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The numerical modelling of a middle strength rock material under Flexural test by Finite Element method-coupled to-SPH

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Abstract

Proper fracture assessment of the geological materials, which are highly exposed to hydrostatic loading, is a persistent challenge, in particular when aiming to develop an adequate numerical modelling technique. The mechanical response of a middle strength rock, namely Pietra Serena sandstone, under a Flexural (Four-Point Bending) test is investigated numerically in this study. The FEM-coupled to-SPH numerical technique has been approached in conjunction with an advanced material model implemented in LS-DYNA, namely the Karagozian and Case Concrete (KCC) model. The state of stress is investigated in different parts of the specimen in order to determine the strength of the material and the crack initiation area. The numerical results are finally validated by experimental data to show the reliability of the model.

Keywords: Rock; Flexural; ASTM; KCC; FEM; SPH; LS-DYNA

1. Introduction

The purpose of this study is to investigate the mechanical response of a middle strength rock to a Flexural test, also called Four-Points Bending test, by means of an appropriate numerical modelling technique and validation via a standard experimental testing program. Due to several issues, it is inconvenient to determine the maximum principal

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tensile strength of rock materials, which is one of the most significant parameters in the deformability of rocks, by means of the direct tensile test. Therefore, rock engineers are required to design other testing approaches which are capable of indirectly presenting the normal tensile stresses (at least) in a specific portion of the specimen.

The implementation of adequate numerical modelling in conjunction with affordable constitutive models has become an indispensable tool in the stress analysis domain. As far the numerical modelling technique of this study is concerned, it was decided to apply the Finite Element Method (FEM) coupled to Smooth Particle Hydrodynamics (SPH), so that the specimen was first modelled by hexagonal Lagrangian three-dimensional elements. An external algorithm was then implemented to eliminate those elements which reach a specific failure level and subsequently these eroded elements were replaced by SPH particles with exactly the same mechanical properties. This method takes advantage of both the accuracy of the Lagrangian FE (before the occurrence of high distortion) and the ability of the SPH method to cope with large deformation, mesh distortion, etc.

The commercial numerical solver LS-DYNA was implemented due to the existence of a large and adequate library of material models as well as due to the solver's capability to deal with high nonlinear numerical simulations. The Karagozian and Case Concrete (KCC) model was employed in this study. It is an advanced material model which consists of three fixed independent failure levels. This material model decouples the volumetric and deviatoric responses and also analyses the accumulated damage of the elements. The comparison of the numerical and experimental results was critically discussed in order to show the precision of this study.

Nomenclature

σ_{fl}	flexural strength, [MPa]
W	maximum load [N]
L	span length of the specimen
b	width of the specimen
d	depth of specimen
a	further nomenclature continues down the page inside the text box
f'_c	unconfined compressive strength
f_t	tensile strength
ψ	empirical strength index of a brittle material

2. Experimental test arrangement

The experimental configuration for the Flexural test, suggested by the ASTM standard (ASTM, 1998), consists of a rectangular cubic specimen which is supported by two fixed rollers near the end of its length span and loaded vertically by means of two compressive rollers at a certain distance from the center of the specimen (see Fig. 1. a). This symmetrical configuration causes nominally zero shear forces between the two compressive rollers, and accordingly constant bending moment at this area. The normal compressive and tensile stresses act at the top and bottom of this middle span, respectively. The maximum principal stress, which corresponds to the ultimate loading value, according to the beam theory, can be determined. This maximum stress is called the flexural strength and gives a rough approximation about the principal tensile strength. However, the flexural strength tends to overestimate the tensile strength due to some issues, i.e. the estimation process considers a linear relationship as the stress-strain behaviour of the material at its critical cross-section and furthermore all the materials have a certain amount of anisotropic level in their structure (Biolzi, Cattaneo, & Rosati, 2001). Therefore, the flexural strength σ_{fl} [MPa], which is given by the equation (1), can be considered as a parameter to validate the numerical models.

$$\sigma_{fl} = \frac{3WL}{4bd^2} \quad (1)$$

The experimental tests within this research work were conducted on three rectangular cubic specimens of Pietra Serena sandstone with the same geometries. The span length L, width b and depth d of all the specimens are equal to 318,