Numerical Finite-element Modelling of Pumping Data in a Confined Aquifer at the Sangan Iron Mine to Design a Mine Dewatering system

Ahmad Aryafar [a], Faramarz Doulati Ardejani [b], Raghu Singh [c], Ernest Baafid [d]

[a] *PhD student, Faculty of Mining, Petroleum and Geophysics, Shahrood University of Technology; email: aariafar@shahroodut.ac.ir*
[b] *Faculty of Mining, Petroleum and Geophysics, Shahrood University of Technology, Shahrood, Iran e-mail: fdoulati@shahroodut.ac.ir*
[c] *Nottingham Centre for Geomechanics, School of Civil Engineering, University of Nottingham, UK e-mail: Raghu.Singh@nottingham.ac.uk*
[d] *School of Civil, Mining and Environmental Engineering, University of Wollongong, Wollongong, NSW 2522, Australia e-mail: ebaafi@uow.edu.au*

Abstract
Prediction of groundwater inflow and subsequence design of pumping system is an important problem in surface mine development. The mining operation will be carried out without any major problem if the pumping system is appropriately designed. The hydrogeological studies are necessary at the early stages of mine development. The main objective of this research was to predict hydraulic head changes versus time and distance in a confined aquifer at Sangan iron mine which is located at 280 km from southeast of Mashhad, Iran. A numerical finite element model using SEEP/W computer software was presented. A Theis analytical solution and field data (well. No. D4W3) were used to verify model prediction. The results show a close agreement between model predictions and those data obtained from the field and the analytical Theis solution.

Key words: Numerical modeling- SEEP/W- Hydraulic head-drawdown -Sangan Iron Mine-Confined aquifer

Introduction
In recent years the importance of mine drainage control and the need for detailed design of mine water systems at the planning stage have been considered. An accurate estimation of water inflow into a mine is the basis for the design of mine drainage control installations such as pumping stations, sediment settlers, pumping equipment\, and for finding the best operational policy throughout the life of the project (Singh and Atkins 1985a and b). When the dewatering system is designed accurately, extraction and mine development can be performed without problems when the pit interacts with groundwater. Furthermore, environmental pollution problems will be reduced (Norton 1983, Slayback 1979). Dewatering is an effective solution to control the groundwater inflow into surface mines. When the groundwater table is intersected by pit advancement, this leads to groundwater flow towards the excavation (Ngah 1985). Hydrogeological investigations of mine area are necessary to establish an appropriate dewatering system. Acquisition of hydrogeological data such as hydraulic conductivity, storage coefficient and understanding the primary regime of groundwater inflow are the main factors for designing a proper drainage system. This paper presents a finite element model using the SEEP/W finite element package to predict drawdown resulted from a dewatering test in a fully penetrating well (No. D4W3) into a confined aquifer at the Sangan iron mine which is located about 280 km southeast of Mashhad in the north east of Iran (Madan Kav Company 2002).

Methods
Modelling tools
In this paper, the SEEP/W software (Geo-Slope International Ltd. 2007) was used to simulate dewatering test in a confined aquifer. This computer model solves the following two-dimensional partial differential equation governing groundwater flow through a porous medium; taking both saturated and unsaturated flow conditions into account (Freeze and Cherry 1979):

$$\frac{\partial}{\partial x}(K_X \frac{\partial h}{\partial x}) + \frac{\partial}{\partial y}(K_y \frac{\partial h}{\partial y}) = C \frac{\partial}{\partial t}(h) + Q \quad (1)$$

where,
K_X and K_y = hydraulic conductivities in directions of x and y, respectively,
H = hydraulic head,
C = slope of moisture characteristic curve and
Q = recharge or discharge rate per unit volume of the aquifer

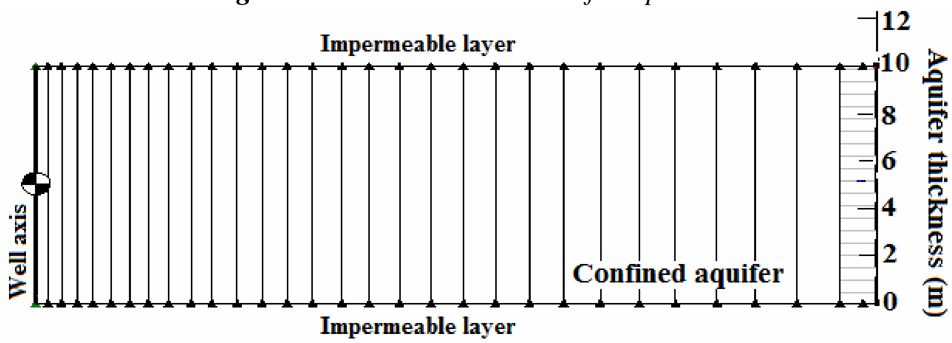
Hydraulic head can be related to volumetric water content (θ) as follows:

$$\frac{\partial \theta}{\partial t} = C\frac{\partial h}{\partial t} \tag{2}$$

Model verification
In order to verify the numerical modelling of pumping test, two problems are described as follows:

