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Optimization of in-situ stress field estimation modeling based on a genetic algorithm

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1. Introduction

The in-situ stress is an important parameter in rock engineering that determines the mechanical evolution of a natural barrier rocks [1]. However, stress investigation campaign has a limitation owing to the complex geological conditions and high cost [2]. Thus, a common procedure for identifying the regional or local scale stress field is to develop a numerical model that fits best all in-situ stress observations. In current approaches to the stress field inversion modeling (numerical back analysis) [3], an important task to determine the reasonable model that minimizes differences between observed and predicted stresses along with an establishment of a standard procedure for quantifying the discrepancy.

2. Stress characterization campaign in KURT site

The in-situ stress characterization was conducted from a series of hydraulic fracturing tests and borehole image logs to constrain the direction and magnitude for the three principal stress components [4]. The depth-dependent trend in S_{Hmax} magnitude deviated below ~500 m depth (Fig. 1). The characterization results suggested that the site-scale stress state is affected by pre-existing fracture zones with various geological features.

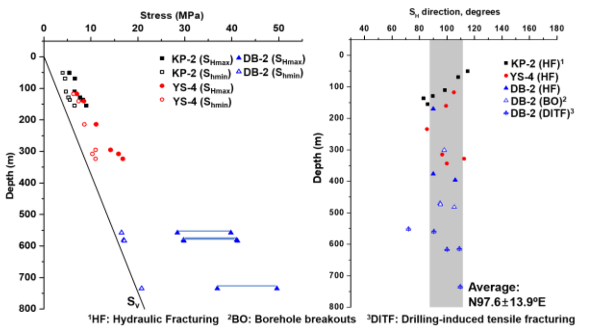

Fig. 1. Magnitude and direction of in-situ stress in the KURT site along the depth [4]

3. Development of Stress Inversion Model

3.1. Model definition

We consider the domain volume of interest as defined from lineament in site scale around the KURT site (Fig. 2. (a)). This domain contained topographical feature and critical fracture zone structure of non-planar shape from several Geo-CAD data (Fig. 2. (b)) [5]. Its mechanical behavior was solved with discrete element method using the software 3DEC. High-quality conformal mesh (composed of 227,880 elements) for 3DEC was constructed through the Griddle plug-in application in Rhino CAD software (Fig. 2. (c)). The mechanical properties were assigned to rock mass and fracture zones which are suitable for the Mohr-Coulomb model (Fig. 2. (d)).

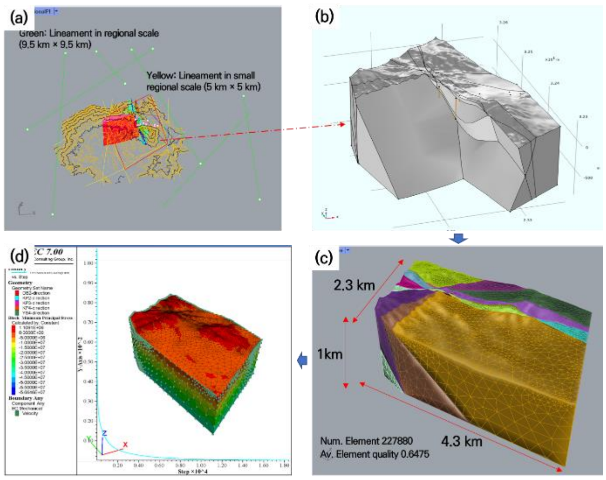

Fig. 2. Construction process of site scale stress estimation model

3.2. Stress components in model

The stress analysis can be evaluated by considering the vertical component and two horizontal components as principal stresses. The vertical stress is considered to be primarily gravitational force with self-weighed rock mass. The horizontal stresses include both gravitational and tectonic stress components [6]. Therefore, the rock at the target depth is influenced substantially by topography. The stress tensor is usually decomposed into tensor components or principal stress magnitudes and orientations:

$$\sigma^{o} = \begin{bmatrix} \sigma_{xx} & \sigma_{xy} & 0 \\ \sigma_{yx} & \sigma_{yy} & 0 \\ 0 & 0 & \sigma_{zz} \end{bmatrix} \tag{1}$$

Each tensor components reflects a series of geological structure effect as well as gravitational and tectonic stresses [7]. For stress estimation models that incorporate topographical features, such as this study, the gravitational loading is applied along with ratios for the horizontal stress. Generally, the ratio is indeed non-linear and the trend represents as a hyperbolic coefficient (a_H, b_H, a_h, b_h) along with the depth (z):

$$\frac{\sigma_{xx}}{\sigma_{zz}} = a_H + \frac{b_H}{z} \tag{2}$$

$$\frac{\sigma_{yy}}{\sigma_{zz}} = a_h + \frac{b_h}{z} \tag{3}$$

And the shear stress components (σ_{xy}, σ_{yx}) can be simulated according to the applied stress direction. Therefore, in this study, the varies on the two-way horizontal stresses and direction was assigned so that we can reflect the in-situ stresses at several measurement points at KURT site.

