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Numerical Simulation and Inflow Prediction by the Outflow Test of Coal Mine

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Abstract This article, by using the east mining area outflow water test data of No. 5 coal mine in Fengfeng coal field, presents a numerical simulation of groundwater flow and a prediction of drainage. First of all, according to the hydrogeologic condition, the groundwater seepage numerical model of this mining area is established. Then, the model is verified by using the drainage experiment data. The measured and simulated water levels of observation wells fit well during the model verification. Finally, the water inflow of the coal mine is forecasted by using the established model. The result of the prediction has shown that it is feasible for the Daqing limestone aquifer to take measures of the water discharge method for the safety mining of Shanqing coal seam below -100 m level.
Keywords Fengfeng coal field, drainage experiment, mine water inflow, numerical simulation, water inrush coefficient

Introduction

Fengfeng coal field is located in the south of Hebei province. The eastern part of the field is the North China plain, and the western is Mount Tai-hang. It’s the Drum Mountain which located in the center of the coal field that divided the whole field into two parts. The study area is in the center of the east Drum Mountain, and its landform presents to be hilly region.

There’s no a natural river or large surface water in the mining field. The data gathered from Fengfeng weather station demonstrates that the annual mean precipitation is 566 mm, and mainly concentrated in late summer (July to September).

Hydrogeological characteristics

Geological conditions

The stratum of No. 5 mining field is classified as the North China type and it contains Ordovician (O), the Carboniferous (C), Permian (P) and Quaternary (Q) system. As the bedrock is mostly covered by the Quaternary system, the outcrop area becomes very small. The Ordovician is outcropped in the Drum Mountain located on the west of the mining field, and the field that buried under C-P stratum，which contains 7 minable coal beds and 5-8 layers of thin limestone, constitutes basement strata.

The whole structure of the field presents itself as a rift structure whose edge uplifts, whereas the center drops. The faulted structures are well developed and among which are mostly high-angle normal faults. The overall structure is ore anticline.

Hydrogeological characteristics

According to geological structures and hydro-geological features, the field has been classified into three hydrological areas, namely the northwest area, the central part and the east limb area which is the emphasis of this article.

At present, the aquifers that threaten the mining security are mainly Daqing limestone aquifer(The Carboniferous thin limestone)and the Ordovician limestone aquifer.

(1) The Daqing limestone aquifer: This aquifer is the direct roof of Daqing Coal Seam, which is 45 m away from the upper Shanqing Coal Seam and 28 m away from the O_2 limestone below. The thickness is between 4 to 6 m, and its distribution is stable. The fissure is well-developed with good water-abundance capacity. The discharge of a single hole down-well is 2~3 m^3/min. Its hydro-chemical type is $HCO_3 \cdot SO_4$-Ca·Na, the degree of mineralization is 0.45~1.1 g/L, and the pH value is 6.4~8.0. Ordovician Limestone water recharges the Daqing limestone aquifer with plutonic confined karst fracture water laterally. The water storage capacity of Daqing limestone is limited because of its small thickness. As the influence of mine drainage perennially, the aquifer would have been dewatered if there is no recharge from the Ordovician Limestone water. Therefore it is the Ordovician Limestone water that supplies mainly the Daqing limestone aquifer. What's more, its main drainage method is mine drainage.

(2) Ordovician limestone aquifer: Its thickness is 545 m, The karstic fissure is also well-developed with good water-abundance capacity. The discharge of a single hole down-well is 1.5~4 m^3/min. Its hydro-chemical type is $HCO_3 \cdot SO_4$-Ca·Mg, the degree of mineralization is 0.5 g/L, and the pH value is 7.4~9.3. The karstic confined aquifer with strong water-abundance capacity constitutes a great threat to safety mining.