Problem 1: prediction of hydraulic head in a pumping test in an infinite confined aquifer under transient flow conditions
In this example, results from the SEEP/W model are compared to those from analytical solutions incorporating the Theis and the Jacob equations (Walton, 1970). The problem deals with a dewatering test in a confined infinite aquifer under transient flow conditions. The thickness of the aquifer was 10 m. The initial hydraulic head was 20 m. The aquifer had a storage coefficient of 0.0001 and a hydraulic conductivity of 0.0005 m/s. The radius of the well was 0.2 m and the pumping rate was $0.15\,m^3/s$. The finite element model consists of 30 elements and 62 nodes in a single layer of 10 m thick. The model is shown in Figure 1.

Figure 1 *Finite element mesh of the problem*



The main purpose of this problem is to predict the drawdown in pumping well versus time and distance from the well axis. To solve the model numerically, the following initial and boundary conditions were specified:

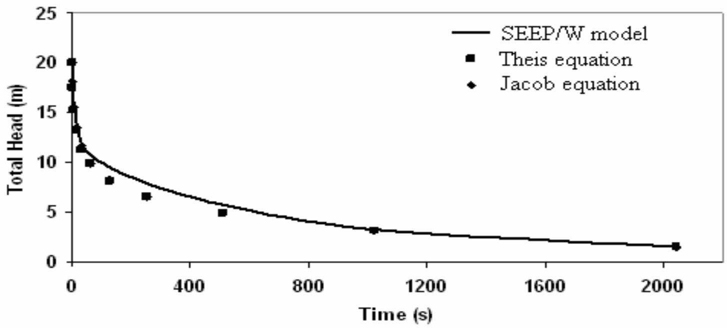
Initial condition
A steady state simulation was first performed to make an initial condition. The head at the two ends of the aquifer was set as 20 m.

Boundary conditions
For transient analysis, the following boundary conditions were considered:

- No-flow boundary conditions at the upper and lower boundaries of the aquifer in order to simulate a confined aquifer
- A head boundary value equal to 20 m at the right side of the model, and
- A flux boundary condition at the left side of the model, next to the dewatering well to simulate the pumping rate

10 time steps were considered for transient simulation. The elapse times were selected as 2, 6, 14, 30, 62, 126, 254, 510, 1022, and 2046 (s). Figure 2 compares the hydraulic heads as a function of time predicted by the numerical model and those calculated by the Theis and Jacob analytical solutions.

Figure 2 *Comparison of hydraulic head versus time predicted by numerical model and calculated values by the Theis and Jacob analytical equations at the well axis*

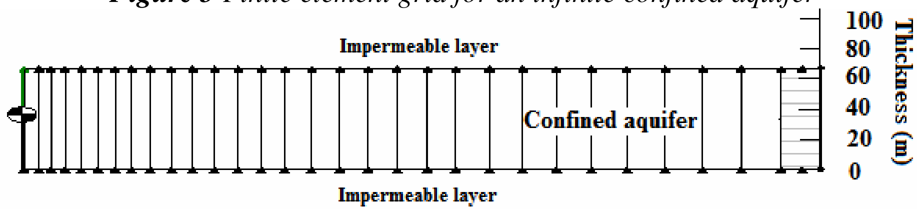


Problem 2: prediction of hydraulic head and drawdown in a pumping test from well No D4W3 penetrated in a confined aquifer associated with Sangan iron mine under unsteady state flow condition

In this example, results from the SEEP/W model are compared to those results obtained from the Theis equation and field data for a pumping test carried out in a confined aquifer at Sangan iron mine. The data obtained from well No D4W3 was selected for comparison purpose. The aquifer had an average thickness of 66 m. The aquifer had a hydraulic conductivity of 0.0003 m/s and a storativity of 0.0027. The pumping rate was 0.0372 m^3/s and the well radius was 0.3048 m. The distance between pumping well and observation well was 22 m. The total hydraulic head in the aquifer was 926 m (Mahvi, 2004).

For a numerical solution of the problem, a finite element grid was constructed with 62 nodes and 30 elements in a single layer 66 m thick (Figure 3).

Figure 3 *Finite element grid for an infinite confined aquifer*



An axi-symmetric analysis was performed to model radial flow to the well (D4W3). The rectangular grid consisted of four-noded elements with an infinite element at the right end of the model (outer boundary). The length of the grid was 100 m. The number of time steps used was 31. The elapse times were selected as 30, 60, 90, 120, 150, 180, 210, 240, 270, 300, 360, 420, 480, 540, 600, 720, 840, 960, 1200, 1800, 2400, 3000, 3600, 4200, 4800, 5400, 6000, 9000, 18000, 36000 and 72000 s. The initial and boundary conditions are similar to those specified in problem 1.

