Technical Article

A Finite Element Model to: 2. Simulate Groundwater Rebound Problems in Backfilled Open Cut Mines

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Abstract. A two-dimensional finite element software called SEEP/W can be easily modified to simulate the groundwater rebound process within the spoil of an open cut mine taking into account saturated and unsaturated flow, hydraulic conductivity, and water content (as a function of pore-water pressure). Flexibility in the model is achieved by assigning different boundary conditions. In this paper, the results of the numerical model of the ground water rebound are presented and compared with those obtained from analytical solutions, another numerical model, and with data measured at the Horsley backfilled site in the UK. This model calculates realistic results that can be used by mine operators and environmental engineers to control the quality of mine drainage in a backfilled open cut operation.

Key words: Backfilled open cut mine, finite element method, groundwater rebound, Horsley opencast mine

Introduction

The depletion of shallower deposits and improvements in mining techniques have led to a considerable increase in economic working depths in open cut mines. Surface mining can now be carried out well below the groundwater table. However, associated water-related problems can affect the operational efficiency and economic viability of the mining operation. Abandonment, groundwater rebound due to cessation of dewatering, and associated pollution issues are also serious problems associated with open cut coal mining (Henton 1981) and sulphide ore mines. If the effects and magnitude of a water-related problem can be properly identified in advance of mining, appropriate water management strategies can be undertaken to minimize the socio-economic and environmental impacts of mine dewatering.

Dewatering of surface mines during mining operations can place considerable hydrological stress on the regional groundwater flow system. When mining is completed and the dewatering operations have ceased, the water table rebounds. The rising groundwater saturates the mine spoil, which may be contaminated with pyrite-oxidation products. Prediction of post-mining water table elevation within the mine spoil is important so that the adverse effects can be countered with an appropriate addition of alkalinity to the backfill and special re-handling techniques.

Numerical groundwater flow models can be used to predict groundwater rebound after mining (Henton 1981; Norton 1983; Naugle and Atkinson 1993; Vandersluis et al. 1995; Davis and Zabolotney 1996; Shevenell 2000).

Groundwater Model

Predicting inflow to an open cut mine during mine extensions and estimating the groundwater rebound at backfilled open cut mines are among the more complex problems encountered in mining operations. Predicting the configuration of the ground water table and the height of the seepage face in highwalls for slope stability analysis is also very important. Problems concerning groundwater flow in partially saturated porous media are relatively difficult to model for cases involving highly nonlinear ground characteristics. In particular, it is difficult to assign to the model the highly sensitive behavior of unsaturated field variables such as hydraulic conductivity, specific storage and atmospheric boundary conditions associated with the seepage face, infiltration and evaporation.

Due to the limitations of the most common groundwater flow codes in dealing with these problems, a two-dimensional finite element software called SEEP/W (Geo-slope International Ltd 2002) has been modified to predict post mining groundwater rebound within the spoil of a open cut mine.

Governing equation of groundwater rebound model

As discussed in the preceding paper, the governing equation for the two-dimensional groundwater flow incorporating both saturated and unsaturated conditions can be expressed as follows (Freeze and Cherry 1979):
\[
\frac{\partial}{\partial x} \left( K_x \frac{\partial h}{\partial x} \right) + \frac{\partial}{\partial y} \left( K_y \frac{\partial h}{\partial y} \right) = C_{uw} \frac{\partial h}{\partial t} - W
\]  

where \( K_x \) and \( K_y \) are components of the hydraulic conductivity tensor in the \( x \) and \( y \) directions respectively, \( W \) is the recharge or discharge per unit volume, \( t \) is the time, \( C_{uw} \) is the slope of the water storage curve and \( h \) denotes the hydraulic head.

**Groundwater Rebound Model**

Final measurements of the groundwater table elevations made during the mine dewatering program were used as an initial condition for the transient simulations of the groundwater rebound after mining. For prediction of groundwater rebound within spoil, it was necessary to assign new hydraulic characteristics to those parts of the model elements that represented excavated rock as well as backfilled materials. A finite hydraulic conductivity value was assigned to the part of the model that represents excavated rocks and spoil (Naugle and Atkinson 1993). Hence, the predicted groundwater elevations were different in the spoil at the edges and the centre of the excavation. To reduce the error in the predicted water table elevations within the spoil and the pit, the permeability was modified to a value that would minimize the differences of water table levels. The hydraulic conductivity of backfilled material was assigned about two orders of magnitude greater than that of the unmined strata. The following aquifer characteristics were the main input parameters:

- Initial potentiometric heads and rainfall data
- Saturated thickness
- Hydraulic conductivity and transmissivity
- Specific yield and porosity

A flowchart (Figure 1) summarizes the groundwater rebound modelling procedure in an open cut mine.

During model calibration, sensitivity analyses were performed to consider the parameters that most affected the simulation results. Transmissivity and storage coefficient appeared to be the most sensitive of the input parameters. Davis and Zabotlomy (1996) have reported the same results during the sensitivity analyses of groundwater modelling for the determination of post mining recharge rates at the Belle Ayr mine. The present model results were compared with the analytical Theis solution and a close agreement was achieved.

**Model verification**

Three problems are described to verify the numerical modelling of groundwater rebound after mining:

**Problem 1**—Dewatering simulation in a confined infinite aquifer

This first problem is modelled to compare the results of a dewatering test in a confined infinite aquifer under transient conditions using an analytical solution incorporating the Theis equation (Walton, 1970; Watson and Burnett 1993) with the numerical model. The recovery period has been taken into consideration. An axisymmetric analysis was used to simulate radial flow to a well. The total hydraulic head in the aquifer was taken as 15m. The aquifer had a hydraulic conductivity of 2.0 x 10^{-3} m/s and a storativity of 0.06. The dewatering rate was 0.12 m^3/s and the well radius was 0.15 m. The first part of the simulation was mostly taken from the SEEP/W user’s manual (Geo-slope International Ltd. 2002) but it was slightly modified.