Drain test numerical simulation

The east area of Daqing limestone water drain test profile

The drainage test abstract to the east limb of Daqing limestone

The Eastern area is one of the primary regions of production. The further study of hydrogeological conditions is to provide foundation to ensure safety in mining Shanqing coal seam below -100 m. It is high time to operate the Daqing limestone drainage test. The water discharge scouring time is from 1996.4.15 to 1996.4.23, its drainage stratum is located in the Daqing limestone aquifer, and its discharge is 1.2~1.6 m^3 min. There are two drainage holes: Hole FD34, Hole FD22, six Daqing limestone observation holes, that is Hole FD16, FD21, FD23, FD20, FD32, FD33, and one Ordovician limestone observation hole: Hole FO8. After observing all the holes on April 13th to 15th, a table presented original water levels of the whole was listed. See table 1.

Table 1 *The water level of east wing area before the drainage*

No.	FD16	FD22	FD33	FD20	FD23	FD34	FD21	FD32	F08
Water level (m)	+106	+108	+66	+112	+110.5	+103	+92.5	-31.6	+114

The general hydrogeological conditions in the east area

Boundary

East limb area is located in the eastern part of the mining field, east to F12 fault, west to F11 fault, and these two faults intersects in the north and the south boundary of the field, which makes the area on the plane just like a date stone. It covers an area of 1.2 km^2.

Hydrodynamic conditions

Before drainage tests, the water level in the eastern part that closes to F12 fault is the lowest. After drainage test, a depression cone is formed whose center is Hole FD34. The core is expanded along the north and south direction-the south extension is further-and is consistent with the major axis direction of the East Limb area, however the water level which is near to

F12 fault is still low. The drawdown formed from the drainage test is between 20 m to 80 m from south to north. The maximum drawdown reaches 83 m in FD34 plughole. Every water level of observation holes will soon become normal after stopping the drainage, and it will close to the former water level.

Aquifers

The discharge of a single well down-well in the east area of Daqing limestone is 0.1~0.3 m^3/min, the maximum is 2.8 m^3/min(FD34). The fissure is well-developed in this area which weakens water-resisting property of the confining bed below, and there is Ordovician limestone with high pressure under the layer. Therefore the condition is satisfied that the Ordovician limestone aquifer leakage up recharge Daqing one. It is the Ordovician Limestone water that supplies mainly the Daqing limestone aquifer. After drainage test, put the fluorescent yellow 3 kg into Hole FO8, then the FD34, FD16 hole has received one after another, which also proved the former point. Therefore, the Daqing limestone aquifer in east limb area can be generalized as the heterogeneous 2D confined water flow system model.

Mathematical model

Daqing limestone aquifer hydrogeological model can be described available as the following mathematical model:

$$\begin{cases} \frac{\partial}{\partial x}(T\frac{\partial H}{\partial x}) + \frac{\partial}{\partial y}(T\frac{\partial H}{\partial y}) + K_1\frac{H_1 - H}{M_1} + Q = S\frac{\partial H}{\partial t} \\ H(x,y,t)\big|_{t=0} = H_0(x,y) \qquad (x,y)\in\Omega\ ,\ t=0 \\ T\frac{\partial H}{\partial n}\big|_{\Gamma_2} = q(x,y,t) \qquad (x,y)\in\Gamma_2\ ,\ t>0 \end{cases} \tag{1}$$

Notes

H—Daqing limestone aquifer water level (m);
H_1—Ordovician limestone aquifer water level (m);
H_0—Daqing limestone aquifer initial water level (m);
t—Time (d);
T—Daqing limestone aquifer hydraulic conductivity coefficient (m^2/d);
S—Daqing limestone aquifer storage water coefficient (non-dimensional);
K_1—The leaky layer permeability coefficient (m/d);
M_1—The leaky layer thickness (m);
Q—The source sink term (m^3/d);
q—The boundary single wide flow rate (m^3/d), zero for impervious boundary;
Ω—The seepage area ;
Γ_2—The second boundary of the seepage area;
N—The point (x, y) outside normal direction on the boundary of Γ_2.

$$\sum_j C_{ij}\left(H_j^{k+1} - H_i^{k+1}\right) + D_i\left(H_{1i}^{k+1} - H_i^{k+1}\right) + Q(i) = F_i\frac{H_i^{k+1} - H_i^k}{\Delta t} \tag{2}$$

Notes

C_{ij}—The lateral water coefficient;
D_i—The potential coefficient of water;
Q(i)—The vertical water;
F_i—The storage capacity of the coefficient of water;
i, j—The node number (i, j = 1, 2,..., n, n for node number);
H_{1i}—The node I on Ordovician limestone level;
H_i—The node I that the Daqing limestone water level;
t—The time step;
k—The calculation time (k = 1, 2,..., m, m for time number).

