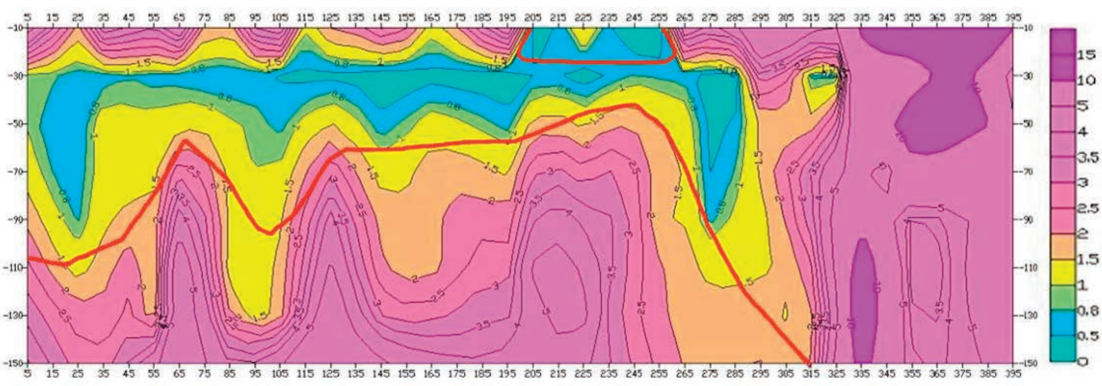

Fig. 2 *Apparent resistivity section of the floor of track tunnel for E3206 work face.*

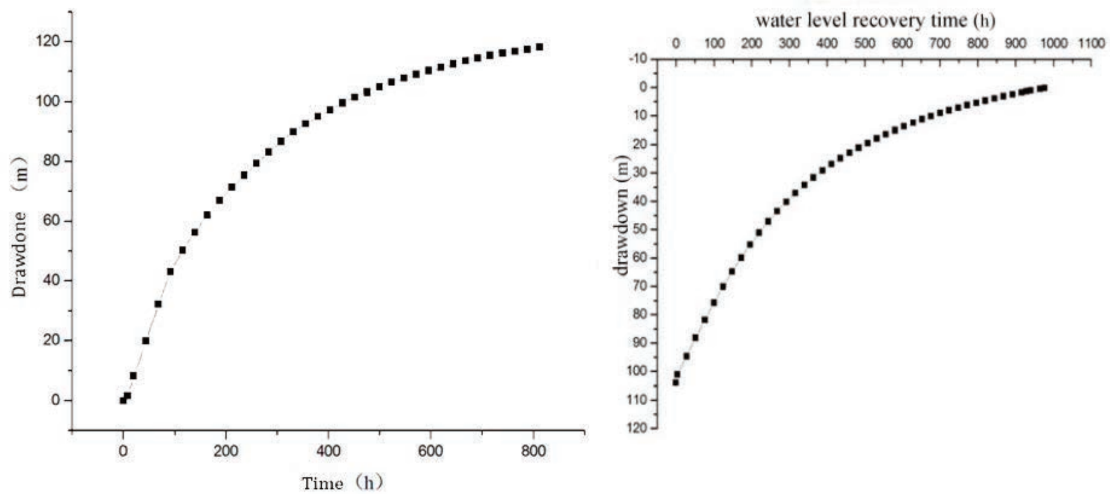

Fig. 3 *Curves of drawdown-time in S5 during the dewatering and recovery tests. left: dewatering; right: recovery.*

ground borehole (S2) in the coal mine to determine the groundwater abundance of the OCA and its hydrogeological parameters, such as the transmissivity (T) and the specific yield (q). The underground borehole S2 acted as the main dewatering drilled well of Ordovician limestone aquifer, and S5 as the water level observation well. We carried out two dewatering and two recovery tests. Some data of drawdown (water level) variation with time during the dewatering and recovery observed in S5 are as in Fig. 3.

Analysis of water abundance of Ordovician limestone

Fig.3 shows that the water level in S5 decreases gradually during the dewatering and rises slowly during the recovery in the two tests. So we can preliminarily draw the conclusion that the recharge of the Ordovician limestone aquifer is not sufficient. The parameters are calculated by Jacob linear distribution method and the water level recovery data. The results list in Tab. 1.