3.3. 3DEC-Python coupled model

In-situ stresses are investigated in terms of maximum and minimum principal stress magnitudes as mentioned in section 2. Therefore, the estimated stresses in the numerical model should be set to be the principal stresses components that are corrected by stress components when the σ_{xy} and σ_{yx} are zero.

A genetic algorithm (GA) was used to perform an optimization simulation that represented magnitudes similar to the principal in-situ stress magnitudes. The optimization method can be determined by adjusting the GA individual of the hyperbolic coefficient and the stress direction. To perform optimization modeling process, the python-3DEC coupled model was constructed. The GA was configured to perform an auto-iteration simulation and evaluate the fitness function using in-situ principal stresses. Fig. 3. shows the flow chart of this sequential analysis method, which can be categorized as follows: a) Reflecting field data to set the initial ratios for the horizontal stress in the model. b) Perform iterative analysis using Python libraries (Numpy, Pandas, Deap, etc.) and 3DEC model. c) Determine the optimal hyperbolic coefficient and stress direction using fitness function (evaluated stress vs in-situ stress) in genetic algorithm.

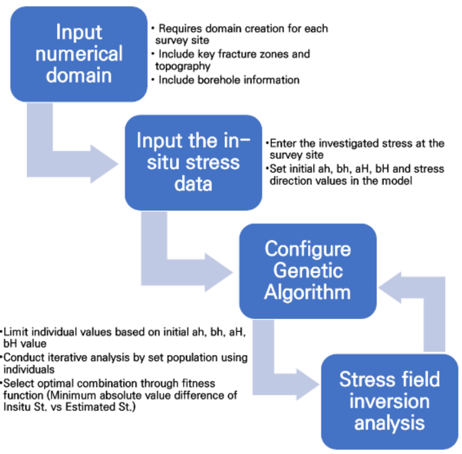

Fig. 3. Stress Analysis Process Using Genetic Algorithm in 3DEC

4. Results of site stress field correction

In genetic algorithm, the fitness function was defined as shown in below equation [8]:

$$\text{Fitness} = \min(\frac{1}{M}\sum_{k=1}^{M}[(S_{x,e}^k - S_{x,i}^k)^2 + (S_{y,e}^k - S_{y,i}^k)^2 + (S_{z,e}^k - S_{z,i}^k)^2]) \tag{4}$$

where M is the number of stress measurement locations, S_e is estimated stress in the model and S_i is in-situ stress that denote the principal stress along with the direction. The optimization simulation results corrected revised stress similarity with the in-situ stress as shown Fig. 4. Significant improvement in the magnitude components of the maximum horizontal principal stress, which was underestimated at deep depths. The model predicts that the depth-dependent principal stress ratio between maximum, minimum horizontal stresses and vertical stress at KURT site may vary as follows:

$$K_H = 1.72 + \frac{123.8}{z} \tag{5}$$

$$K_h = 0.95 + \frac{113.4}{z} \tag{6}$$

where z is the depth. And the direction of the maximum principal stress is approximately 98.9°. The stress inversion analysis was produced only KURT site-specific calibration in current stage. However, we have standardized the analysis process as shown in Fig. 3. so that it can be applied to other candidate sites.

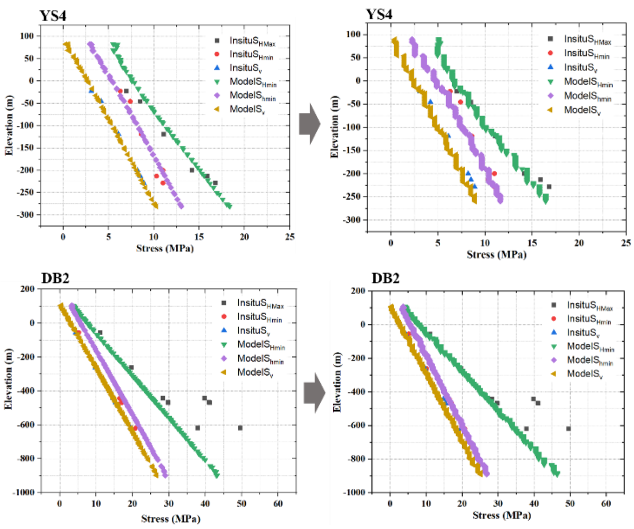

Fig. 4. Local stress comparison results after performing automated iteration analysis based on genetic algorithm

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