If use $\boldsymbol{X}$ says unknown water level $\boldsymbol{H}$ column vector, using $\boldsymbol{A}$ said equations of coefficient matrix, $\boldsymbol{b}$ said constant term array, the above numerical equations can be written as $\boldsymbol{A}$ matrix form:

$$\boldsymbol{AX} = \boldsymbol{b}$$

Coefficient matrix $\boldsymbol{A}$ is one who has $\boldsymbol{A}$ diagonal advantage height sparse symmetric positive definite matrix, for large sparse matrix using iteration method is appropriate to solve based on the successive over relaxation (SOR) iterative method.

Model identification and debugging

Daqing limestone aquifer hydrogeological model can be described as the following mathematical model:

East limb area split results: triangle unit number is 142 (Numbers 2, 3,..., 143), 87 points (Numbers 2, 3,..., 88), including 30 boundary knot points(for kind boundary node) (fig.1). Pumping well node is 2, select fitting of Daqing limestone aquifer observation hole is 4.

With the east limb area of Daqing limestone water drain test data for model identification, simulation time of 11500 minutes(1996.4.15-1996.4.23) can be divided into a total 43 periods (n t = 43). Time step--Δt=10-500 minutes, getting step length, drain initial water level drawdown fast, use small t =10 minutes, and then gradually increase step length, relatively step length t=500 minutes. The initial water level is the measured level before drainage test (see table 1). The determination of initial parameters, according to drainage test data and water recovery data with groundwater dynamics and formula given, the initial value can be calculated by using water level drawdown curve and water recovery curve.

By constantly adjusting parameter, to make simulation of water level dynamic curve and measured water level dynamic curve achieve better fitting. The water level simulated at 11500 minutes is shown in fig.2, the four observation holes fitting curve is shown in fig.3.

Through the model identification, aquifer parameter of Daqing limestone aquifer can be classified into 3 regions. The size of different regions' parameters see table 2. The simulation shows that it is the Ordovician Limestone water that supplies mainly the Daqing limestone aquifer. Though the discharge is small, it is quite big the drawdown of the observation holes in Daqing limestone area. The maximum drawdown of Hole FD34 is 83 m. When the water level recovery, each observation well water level recovery quickly each observation well water level have been returned to normal after 24 hours. These characteristics show that the East Limb District, Daqing limestone storage water, recharge water flowing fractured but fissures' connectivity is good and dewatering is easy. Experienced a substantial decline in the water level and the rising process model identification is very important, the use of such a large change can be better test of the model. Coverage of the observation wells used to validate the model is relatively large, both in southern and northern, and the observations the hole calculated and measured water level changes in the process of fitting better. So the model is correct, the numerical method is feasible to achieve a numerical simulation of the effect, you can take advantage of the model hydrogeological aspects forecast.

