# Possibilities of rock constitutive modelling and simulation

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Abstract

The paper deals with a problem of rock finite element modelling and simulation. The main intention of authors was to present possibilities of different approaches in case of rock constitutive modelling. For this purpose granite was selected, due to its wide mechanical properties recognition and prevalence in literature. Two significantly different constitutive material models were implemented to simulate granite fracture in various configurations: Johnson – Holmquist model which is very often used for predicting rock and other brittle materials behaviour, and a simple linear elastic model with a brittle failure which can be used for simulating glass fracturing. Two cases with different loading conditions were chosen to compare aforementioned constitutive models: uniaxial compression test and notched three-point-bending test.

*Keywords: granite, rock, brittle fracture, Johnson – Holmquist model,*

## 1. Introduction

The most common method for excavating copper ore in Polish mining industry is a blasting technique, which involves drilling holes in the mining face. Therefore, an implementation of numerical methods for simulating mining face fragmentation seems to be justified and can be very helpful in acquisition of any field data different than an amount of the burden [8]. However, in order to conduct reliable numerical simulations of such a phenomenon, a proper constitutive model describing mechanical character of brittle material is desired. This will ensure that the obtained results are correct and close to the real ones. In the article, the authors present possibilities of different approaches in case of rock material (granite) constitutive modelling.

## 2. Constitutive material models

Two significantly different constitutive material models were implemented to simulate granite fracture in various conditions: Johnson – Holmquist model (JH-2) which is very often used for predicting rock and other brittle materials behaviour [4-6], and a simple linear elastic model with a brittle failure which can be used for simulating glass [7].

The JH-2 constitutive model assumes that the strength of material, both intact and fractured, is dependent on pressure, strain rate, and damage. The dependence of strength on these parameters, as well of equation of state (EOS) of the material, is represented by a set of constants. These constants are derived from standard dynamic and quasi-static measurements [6]. A summary of the constants of JH-2 model for granite is listed in Table 1 and were taken from [1].

The linear elastic model can be used for preliminary numerical simulations which analyses the overall response of brittle materials to the given load. Due to the small number of input parameters, this model is often used to simulate the brittle materials such as glass subjected to dynamic loads [7]. Based on the selected granite parameters, i.e.: Young's modulus and compression strength a failure criterion was assessed, which corresponds to the uniaxial strain at which fracture of the material was observed. The material properties for the discussed linear elastic model are presented in Table 2.

Table 1: Material constants for JH-2 model [1]

| Elastic constants | | | | | |
|---|---|---|---|---|---|
| $\rho$ [kg/m$^3$] | $E$ [GPa] | $K_1$ [GPa] | $G$ [GPa] | $v$ [-] | |
| 2657 | 80.0 | 49.5 | 30.0 | 0.29 | |
| Strength constants | | | | | |
| $HEL$ [GPa] | $\sigma_{HEL}$ [GPa] | $P_{HEL}$ [GPa] | $\mu_{HEL}$ [-] | $T$ [GPa] | $T^*$ [-] |
| 4.5 | 2.66 | 2.73 | 0.045 | 0.15 | 0.055 |
| $A$ [-] | $B$ [-] | $C$ [-] | $M$ [-] | $N$ [GPa] | $\sigma^*_{HEL}$ [-] |
| 1.01 | 0.68 | 0.005 | 0.76 | 0.83 | 0.2 |
| Presure and damage constants | | | | | |
| $K_1$ [GPa] | $K_2$ [GPa] | $K_3$ [GPa] | $\beta$ [-] | $D_1$ [GPa] | $D_2$ [GPa] |
| 55.60 | -23 | 2980 | 1.0 | 0.005 | 0.7 |

Table 2: Material properties for linear elastic model

| $\rho$ [kg/m$^3$] | $E$ [GPa] | $v$ [-] | $R_e$ [GPa] | $fs$ [-] |
|---|---|---|---|---|
| 2657 | 80 | 0.29 | 0.30 | 0.00375 |

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## 3. Simulated loading scenarios

In order to compare two aforementioned constitutive models two cases with different loading conditions were chosen: uniaxial compression test and three-point-bending (3-p-b) test (Fig. 1). Numerical simulations were carried out using explicit LS-Dyna code [3].

