8th European Solid Mechanics Conference
Gerhard A. Holzapfel and Ray W. Ogden (Eds)
Graz, Austria; July, 2012

Development of Techniques for Rock Cutting Applications

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ABSTRACT

A method for the numerical simulation of the rock cutting process is developed in the present work. Two different modeling approaches are compared and evaluated with respect to usability and accuracy. The first one uses an existing constitutive law [1-3], which is extended with subroutines to an extended constitutive law (ECL).

The yield function of the constitutive law is described with eq. (1).

$$F = \frac{1}{1-\alpha}\left(\bar{q} - 3\alpha\bar{p} + \beta\left(\tilde{\varepsilon}^{pl}\right)\langle\hat{\bar{\sigma}}_{max}\rangle - \gamma\langle-\hat{\bar{\sigma}}_{max}\rangle\right) - \bar{\sigma}_c\left(\tilde{\varepsilon}_c^{pl}\right) = 0 \qquad (1)$$

The parameter $\bar{p}$ is the hydrostatic pressure, $\bar{q}$ is the Mises equivalent effective stress, α describes the ratio of initial equibiaxial compressive yield stress to initial uniaxial compressive yield stress, β denotes the ratio of uniaxial compressive strength to uniaxial tensile strength, and γ denotes the ratio of the second stress invariants on the tensile and the compressive meridians. The parameter $\hat{\bar{\sigma}}_{max}$ is the maximum principal effective stress, where $\langle . \rangle$ denotes the Macauley brackets, and $\bar{\sigma}_c$ is the effective compressive cohesion stress [1]. The total and compressive accumulated plastic strains are denoted by $\tilde{\varepsilon}^{pl}$ and $\tilde{\varepsilon}_c^{pl}$.

In order to describe the dilation correctly, a non-associated flow rule with a flow potential G based on a hyperbolic Drucker-Prager criterion is introduced,

$$G = \sqrt{(\epsilon\sigma_{t0}\tan\varphi)^2 + \bar{q}^2} - \bar{p}\tan\varphi, \qquad (2)$$

where ϵ is a parameter referring to the eccentricity of the hyperbola, σ_{t0} is the uniaxial tensile stress at failure, and φ is the dilation angle [1].

This plasticity model is extended by the following two features, both implemented as user-defined subroutines in the commercial finite element package Abaqus:

1. The dilation angle φ is allowed to vary depending on the state of the material.
2. A criterion for element deletion is implemented depending on a damage variable computed from $\tilde{\varepsilon}^{pl}$; it is this feature which is crucial for the application of the model to rock cutting.

The second modeling approach uses the constitutive law [1] without these extensions; in order to model the tensile behavior and to allow propagation of the cut, cohesive elements are inserted at all interfaces between adjacent brick elements similar to the approach presented in [4]. The cohesive elements are modeled with a linear traction-separation law [1].

For the comparison of both modeling approaches the impact of a pick on a standardized cube with estimated material parameters is investigated. While the cohesive element approach allows to take into account the effects of debris still influencing the cutting process, it has some drawbacks concerning calculation time and versatility.

The material parameters needed for the ECL are obtained from triaxial and Brazilian tests. To calibrate and evaluate the ECL, a Brazilian test is simulated and then compared with the experimental results. The results from the numerical calculation and from experiment show good agreement.

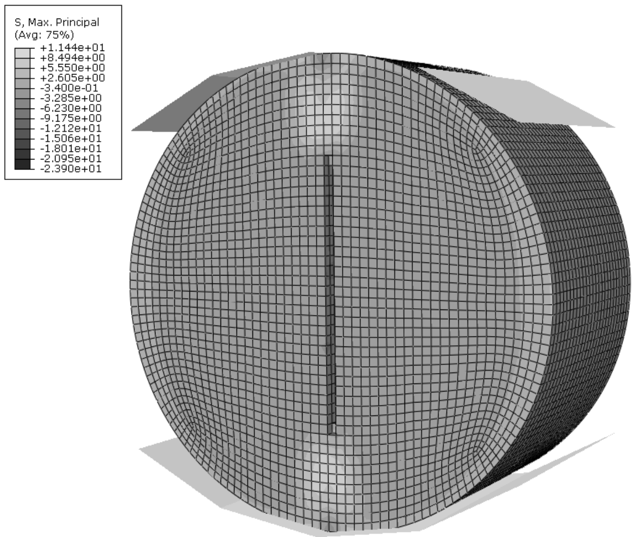

Figure 1: Maximum principal stresses in Brazilian Test calculated with the extended constitutive law.

References

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