By the hydrogeological test, we obtained the specific yield of the aquifer as 0.01864 L/(m·s). The drawdown speed and the hydrogeological parameters indicate that the groundwater in the OCA in this coal mine is not as abundant as in other areas. We reasonably presume that the faults around the work face cut off some of the lateral recharge. This provides a very important basis for generating an enough drawdown by dewatering or drainage.

Parameters	Results in the first test	Results in the first recovery test	Results in the second test	Results in the second recovery test	Average results
Transmissivity T（m^2/h）	0.11	0.149	0.12	0.0643	0.115
storage coefficient S	1.71×10^{-5}		1.4×10^{-5}		1.56×10^{-5}

Table 1 *Parameters calculated by the hyrdrogeological tests*

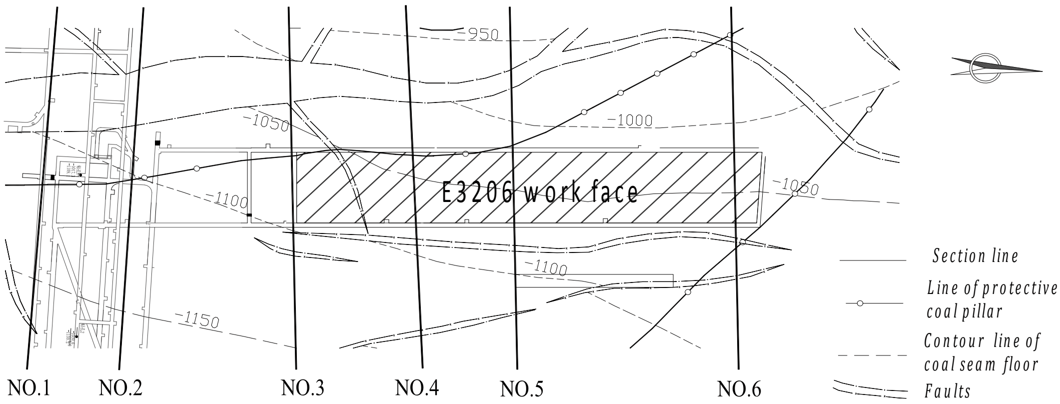

Fig. 4 *Distribution of the six section lines in E2306 work face*

Evaluation and Application

In order to evaluate the feasibility of depressuration of the OCA in this coal mine, we calculated the drawdown and time needed to eliminate the possibility of water inrush by two steps.

Calculating the drawdown needed

We calculated the water pressure which is in the safe range corresponding to the thickness of aquifuge. Considering that the water pressure and the thickness of aquifuge are not exactly the same at different locations due to the formation slope in E3206, six section lines were set up to determine the specific data for calculating the drawdown (Fig. 4).

We used the water inrush coefficient method (Eq. 1) to estimate if it is safe or dangerous in the cases of mining on a confined aquifer. By comparing with the critical value of water inrush coefficient, the water pressure allowed was calculated and then induced to the drawdown.

$$T = P/M \quad (1)$$

Where T is the water inrush coefficient (MPa/m), P is the groundwater pressure of floor aquifer (MPa), and M is the aquifuge thickness between the confined aquifer and the coal seam (m). The critical values of water inrush coefficient is 0.06 MPa/m in the area of fault well developed and 0.1 MPa/m in others. According to the aquifuge thickness at the six section lines, we determined the safety drawdown required to avoid water inrush (Tab. 2).

Forecasting the groundwater field variation during depressurization

For an engineering application in coal mines, the feasibility of depressurization of OCA also depends on the time which is needed to lower the water level to a safe value, therefore the drawdown of the water level and the spreading velocity of the cone of depression were calculated based on the specific hydrogeological parameters and given flowing drainage wells. We designed several different dewatering plans with different number of wells and different flow quantity, and then forecasted the groundwater field variation in the Xingcun coal mine area by the methods of the Theis equation and numerical simulation.

By comparing the forecasting results of different drainage plans, we found that the drawdown would meet the requirement after 60 days with two drainage wells and flow quantity of 120 m^3/h in the area of E3206 work face. The maximum drawdown would reach 580 m at the centre of the cone of depression and 320 m at the end of the work face. The original flow field before drainage and the

Section line	Water pressure in Ordovician limestone （MPa）	Distance between Ordovician limestone and No.3 coal seam （m）	Water inrush coefficient （MPa/m）	Safety water pressure （MPa）	Safety drawdown （m）
No.1	12.975	150	0.087	9.00	405
No.2	12.775	143	0.089	8.58	428
No.3	12.39	145	0.085	8.70	376
No.4	12.39	171	0.072	10.26	123
No.5	12.39	191	0.065	11.46	95
No.6	12.78	215	0.059	12.90	0

Table 2 *Evaluation results by water inrush coefficient method*

forecasting drawdown after 60 days are illustrated in Figure 5.