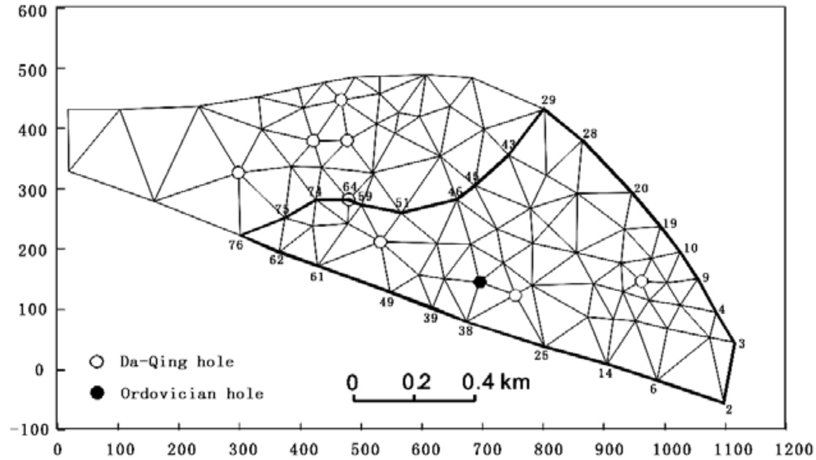

Fig.1 *Eastern subdivision graph*

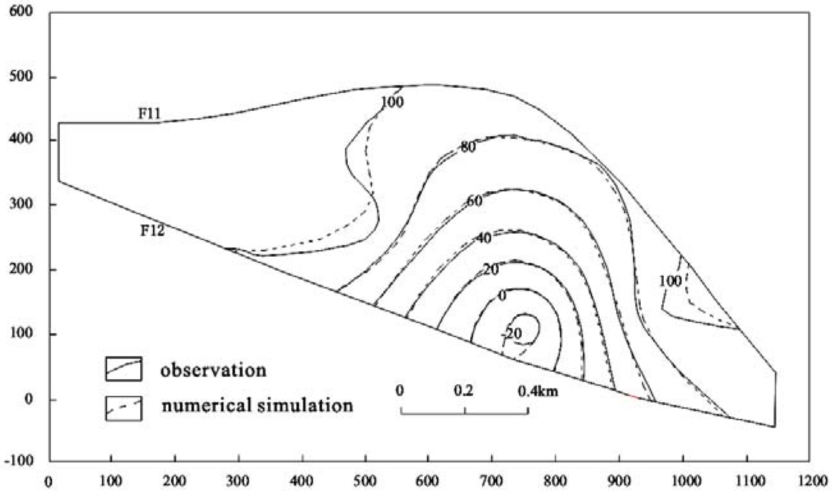

Fig.2 *Simulation of water level*

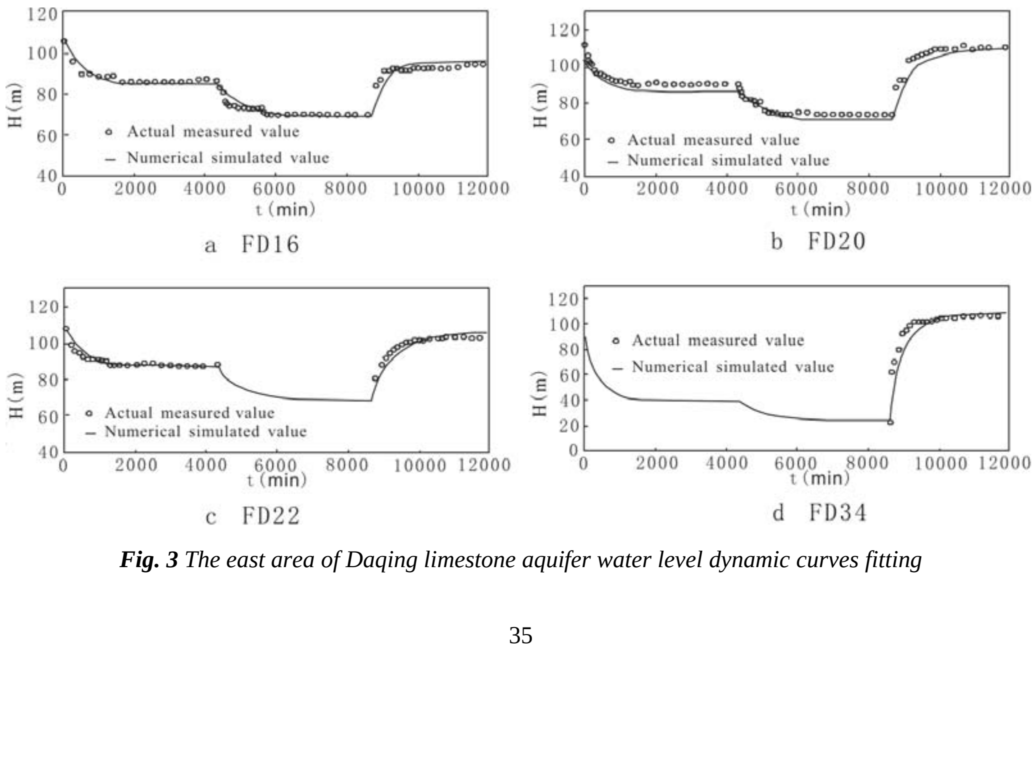

Fig. 3 *The east area of Daqing limestone aquifer water level dynamic curves fitting*

Table 2 *Prediction of dewater for different levels of east area*

Partition	1	2	3
Transmissibility coefficient T (m^2/d)	70	60	30
Storage coefficient S	0.00002	0.00003	0.00001
Leakage coefficient K_1/M_1	0.00004	0.00004	0.000004

Hydrophobic mining forecast of Shanqing seam below -100 m

Because the water level of Daqing limestone aquifer is high and water head pressure is big, to ensure the safety of coal mining 100 m below the level of Shanqing, Daqing limestone aquifer beneath implementation of the hydrophobic buck. Forecast range:-100~-170 m Shanqing seam contour delineation of the range (fig.1 in thick lines delineated range). Impermeable layer thickness determination of borehole data: East Wing area, Shanqing stratum rock roof of the coal seam floor surface spacing of 34-50 m, the average thickness of 40 m.

Security head of calculation formula for the coefficient of water bursting:

$$c = \frac{P}{M} \tag{3}$$

Notes

P— water pressure under the floor (Pa);

M—Water-resisting layer thickness (m);

c—The allowed water pressure of every meters water-resisting layer (Pa/m).

For the reservoir of Daniudi gas field, pore types are mainly intergranular pores and intragranular dissolved pores. The reservoir rock volume models, and acoustic and density log response equations had been established based on the actual situation. The porosity was obtained by solving the equations and also corrected for muddy, residual oil and gas. The porosity was calibrated by core porosity, and makes it more accurately.

$$P_l = M_s \times c \tag{4}$$

Notes

