Development of high-accuracy numerical methods for Hot Dry Rock geothermal reservoir and Compressed Air Energy Storage

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Introduction

(1) Hot Dry Rock heat extraction is one of the new and environmentally clean ways of energy exploitation. A typical configuration contains inlet and outlet wells and a fractured reservoir at the depth where rocks are hot. Then heat can be drawn from surrounding rock mass by circulating water that flows through fractures. Besides the laboratory and field experiments, numerical modelling play an important role in predicting product efficiency and life expectancy. Particularly, a fast, accurate and precise shape approximation BEM software project[1],[2],[3] is extremely potential in a long run. In order to be applied to fracture mechanics problem, a more sophisticated triangular crack edge element for 3D DDM has been developed due to constant element can't figure out the satisfactory result in the vicinity of crack front. [4],[6]. Furthermore, by taking advantage of symbolic computation technology, the feasibility of pure analytical formula for evaluating the influence function of parabolic edge element has got impressive success[5],[6].

(2) Due to the efficiency of electricity generation from the power plants is stable but the electricity usage within one day is various, i.e., the peak at noon is much more than the amount in the morning, the projects named as Compressed Air energy Storage proceed recently. The raising and releasing of pool water is used to compressed the air within underground excavated space in order to storage the energy and adjust the power output. The airproof of holes needs to press bentonite into surrounding rock to seal the crack. Then the ingress of bentonite along the crack, which comprises the computations for interfacial tension and stress intensity factor, is modeled by the combination of Fictitious Stress Method and Displacement Discontinuity Method.

Results

1. Comparison of σ_{zz} on continuity of crack and in vicinity of crack front figured out by different methods.

2. Estimated stress intensity factor K_I

It shows that crack edge element can give good estimation of K_I close to the crack edge, where constant element is totally unreliable.

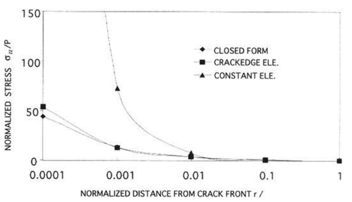

Fig. 1 Comparison of σ_{zz} from different ways

Table 1 Accuracy of estimated stress intensity factor

Relative distance r/c from crack front ($c=1.0m$)	Closed form $K_I=1.128$			
	By crack edge element		By constant element	
	K_I	Error	K_I	Error
0.1	0.521	54%	0.600	47%
0.01	0.856	24%	1.850	64%
0.001	0.983	13%	5.783	413%
0.0001	1.341	19%	18.42	1533%

3. Analytical formula

Based on mathematical demonstration, to evaluate the influence function for crack edge root element lies in to get analytical formula for the following indefinite integration,

$$\int \frac{(K\xi + D - y)\sqrt{\xi}}{(\xi - x)^2\left[(\xi - x)^2 + (K\xi + D - y)^2\right]^{1/2}} d\xi \qquad (1)$$

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After the regulation and simplification work by combination of operating the symbolic computation and artificial manipulation, the analytical solution for Equation (2) and Equation (3) can be expressed as follows

$$I_1 = \int \frac{\sqrt{\xi + x}}{\xi^2\sqrt{\xi^2 + (K\xi + D')^2}} d\xi \qquad (2)$$

$$I_2 = \int \frac{\xi\sqrt{\xi + x}}{\xi^2\sqrt{\xi^2 + (K\xi + D')^2}} d\xi \qquad (3)$$

$$I_1 = \mathrm{Re}[\beta_0 + \beta_1 EllipticF(\alpha_1,\alpha_2) + \beta_2 * EllipticE(\alpha_1,\alpha_2) + \beta_3 EllipticPi(\alpha_3,\alpha_4,\alpha_5)] \qquad (4)$$

$$I_2 = \mathrm{Re}[\beta_4\, EllipticF(\alpha_4,\alpha_5) + \beta_5 EllipticPi(\alpha_3,\alpha_4,\alpha_5)] \qquad (5)$$

where

$$\beta_0 = -\frac{\sqrt{x+\xi}\sqrt{\xi^2 + (K\xi + D')^2}}{D^2\xi} ;$$

$$\beta_1 = \frac{D' - (K+i)x}{D'} \cdot \frac{\sqrt{[D' + (K-i)\xi]/[D' + ix - Kx]}}{\sqrt{x+\xi}} \cdot \gamma_1 ;$$

$$\beta_2 = -\frac{D'^2 - 2D'Kx + (1+K^2)x^2}{D'[D' - (i+K)x]} \cdot \beta_1 ;$$

$$\beta_3 = -\frac{D'^2 - D'(i+3K)x + 2K(i+K)x^2}{\sqrt{2}D'^2\sqrt{x+\xi}} \sqrt{\frac{(1-iK)[D' + (K-i)\xi]}{D'}} \cdot \gamma_1 ;$$

$$\beta_4 = \frac{[D' + (i+K)\xi]\sqrt{\frac{(i+K)(x+\xi)}{(i+K)x - D'}}}{(i+K)\sqrt{\frac{D' + (i+K)\xi}{D' - (i+K)x}}} \cdot \gamma_2 ;$$

$$\beta_5 = \frac{x[-D' + (i+K)x]}{D'} \sqrt{-\frac{(i+K)(x+\xi)[D' + (i+K)\xi]}{[D' - (i+K)x]^2}} \cdot \gamma_2$$

$$\alpha_1 = \sqrt{\frac{x+\xi}{-\frac{D'}{i+K} + x}} ; \quad \alpha_2 = \frac{(K-i)(D' - ix - Kx)}{(K+i)(D' + ix - Kx)} ; \quad \alpha_3 = \frac{D' - ix - Kx}{D'} ;$$

$$\alpha_4 = ArcSin\sqrt{\frac{D' + i\xi + K\xi}{D' - ix - Kx}} ; \quad \alpha_5 = \frac{(1+iK)(D' - ix - Kx)}{2D} ;$$

$$\gamma_1 = \sqrt{-\frac{(i+K)(x+\xi)[D' + (i+K)\xi]}{[D' - (i+K)x]^2}} \Big/ \sqrt{\xi^2 + (D' + K\xi)^2} ;$$

$$\gamma_2 = \frac{\sqrt{2}\sqrt{\frac{(1-iK)[D' + (K-i)\xi]}{D'}}}{\sqrt{x+\xi}\sqrt{\xi^2 + (D' + K\xi)^2}}$$

where is the imaginary unit and the elliptic integral of the first kind is given by:

$$EllipticF[\Phi, m] = \int_0^{Sin(\Phi)} [(1-t^2)(1-m\cdot t^2)]^{-1/2} dt ,$$

the elliptic integral of the second kind is given by:

$$EllipticE[\Phi, m] = \int_0^{Sin(\Phi)} [(1-t^2)(1-m\cdot t^2)]^{-1/2} dt ,$$

and the elliptic integral of the third kind is given by:

$$EllipticPi[n, \Phi, m] = \int_0^{Sin(\Phi)} (1-n\cdot t^2)^{-1}[(1-t^2)(1-m\cdot t^2)]^{-1/2} dt .$$

4. The rule for bentonite ingress into crack

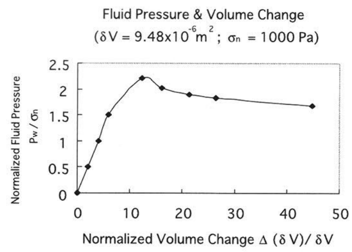

fig.2 Ingress pressure and volume change

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