Application result of depressurization

Two underground flowing drainage wells near the E3026 work face, S2 and S6 (the black circles in Fig. 5), were used to drainage the groundwater in the OCA. The flow quantity of S2 and S6 were respectively 39 m^3/h and 57 m^3/h. Finally, the water pressure of the Ordovician aquifer in E3206 was finally reduced to 2.2 MPa, and the risk of water inrush was avoided. The actual depressuring result of the aquifer is illustrated in Fig. 6. The coal mining finished successfully and safely by the end of 2012.

Conclusions

E3206 work face mining began on 5/29/2012 and ended on 11/18/2012 without water inrush caused by Ordovician limestone and faults. The mining and calculation results of drainage show that depressurization is an effective way to prevent and control the water inrush in this

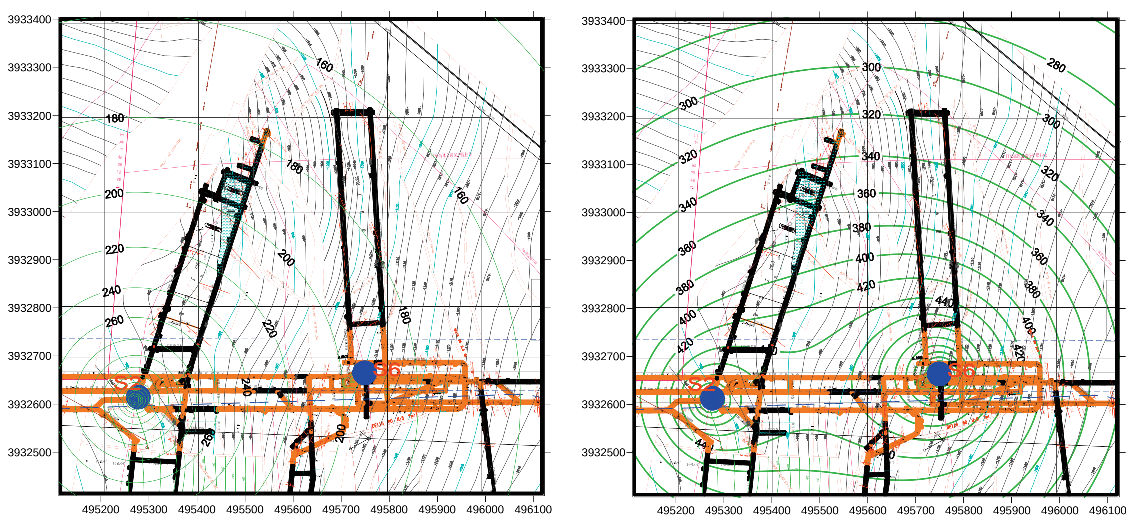

Fig. 5 *left: Contour map of drawdown before drainage in E2306 work face; right: Contour map of forecasting drawdown after 60 days of drainage*

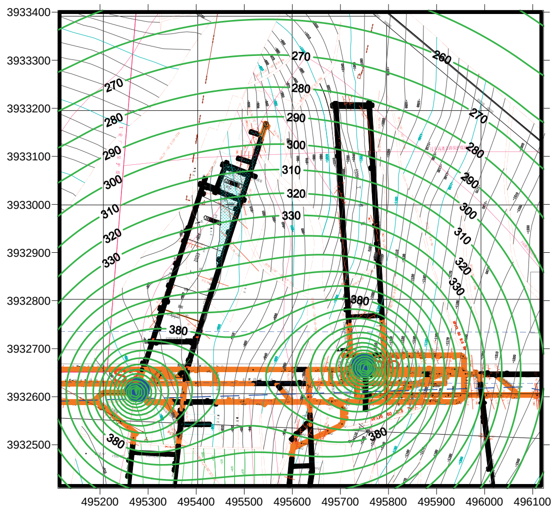

Fig. 6 Contour map of drawdown after drainage and before mining in E2306 work face.

region, and the comprehensive method with geophysical exploration, hydrogeological test and calculation is available to evaluate the feasibility of depressurization in the case of the limestone aquifer with high pressure and intensive nonhomogeneous karst development.

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