P_l—The safety head pressure in theory (Pa);

M_s—The actual water-resisting layer thickness (m).

First prediction of water inrush coefficient formula to calculate the theoretical safety head pressure = 2.4 MPa, and then converted to the security level of the different levels of exploitation. This article takes c=0.06 stope safety water pressure calculation. -120 m level of safety of the water level by calculating 80 m, it is necessary to guarantee the safety of coal -120 m level Shanqing stoping, Daqing water level must not exceed 80 m, otherwise it will lead to the occurrence of water inrush -150 m level security water level is 50 m ,-170 m level of safety of the water level of 30 m.

Now predict from the following three levels: ①-120 m ②-150 m ③-170 m level. From the east wing area of Daqing limestone aquifer, the single span water inflow is generally 0.1~0.3 m^3/min, the maximum can be 2.8 m^3/min. So each node to predict the water general set to 0.5~1.5m^3/min, hydrophobic decompression hole position arrangement in the near FD34 hole. Different levels hydrophobic precipitation forecast can be 2~5 m^3/min(see table 3).

Table 3 *prediction of dewater for different levels of east area*

Level（m）	-120	-150	-170
Security level (m)	80	50	30
Flow rate (m^3/min)	2－3	3－4	4－5
Dewatering time (h)	12－13	16－24	16－24

Conclusions

From the prediction of drainage test to numerical simulation, it shows that Daqing limestone aquifer in the area of east wing has the characteristics of high water pressure, few water volume, easy to discharge. As long as appropriate measures, getting prepared to prevent Ordovician limestone water irruptive work, it is feasible for the Daqing limestone aquifer to take measures of the water discharge method for the safety mining of Shanqing coal seam below -100 m level.

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