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Procedia Engineering 191 (2017) 536 – 542

Procedia Engineering

www.elsevier.com/locate/procedia

Symposium of the International Society for Rock Mechanics

Investigating the Relationship Between Far-Field Stress and Local Values of the Stress Tensor

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Abstract

In situ stress is an important parameter in rock mechanics, thus robust estimation of far-field stress to be used as boundary loadings for further rock engineering analysis based on the local *in situ* stress data seems indispensable. Here, as part of a preliminary investigation into this problem, we use the combined finite-discrete element method to examine how the mean of local stress tensors is related to the far-field stress. We have conducted a series of stress simulations on a model of a fractured rock mass subjected to various boundary loadings, and calculated the Euclidean mean of the stress data and compared them with the boundary loadings. The results shows that the Euclidean mean and boundary loadings are approximately equal, which gives us an indication that the Euclidean mean of the stress data can be a reasonable estimation of the far-field stress.
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Peer-review under responsibility of the organizing committee of EUROCK 2017

Keywords: stress tensor; far-field stress; Euclidean mean; boundary loadings; stress heterogeneity; FEMDEM

1. Introduction

Unlike artificial materials like concrete and steel, natural materials such as rock masses are initially stressed in their natural state, mainly due to the weight of overlying strata and tectonic effects [1]. Thus, *in situ* stress is an important parameter in many aspects of rock mechanics, including rock engineering design, hydraulic fracturing analysis, rock mass permeability and earthquake potential evaluation [1–5]. In these stress-related applications, robust estimation of far-field stress based on the local *in situ* stress data seems indispensable. However, local values

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Peer-review under responsibility of the organizing committee of EUROCK 2017
doi:10.1016/j.proeng.2017.05.215

of the *in situ* stress field within a fractured rock mass may display considerable variability, and so determining the value of the far-field stress to be used as input or boundary loadings for further rock engineering analysis is difficult [1–3, 5].

Here, as part of a preliminary investigation into this problem, we use the combined finite-discrete element method (FEMDEM) to examine how the mean of local stress tensors is related to the far-field stress. We first explain the calculation of mean stress [6] and illustrate the rock mass model establishment for the FEMDEM simulation. Then, for the rock mass subjected to various boundary loadings, we calculate the means of stress data extracted from the model and compare these with the far-field stress. As a result we are able to give suggestions for the selection of appropriate far-field stress or boundary loadings for further rock engineering applications based on local *in situ* stress measurement data.

2. Mean stress calculation approaches

Currently in rock mechanics, stress magnitude and orientation are customarily processed separately [7–16]. This effectively decomposes the stress tensor into scalar (principal stress magnitudes) and vector (principal stress orientations) components, and statistically analyses them using classical statistics [17] and directional statistics [18], respectively. One typical example is shown in Fig. 1, where the histograms of principal stress magnitude and density contours of principal stress orientation are given, and based on which the statistics of the principal stress magnitudes and orientations such as their mean are calculated as input far-field stress or boundary loadings for further rock engineering analyses. However, this customary scalar/vector approach violates the tensorial nature of stress, may either yield biased results, or be difficult to interpret [19–24]. One manifest drawback of it is that orthogonality of the calculated mean principal stresses is not guaranteed.

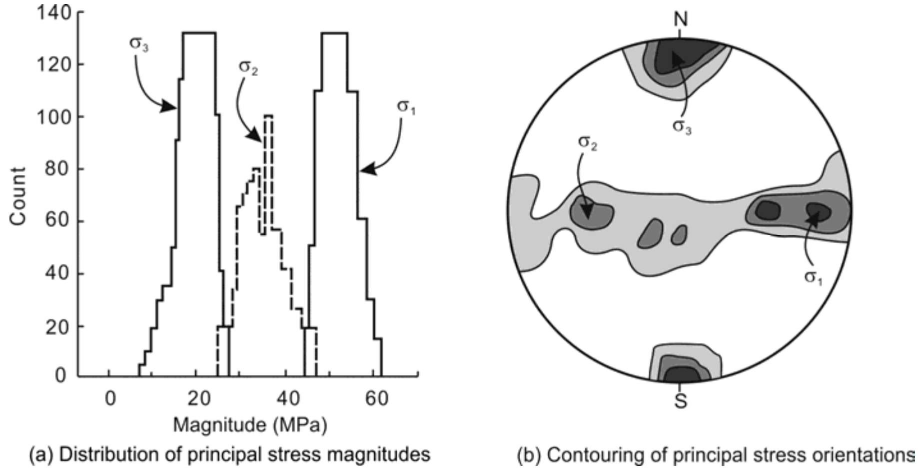

Fig. 1. Customary analyses of stress examine principal stress magnitude and orientation separately using classical statistics and directional statistics, respectively [after 25].

Since stress is a second order tensor, processing of it needs to use stress tensors referred to a common Cartesian coordinate system. By considering the tensorial nature of stress, Gao and Harrison [6] gave a derivation of how the mean stress can be calculated in a tensorial manner – the so-called Euclidean mean – based on the distance measure between stress tensors in Euclidean space. For example, let the *i*th stress tensor $\mathbf{S}_i$ be denoted by

$$\mathbf{S}_i = \begin{bmatrix} \sigma_{x_i} & \tau_{xy_i} & \tau_{xz_i} \\ & \sigma_{y_i} & \tau_{yz_i} \\ \text{symmetric} & & \sigma_{z_i} \end{bmatrix}, \tag{1}$$

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