Estimating the Dual Permeability Parameters of the Fractured Environment of the Richard Nuclear Waste Repository

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Abstract

When modelling the flow and contaminant transport in the surroundings of underground nuclear storage facilities usually we have to deal with a fractured rock environment.

The mainstream approach is based on a so-called equivalent porous media. The whole complex of fractures together with the matrix permeability is substituted by a porous medium with an equivalent Darcy's K value.

A research based on evaluating dual permeability properties was conducted in order to specify more accurate results for further evaluation of flow and contaminant transport at Richard nuclear waste repository, Litoměřice, Czech Republic. A fracture flow was modelled in order to obtain a data for optimization procedure to identify dual permeability parameters.

The Goal of the Research

- fracture environment analysis
- construction of the representary elementary volume
- flow simulation on the fractures and matrix (FEFLOW code)
- fitting the outflow curve with dual permeability model (S2D code)

Properties of the Rock Environment

Geotechnical Properties

- the Geotip group (a company contracted for the longtime monitoring) conducted a research evaluating a system of tectonic fractures
- an in situ measurement ⇒ three main fracture systems (one horizontal and two vertical)

⇓

- occurance of horizontal fractures – each 0.2 m, form an angle 5 degrees with horizontal plane
- occurance of vertical fractures – each 0.5 m and form an angles of 87 and 70 degrees with horizontal plane (see [5]) (figure 1)

Hydraulic Properties

- The hydraulic properties of matrix are obtained from technical documentation of RAWRA authority (table 1) (see [2])

θ_r [-]	θ_S [-]	α $[cm^{-1}]$	n [-]	K_S $[cm.d^{-1}]$
0.064	0.140	0.010	2.500	0.864

Table 1 *Coefficients of matrix obtained from [2]*

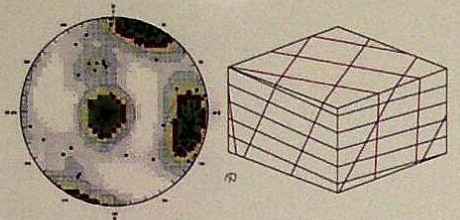

Figure 1 *The fracture analysis – left diagram of fracture occurrence density which was used for evaluating the generalize system of fractures, right – the generalized evaluated system of fractures.*

Methodology

Fracture and matrix flow model

- This model is based on application of Richard's and Hagen-Poisseulle law
- The simulation was conducted on a commercial software code WASY Feflow version 5.2, produced by DHI group

Richard's equation

$$\frac{\partial \theta}{\partial t} = \frac{\partial}{\partial x}\left(K(\theta)\frac{\partial h}{\partial x}\right) + \frac{\partial}{\partial y}\left(K(\theta)\frac{\partial h}{\partial y}\right) + S \qquad (1)$$

Where θ is water content (-), $K(\theta)$ unsaturated hydraulic conductivity $(L.T^{-1})$, h - pressure head (L), S - sink/source term (T^{-1}).

Hagen-Pouisell law

$$u = \frac{1}{b}\int_{y=0}^{b} u.dy = -\frac{b^2}{12\mu}\left(\frac{dp}{dx} - \rho g_s\right) \qquad (2)$$

Where u - average velocity $(L.T^{-1})$, Q - discharge $(L^3.T^{-1})$, b - aperture of fracture (L), p fluid pressure $(M.L^{-1}.T^{-2})$, ρ- fluid density $(M.L^{-3})$, μ - dynamic viskozity $(M.L^{-1}.T^{-1})$, g - gravity acceleration $(L.T^{-2})$ [3]

Dual Permeability Flow Model

- The dual permeability approach is based on assumption that Darcy-type water flow is considered both for the fracture and matrix pore system. Transfer of water between systems – first order coupling term. [6]
- The dual permeability model was simulated on S2D code with compliance of its author prof. T. Vogel, CTU Prague.
- Finite element mesh was created using Menhardt algorithm with compliance of its author prof. ass. J. Mls, Charles University in Prague.

