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단열암반 대수층에서 수직분산도 추정에 관한 연구

A Study on Estimation of Vertical Diffusivity in Fractured Bedrock Aquifer

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ABSTRACT

This study focused on developing a convolution solution for estimating vertical diffusivity of a less permeable hydrogeologic unit in a bedrock aquifer. The diffusivity and corresponding hydraulic conductivity were estimated using the developed convolution equation. An application case was presented in this study.

Key words : Diffusivity, Convolution, Bedrock aquifer

I. Introduction

Neuman and Gardner (1989) proposed a method to estimate aquitard/aquiclude vertical diffusivities on the basis of water-level measurements by deconvolution. They stated that if water-level fluctuations in aquifers adjacent to confining layers of interest are sufficiently large to cause measurable pressure changes in the confining layer, the vertical hydraulic diffusivity of the confining layer can be determined without pumping tests. It is also indicated that if water-level variations in the aquifer are too weak to cause a detectable response in the confining layer, pumping is required.

Especially in fractured rock aquifer, it is not uncommon that two piezometers screened in different depths in proximity show a significant water-level difference which is even more 1 m. One is screened in a shallow soil zone and the other is in a deeper fractured zone. There is a less permeable layer between the two wells. So the fractured zone has confined characteristic. Hydraulic communication between two layers is observed. If a well in the fractured zone is pumped, significant drawdown appears in the upper soil zone. The study site is in this case. A weathered bedrock zone exists between an upper soil zone and a fractured bed rock zone. The weathered bedrock zone is relatively less permeable than the layers below and above. The mean hydraulic conductivities of both layers are larger than that of the weathered bedrock zone by at least two orders or even more. A flow in the weathered bedrock zone may be vertical according to the vertical hydraulic gradient. If any infiltration through upper soil zone from precipitation or artificial irrigation exists, vertical percolation through the weathered zone will be large.

In this study, pumping test data were used to estimate a vertical hydraulic diffusivity of the weathered bedrock zone. If it can be assumed that vertical flow component from groundwater in the upper soil zone is very important to change water-level of a piezometer screened in the fractured zone, a method suggested by Neuman and Gardner (1989) is applicable. Here it is assumed that variations of water-level in the upper soil zone cause variations of water-level in the lower fractured aquifer during pumping test.

II. Application Theory

One-dimensional vertical flow can be assumed if the vertical component is dominant and horizontal hydraulic gradient is negligible. Assumptions are extended to that the layer of interest has no interior sources and that it is homogeneous. When hydraulic head of a lower zone varies with time, variation of the head at a depth of interest can be deduced by Duhamel's theorem (Carslaw and Jaeger, 1959). In a semi-infinite layer, where h has to satisfy:

$$\frac{\partial h}{\partial t} = x\frac{\partial^2 h}{\partial z^2} \tag{1}$$

subject to the initial boundary condition, $h(t=0)=0$ and the boundary condition, $h(z=0,t)=h_0(t)$. Given a known or estimated x, the head at the depth of interest z, $h(z,t)$, can be estimated for a known upper zone hydraulic head time series using convolution summation. Reversely, the diffusivity can be estimated using two head time series of different depths at the same location by deconvolution.

The solution is given by

$$h=\int_0^t h_0(\lambda)\frac{\partial}{\partial t}F(z,t-\lambda)d\lambda,\ \text{where}\ F(z,t-\lambda)=\frac{2}{\sqrt{\pi}}\int_{z/2\sqrt{x(t-\lambda)}}^{\infty} e^{-\zeta^2}d\zeta.$$

In this case

$$\frac{\partial}{\partial t}F(z,t-\lambda) = -\frac{2}{\sqrt{\pi}}e^{-z^2/4x(t-\lambda)}\frac{\partial}{\partial t}\left[\frac{z}{2\sqrt{x(t-\lambda)}}\right]=\frac{z}{2\sqrt{\pi x(t-\lambda)^3}}e^{-z^2/4x(t-\lambda)}.$$

Therefore the solution of the problem is:

$$h(z,t)=\frac{z}{2\sqrt{\pi x}}\int_0^t h_0(\lambda)\frac{e^{-z^2/4x(t-\lambda)}}{(t-\lambda)^{3/2}}d\lambda \qquad (2)$$

If screen length of a piezometer is considered, this solution can be written as:

$$h(\Delta z,t)=\frac{1}{\Delta z}\sqrt{\frac{x}{\pi}}\int_0^t h_0(\lambda)\left[e^{-z_1^2/4x(t-\lambda)}-e^{-z_2^2/4x(t-\lambda)}\right]\frac{d\lambda}{\sqrt{t-\lambda}} \qquad (3)$$

where Δz = screen of a piezometer, z_2-z_1, $z_2 > z_1$.

III. Application and Results

A short term pumping test was conducted at the site. Water was extracted from the CII well screened in the fractured zone. Distances between the pumped well and the observation wells are within 10 m. Waterlevel variations in the observation boreholes, PW and TU8, were monitored. Drawdown in the PW well cause that of TU8 well. Flow in the weathered zone will be vertical. TU8 well shows some delayed response. But waterlevel in TU8 well decreases in straight manner while that in PW well decreases rapidly at early pumping period and later drawdown is markedly reduced. After pump was switched off, waterlevel of TU8 well continued to decrease for about 1 hour.

The top of fractured zone is datum. In this case, waterlevels of PW is $h_0(t)$ and those of TU8 is $h(\Delta z,t)$. Mean squared errors between calculated and observed heads were calculated. Mean squared errors reach minimum at about 0.1 m^2/h. But at the range of diffusivity 1.2 ~3 m^2/h, fittings are more reasonable. During pumping, vertical flow components are expected to be dominant. So the estimated vertical diffusivities are reliable.

In the above, the diffusivity can be regard as vertical conductivity divided by specific storage. If a storage coefficient of the medium can is known, vertical hydraulic conductivity can be calculated. In the study, the specific storage of the weathered bedrock zone was estimated by the analysis of slug tests conducted in a well screened in the zone. With an average value, 7.3×10^{-5} m^{-1}, of specific storage, the average vertical conductivity ranging 2.0×10^{-5} to 1.3×10^{-4} cm/s is obtained. This is about ten times smaller than the radial (or lateral) hydraulic conductivity values of the weathered zone estimated from slug tests, pumping tests and tracer tests.

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