Numerical simulation of the uniaxial compression test was carried out according to [2] with the corresponding initial-boundary conditions. The $\phi$ 50×100 mm cylindrical specimens were used. In the second case a notched three-point-bending test (3-p-b) was simulated with the conditions taken from [10]. The specimen dimensions were as follows: length (*L*) = *300 mm*, width (*W*) = *25 mm*, height (*H*) = *70 mm* and notch length (*l*) = *10 mm*. In both cases the interaction between the specimen and rigid walls (compression test) or indenters and supports (3-p-b test) was simulated using contact model based on penalty method (in this particular case, stiffness was calculated based only on the granite stiffness) [3]. Moreover, the specimens were modelled using 1 point tetrahedron elements.

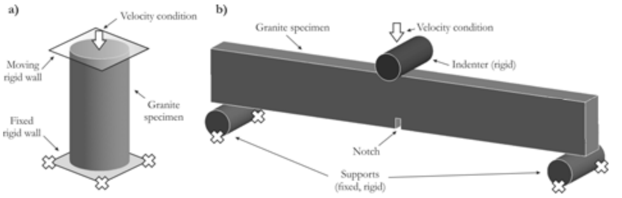


Figure 1: FE granite specimens for numerical analyses with applied initial-boundary conditions, a) uniaxial compression test, b) 3-p-b test

## 4. Results and discussion

From the simulation carried out the fracture characteristics were obtained for both tests. Due to the fact that the JH-2 model with the granite parameters has been already investigated and validated [1,4-6] it was considered as a reference to simpler linear elastic model. It can be noticed, that the results from two investigated constitutive models slightly differ from each other (Fig. 2). This is mainly a result of the fact that in linear elastic constitutive modelling no damage is included and only simple failure (numerical erosion) is implemented using defined criterion. Resultant force vs. displacement curves presented in Figure 3 show that in case of the uniaxial compression tests both models gave similar response of the granite. In 3-p-b test for the linear elastic model the force is slightly overestimated.

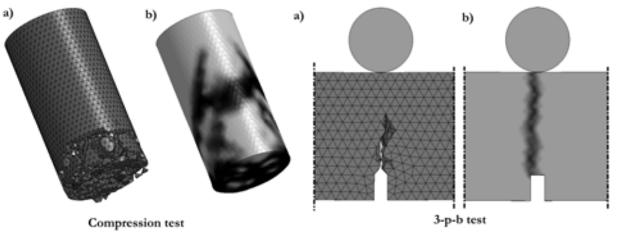


Figure 2: Granite specimen fracture; a) Linear-elastic model test, b) JH-2 model

The authors intention was to present the possibilities of different approaches in case of rock material (granite) constitutive modelling. It was presented that the linear elastic can be used for modelling simple loading conditions or for preliminary studies and results obtained can be the basis for further investigations a wider range. However, the authors are aware of its limitations and simplicity, thus it will be tested in complex loading conditions to verify its effectiveness and reliability in terms of brittle fracture modelling dedicated to rock fragmentation. It should be also stated that the presented modelling is one of the first step for investigating the problem of rock subjected to blast loading. Other constitutive models will be also investigated, which in turn will allow the authors to find the most appropriate one. Moreover, mesh dependence and meshless methods will be analysed in the forthcoming work.

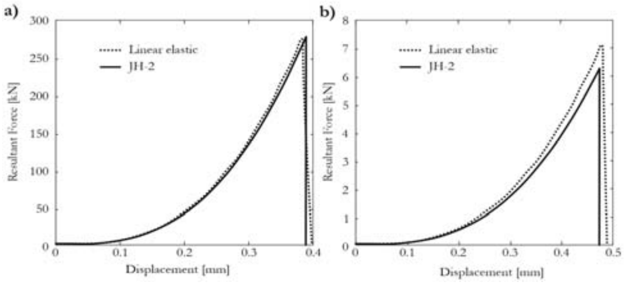


Figure 3: Force versus displacement obtained from numerical simulations of: a) uniaxial compression test, b) 3-p-b test

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