$$\frac{\partial w_f \theta_f}{\partial t} = \frac{\partial}{\partial x}\left(K_f(\theta_f)\frac{\partial h_f}{\partial x}\right) + \frac{\partial}{\partial y}\left(K_f(\theta_f)\frac{\partial h_f}{\partial y}\right) - w_f S_f - w_f \Gamma_f$$

$$\frac{\partial w_m \theta_m}{\partial t} = \frac{\partial}{\partial x}\left(K_m(\theta_m)\frac{\partial h_m}{\partial x}\right) + \frac{\partial}{\partial y}\left(K_m(\theta_m)\frac{\partial h_m}{\partial y}\right) - w_m S_m - w_m \Gamma_m$$

$$w_f \Gamma_f = -w_m \Gamma_m = \alpha_w (h_f - h_m) \qquad (3)$$

Where α_w - first order transfer term between domains [-], f - index for fast domain, fractures, m - index for matrix, $h_{f,m}$ - pressure head of fractures/matrix $[L]$, $S_{f,m}$ - sink/source term of fractures/matrix $[T^{-1}]$, $K(\theta)_{f,m}$ - unsaturated hydraulic conductivity of fractures/matrix [-], $\theta_{f,m}$ - water content of fractures/matrix [-], $w_{f,m}$ - volumetric fraction of fractures/matrix [-].

Optimization algorithm

- Marquardt-Levenberg algorithm
- a free version of PEST code was applied

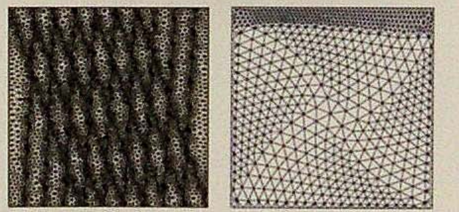

Figure 2 *Left – a domain mesh used for fracture/matrix flow simulation, Right – a domain mesh used for dual permeability flow simulation.*

Dual Permeability and Fracture Flow Simulation

- system of fractures is based on geostatiscal model mentioned above
- horizontal fractures were excluded, it would behave as a seepage face in the flow simulation ⇒ the aim is to deal with the least convenient case
- fracture width – rough estimate – 0.1 mm
- the domain mesh consists of 13595 elements and 6963 nodes with increased density in fracture surroundings
- initial condition – matrix: $\theta = 0.084$, fractures: 60% of saturation
- boundary conditions - vertical – both impereable, horizontal – upper: Dirichlet condition (constant pressure head 5 cm), lower: a combination of Dirichlet and Neumann, when unsaturated - Neumann condition of zero flux, with full saturation a Dirichlet condition of constant pressure head (seepage face)
- dual permeability flow simulation – only 1486 elements and 844 nodes were needed for FEM solution (figure 2)

Results and Conlusions

A dual permeability approach applied in S2D code suffers with a huge numerical instability. It led to many dificulties in the optimization procedure. In order to stabilize the solution, we decided to use the same retention curve parameters for the fast as for the slow domain, only the condition of constraint was to obtain average pore velocities in the fast domain close to the velocities obtained in the fractures. This assumption improved the numerical stability of the solution but it requires some further studies. In spite of the fact we manage to obtain some results, still many problems with numerical stability occured as visible from figure 3. The final coeficients as a result of optimizing procedure are mentioned in table 2.

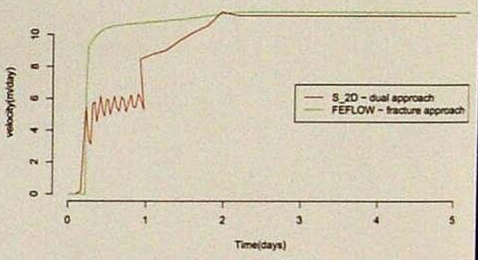

Figure 3 *Time dependency of flow velocities at lower boundary with optimized parameters of dual permeability model. Problems with numericall stability occured as visible*

θ_r [-]	θ_S [-]	α $[cm^{-1}]$	n [-]	K_S $[cm.d^{-1}]$	α_w [-]	w_f [-]
0.000	0.101	0.010	2.500	4800.0	0.00041	0.008

Table 2 *Fitted coefficients of the fast domain and dual permability solution*

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