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Fast Numerical Method to Calculate Mine Water Yield

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Abstract Mine water yield is the main gist for the drainage facilities and prophylactic therapeutic measures of water for department of mine designing. In order to use the numerical method to calculate the mine water yield rapidly, programs are written to obtain mine water yield of inner boundary, and to measure water level and hydraulic gradient with boundary element method. Programs have been tested to run properly. The paper analyzes Xin'an mine hydrogeology and pumping experiment data, then establishes mathematical model. Compared results of large-well method with results of BEM, it shows that results of large-well method are greater than results of BEM. Reasons are listed as follows: a) The actual aquifer has a certain gradient, but large-well method assumes that aquifer is horizontal. The boundary element method supposes that one side of aquifer is zero flow boundary and other sides is specific head which means that the aquifer has a certain gradient. This model is clearly closer to the actual situation. b) Large-well method puts inner boundary as an equal-area circle, however, BEM applys to the actual situation.
Keywords mine water yield, numerical simulation, boundary element method(BEM)

Introduction

Mine water yield refers to the amount of water inflow to the mine in unit time at the process of mine construction and production. It is the main gist for drainage facilities and prophylactic therapeutic measures of water for department of mine designing. Water balance method and relevant analogy method were used at the early stage of calculation of mine water yield, and then with the development of computer science, hydrogeologists began to introduce the numerical method into calculating mine water yield (Brebbia 1980,1984). The numerical method includes finite difference method, finite element and boundary element method. Discretization is only needed to be over the boundary of the body, making the numerical modeling with the BEM easy and reducing the numerical of unknowns by one order. Thus, a remodeling to reflect design changes becomes simple. The method is particularly effective in computing the derivatives of the field function (e.g., fluxes,strains). It can easily handle concentrated forces and moments, either inside the domain or on the boundary. The method is well suited for solving programs in domains with geometric peculiarities, such as cracks (Katsikadelis 2002).

Regional hydrogeology

Xin'an coal mine, Zaozhuang mining (group) co., LTD. ,is located in Liuzhuang town, the west side of Tengzhou City, Shandong Province. Range: Binhu coal mine as the northern boundary, the Ordovician outcrops as the southern boundary, 41 prospecting line as the eastern boundary, 57 prospecting line as western boundary. 3302 coal face strike and trend reach to 554 m and 234 m respectively. It is a monoclinal structure in general. Dip angle of coal seam is between 6° and 16° and the average is 8°. Main coal-bearing strata is in Shanxi group whose extracting seam thickness reaches 8.5m at average. The direct aquifer of coal seam comes from conglomerate in upper of Jurassic and sandstone at the bottom of Quaternary. According to the existing pump experiment data, specific field of Jurassic conglomerate aquifer and Quaternary sandstone aquifer reach 0.00708~0.815 L/s·m and 0.0508 L/s·m respectively.

Establishment of model

The hydrogeological conceptual model

We need to generalize the actual hydrogeology to establish the hydrogeological conceptual model before establishing numerical model of the groundwater flow. According to hydrogeology of the research area, Jurassic conglomerate aquifer and Quaternary sandstone aquifer were treated as a unified aquifer while the groundwater elevation was defined as -95.0 m. The thickness of this unified aquifer is 14.0 m. The groundwater elevation in the coal face is equal to -464.0 m. According to 48-11 pump experiment data, hydraulic conductivity was defined as 0.1315 m/d. Use the empirical formula of influence radius: $R_0 = 10S\sqrt{K}$, equal to 1660 m. We can get the size of outer boundary, 3214×2894. Because the groundwater flow velocity is slow and the actual aquifer has a certain gradient, we assumes that three sides of the outer boundary are defined as specific head boundary, equal to -95.0 m; and the other one is defined as specific flow ,equal to zero. All sides of inner boundary were regarded as specific head boundary with -464.0 m. We regard the upper and lower boundary of hydrogeological conceptual mode as specific flow with zero.

The mathematical model

A two-dimensional homogeneous isotropy medium confined aquifer mathematical model can be used to solve this program which can be described by the following definite programs(Xue 2007):

$$\begin{cases} \dfrac{\partial^2 H}{\partial x^2} + \dfrac{\partial^2 H}{\partial y^2} = 0 & (x, y) \in \Omega \\ H(x, y)\big|_{\Gamma_1} = \varphi_1(x, y) & (x, y) \in \Gamma_1 \\ T\dfrac{\partial H}{\partial n}\bigg|_{\Gamma_2} = q(x, y) & (x, y) \in \Gamma_2 \end{cases}$$

Where φ_1 is known function defined on the Dirichlet boundary Γ_1, q is unit discharge defined on the Neumann boundary Γ_2 ; n is a normal vector pointing always outwards of boundary Γ_2 .

The boundary discretization

The inner and outer boundaries of model are divided into sixteen nodes clockwise and sixteen nodes anti-clockwise respectively. There are 32 nodes that are shown in table 1 at total. Compared to finite difference method and finite element method, the boundary element method requires only to discrete boundary, not to discrete space. Hence, BEM isn't only simple, but also can reduce cumbersome input time.