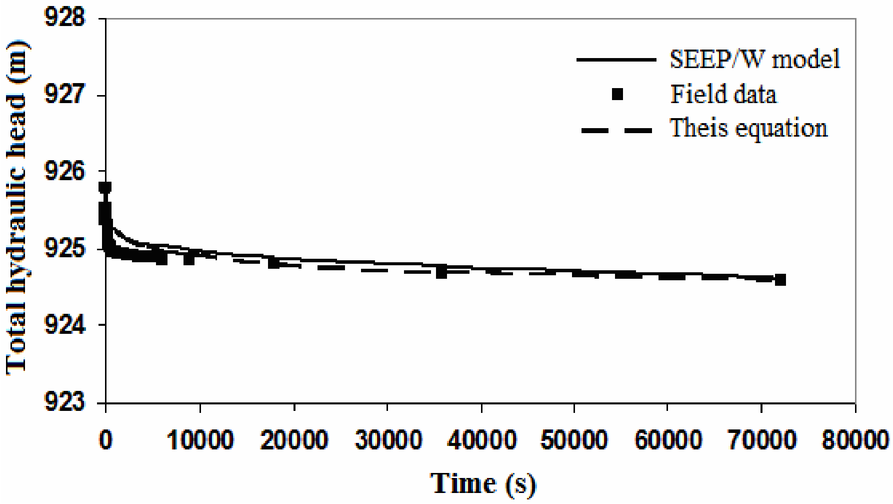
The predicted drawdown at well axis was 1.16 m after 72000 s.

For evaluation of the numerical model, the drawdowns measured in well No D4W3 during pumping test and those drawdowns calculated using a Theis analytical solution were used. Table 1 shows the drawdown calculated by different methods and the relative errors. The comparison of the total hydraulic heads versus time predicted by the SEEP/W model, those calculated using Theis analytical solution and field data related to well No D4W3 at Sangan iron mine is shown in Figure 4.

Table 1 *Comparison of field, numerical and analytical drawdown at the axis of well No* D4W3 *of the Sangan iron mine*

Method	Drawdown (m)	Relative error (%)
Field data	1.19	——
SEEP/W	1.16	2.51
Theis solution	1.17	1.68

__Figure 4__ Comparison of total hydraulic heads versus time predicted by SEEP/W model, those calculated using Theis analytical solution and field data related to well No D4W3 of the Sangan iron mine at the well axis



Conclusion

The study of the hydraulic parameters of an aquifer in a mining area is important for designing an effective dewatering system. In this paper, SEEP/W (a two-dimensional finite element model) was used to simulate a dewatering test in a confined aquifer under transient conditions at the Sangan iron mine. The drawdown predicted using SEEP/W model and calculated by a/the analytical Theis equation in the well axis after 72000 .s were 1.16 and 1.17 m respectively. The comparison of the results of the SEEP/W model and Theis solution shows a good agreement with the measured drawdown in well No D4W3 with a relative error less than 3%. Such results are useful in designing an appropriate dewatering system.

Acknowledgements

The authors would like to express their appreciations to the assistance provided by the Faculty of Mining, Petroleum and Geophysics, Shahrood University of Technology, the support made by the National Iranian Steel Company during data measurements and School of Civil, Mining and Environmental Engineering, University of Wollongong for providing SEEP/W software.

References

Freeze RA, Cherry JA (1979) Groundwater, Prentice-Hall, Inc, Englewood Cliffs, NJ, 604 pp

Geo-Slope International, Ltd., SEEP/W for finite element seepage analysis, Available online at: http://www.geo-slope.com/products/seepw.asp (accessed 25 Feb 2008)

Madan Kav Company (2002) Finial report of detailed exploration of Sangan iron mine, 185 p

Mahvi MR (2004) Report of detailed groundwater exploration in Khaf Basin, International Minerals Engineering Consulting Co, 250 p

Ngah SA (1985) Hydrogeological aspects of surface coal mine dewatering, M. Phil Thesis, Univ of Nottingham, 288p

Norton PJ (1983) A study of groundwater control in British surface mining, Ph.D. Thesis, Nottingham Univ, 460p

Singh RN, Atkins AS (1985a) Application of idealized analytical techniques for prediction of mine water inflow. J Mining Science and Tech 2: 131-138

Singh RN, Atkins AS (1985b) Analytical techniques for the estimation of mine water inflow. Int J Mining Engineering 3: 65-77

Slayback RG (1979) Case examples of hydrogeologic investigations for mine dewatering. The First Int Mine Drainage Symp, Denver, Colorado, p 105-122.

Walton WC (1970) Groundwater resource evaluation, McGraw-Hill, Kogakusha Ltd., 664p