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# Characterization of In-situ Stresses Using Inverse Analysis based on Coupled Numerical Modeling and Soft Computing

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## Theory / Method / Workflow

An inverse analysis method based on coupled numerical modeling and soft computing has been investigated for estimating the magnitude of horizontal in-situ stresses based on borehole displacements. The method integrates genetic algorithm (GA), artificial neural network (ANN) and numerical computation. In the displacement based inverse analysis method, a hybrid ANN–GA model is used to identify horizontal in-situ stresses. An ANN is used to represent the non–linear relationship between the maximum and minimum horizontal in-situ stresses ($\sigma_H$, $\sigma_h$) and borehole displacements. GA is used to search the set of unknown horizontal in-situ stresses based on the objective function. For the hybrid ANN–GA model, results of inverse analysis can be assessed by the fitness and the difference between the predicted displacements and the measured displacements. The entire flowchart of the hybrid ANN–GA model based on displacement back analysis for the identification of the horizontal in–situ stress magnitude and the prediction of the corresponding displacement is illustrated in Figure1.

Drilling process involves the strong coupling between heat transfer, fluid flow, and rock mass deformation (Yin et al., 2010). Distinct element method UDEC software is designed for discontinuous media to carry out the coupled thermal–hydraulic–mechanical (THM) analysis in which fracture conductivity is dependent on the fracture aperture. Also UDEC is used to create the necessary training and testing samples for the hybrid ANN–GA model. The deformation of a fractured rock formation is composed of deformation of intact rock blocks and rock discontinuities. This is represented by Drucker–Prager model in a thermoporoelastoplasticity framework.

The constitutive model of the rock mass can be expressed as

$$\mathrm{d}\boldsymbol{\sigma}'=\mathbf{D}^{\mathrm{ep}}\left(\mathrm{d}\boldsymbol{\varepsilon}\text{-}\mathrm{d}\boldsymbol{\varepsilon}^{\mathrm{p}}\right)-\frac{18KG}{3K+4G}\beta\mathrm{d}\boldsymbol{T}+\alpha d\boldsymbol{p} \tag{1}$$

where $\mathrm{d}\boldsymbol{\sigma}'$ is the effective stress increment; $\mathrm{d}\boldsymbol{\varepsilon}$ is the total strain increment; $\mathrm{d}\boldsymbol{\varepsilon}^{\mathrm{p}}$ is the plastic strain increment; $K$ is bulk modulus; $G$ is shear modulus; $\beta$ is linear thermal expansion coefficient; $\mathrm{d}\boldsymbol{T}$ is the temperature increment; $\alpha$ is Biot's coefficient; $\mathrm{d}\boldsymbol{p}$ is the pore pressure increment. Moreover, $\mathbf{D}^{\mathrm{ep}}$ is the elastoplastic stress–strain matrix.

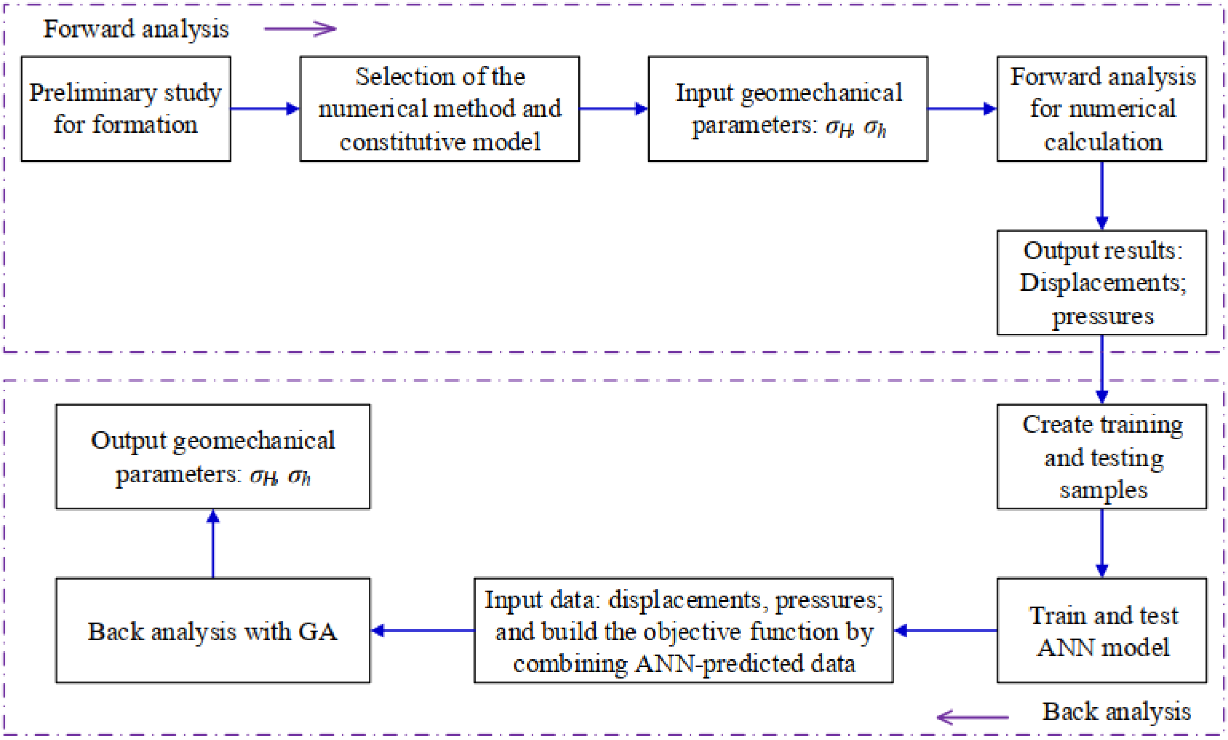

**Figure 1.** Workflow of inverse analysis method using coupled numerical modeling and soft computing

## Results, Observations, Conclusions

Results of mean–squared error (MSE) and correlation coefficient (R–value) demonstrate clearly that the ANN model has an excellent performance of non–linear mapping between horizontal earth stresses and borehole movements. Results of the fitness and the comparison among measured displacements, predicted displacements by ANN–GA and calculated displacements by UDEC illustrate that the proposed hybrid ANN–GA model is effective for identification of the magnitude of horizontal earth stresses based on borehole displacements during drilling (Zhang and Yin, 2014, 2015).

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