Results and discussion

Results of large-well method

The direct aquifer of coal seam is a confined aquifer that it would be transformed into an unconfined one after the aquifer was drained. The state of groundwater flow is steady. Computation formula of mine water yield is as follows:

$$Q = 1.366 \frac{K(2s_w M - M^2)}{\lg(R/r)}$$

Where Q is mine water yield, m^3/d; K is hydraulic conductivity, m/d; R is influence radius, m; r is reference radius, m, r=0.564$F^{0.5}$; F is area of coal face, m^2; s_w is drawdown, m; M is thickness of aquifer, m.

Results: normal mine water yield of large-well method is 92.86 m^3/h. Maximum mine water yield is twice than normal mine water yield at this mine, then we predict that maximum mine water yield of this coal face well be 185 m^3/h. According to the pervious data, mine water yield of 3up 102 coal face is 50 m^3/h at first and stabilize 20 m^3/h at last on October 16, 2001. Mine water yield of 3 up 106 coal face get to 120 m^3/h on May 8, 2003. Mine water yield of 3131 coal face is 100 m^3/h at first on May 24, 2009,and turn into the maximum 260 m^3/h after six hours, become 100 m^3/h two days later. Therefore hydrogeological parameters are reliable.

Table 1 *Coordinate of boundary nodes*

Number	Coordinate	Number	Coordinate
1	(0.0, 0.0)	17	(1330.0, 1330.0)
2	(803.5, 0.0)	18	(1330.0, 1388.5)
3	(1607.0, 0.0)	19	(1330.0, 1447.0)
4	(2410.5, 0.0)	20	(1330.0, 1505.5)
5	(3214.0, 0.0)	21	(1330.0, 1564.0)
6	(3214.0, 723.5)	22	(1468.5, 1564.0)
7	(3214.0, 1447.0)	23	(1607.0, 1564.0)
8	(3214.0, 2170.5)	24	(1745.5, 1564.0)
9	(3214.0, 2894.0)	25	(1884.0, 1564.0)
10	(2410.5, 2894.0)	26	(1884.0, 1505.5)
11	(1607.0, 2894.0)	27	(1884.0, 1447.0)
12	(803.5, 2894.0)	28	(1884.0, 1388.5)
13	(0.0, 2894.0)	29	(1884.0, 1330.0)
14	(0.0, 2170.5)	30	(1745.5, 1330.0)
15	(0.0, 1447.0)	31	(1607.0, 1330.0)
16	(0.0, 723.5)	32	(1468.5, 1330.0)

Table 2 *Hydraulic gradient of inner nodes*

Coordinate	Hydraulic Gradient
(1330.0, 1359.2)	-1.27
(1330.0, 1417.8)	-0.73
(1330.0, 1476.2)	-0.73
(1330.0, 1534.8)	-1.27
(1399.2, 1564.0)	-0.74
(1537.8, 1564.0)	-0.48
(1676.2, 1564.0)	-0.47
(1814.8, 1564.0)	-0.69
(1884.0, 1534.8)	-1.14
(1884.0, 1476.2)	-0.65
(1884.0, 1417.8)	-0.65
(1884.0, 1359.2)	-1.14
(1814.8, 1330.0)	-0.69
(1676.2, 1330.0)	-0.47
(1537.8, 1330.0)	-0.48
(1399.2, 1330.0)	-0.74

Results of BEM

Using the boundary element method to solve the groundwater flow problem, we can only get water level or hydraulic gradient on the boundary. The simulation results of hydraulic gradient of inner boundary nodes are shown in table 2. If we want to get the yield on the boundary, we also use Darcy's law and interpolation method to calculate mine water yield. Linear interpolation method is used in this paper. Derived calculation formula is as follows:

$$Q = KM \sum_{i=1}^{n} L_{i(i+1)}) \frac{dH}{dn}\bigg|_{i+\frac{1}{2}}$$

The results show that hydraulic gradient of inner boundary nodes with BEM are negative. This is because water flows out the study area on the inner boundary. The mine water yield by linear interpolation is 84.78 m^3/h.

Discussion

Compared results of large-well method with results of BEM, it shows that results of large-well method are greater than results of BEM for the following reasons: a) The actual aquifer has a certain gradient, but large-well method assumes that aquifer is horizontal. The boundary element method supposes that one side of aquifer is zero flow boundary which means that the aquifer has a certain gradient. This model is clearly closer to the actual situation. b) Large-well method regards inner boundary as an equal-area circle, however, BEM follows the actual situation.

Conclusions

The boundary element method requires less input data than other numerical methods. Discretization is only needed to be over the boundary of the body, making the numerical modeling with the BEM easy and reducing the numerical of unknowns by one order. Predecessors have proved that BEM is appropriate to solving groundwater flow problem, and the paper uses BEM to get hydraulic gradient on the boundary at first, then mine water yield is obtained by linear interpolation. Compared with large-well method, result of BEM that calculates mine water yield is less. The reason is that the assumption of BEM is closer to the actual hydrogeological model. For simple hydrogeology, BEM is a numerical method with high accuracy and requires less time to calculate mine water yield.

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