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NUMERICAL SIMULATION OF WAVE PROPAGATION IN JOINTED ROCK MEDIA

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Summary. *We consider application of a new non-linear, thermodynamically consistent model for porous rocks for nonlinear wave propagation in a jointed rock media. The model uses phenomenological isentropic plasticity theory to describe all inelastic deformations in geological media. It accounts for dilatancy, porous compaction, poroelasticity and rate-effects. The model includes two scale parameters which reduce the strength properties for rock masses based on the Geologic Strength Index (GSI) .*

1 INTRODUCTION

It is well known that field-scale rock masses exhibit considerably weaker strength due to the presence of joints and inhomogeneities. Because joint spacing in field-scale rock masses is typically at the meter scale, direct lab measurements would require samples that are many meters in size. Since experimental study of such media is problematic numerical modelling of jointed rock media becomes very important to solve many practical problems.

In the present study we compare two approaches to modeling jointed media. The first one uses empirical rules developed by Hoek and Brown [1] to scale the yield surface for the jointed rock masses. The other approach models joints explicitly. Experimental measurements in Salem limestone with a single joint [2] were used to calibrate our joint model.Then, using the calibrated joint model, we studied wave attenuation in a heavily jointed media and compared it with the wave attenuation for in situ rock modeled by scaling down the strength properties using reduced GSI index.

2 MATERIAL MODEL FOR INTACT ROCK

The thermodynamical framework developed in [3,4] was used for the constitutive equations. The yield strength function is chosen in the form

$$Y = Y_{HB}F(\beta)\left[\delta + (1-\delta)\left(\frac{P_c - \max(P_0, P)}{P_c - P_0}\right)^r\right], Y_{HB} = Y_c\left[\sqrt{s + \frac{m^2}{36} + \frac{mP}{Y_c}} - \frac{m}{6}\right], \quad (1)$$

$$0 < \delta < 1,\ \ r > 1$$

where β is the Lode angle, Y_c is the unconfined compressive strength, δ is a function of plastic strain describing material hardening, P_c and P_0 are history dependent variables describing a cap surface moving due to porous compaction and Y_{HB} is the ultimate strength for triaxial compression in the form (1). According to [1], coefficients *s* and *m* depend on the quality of the rock described by the GSI index as

$$s = \exp\left(\frac{GSI - 100}{9}\right), \; m = m_i \exp\left(\frac{GSI - 100}{28}\right) \qquad (2)$$

For the intact material s=1 and the value m_i can be found from the static lab tests.

Using this model we were able to numerically reproduce static laboratory tests under a wide rage of triaxial loading conditions as well as dynamic spherical wave propagation tests for intact rock materials.

3 SIMULATION OF SPERICALWAVE EXPERIMENTS IN JOINTED LIMESTONE

Two sets of spherical wave experiments [2] performed at SRI with Salem limestone were simulated (one with a joint and the other one without). Particle velocities at various ranges were measured in these experiments. The spherical charge consisted of 3/8 g of PETN explosive detonated at its center. A single joint placed 2.6 cm below the charge was studied.

Results of radial velocity (along the joint) measurements are shown in Fig.1 together with the calculated velocity histories.

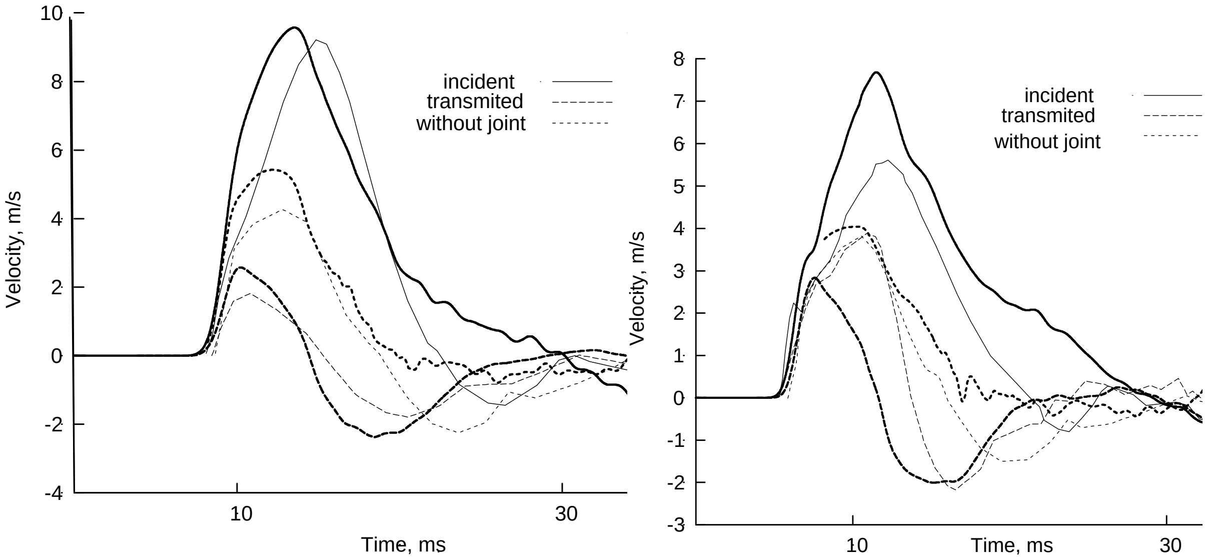

Figure 1: Radial velocity history for a polished joint in dry Indiana Salem limestone for the ranges 2.79 cm (on the left) and 3.97 cm (on the right). Bold lines are calculations, thin lines are experiment [2]

The joints were modeled using a Common Plane method similar to that employed in some Distinct Element codes [5]. A Coulomb friction law with a limited tensile strength was applied for the joints. A Lagrangian staggered mesh, with 2-D quadrilateral elements, was used in the continuum calculations.

4 WAVE ATTENUATION IN A HEAVILY JOINTED ROCK MASS

We have calculated a spherical wave attenuation in various limestones with scaled down strength properties using a few GSI index values (starting from the intact material and up to very weak in situ material). Results of these calculations are shown in Fig.2 together with available experimental points for the intact limestone [2].

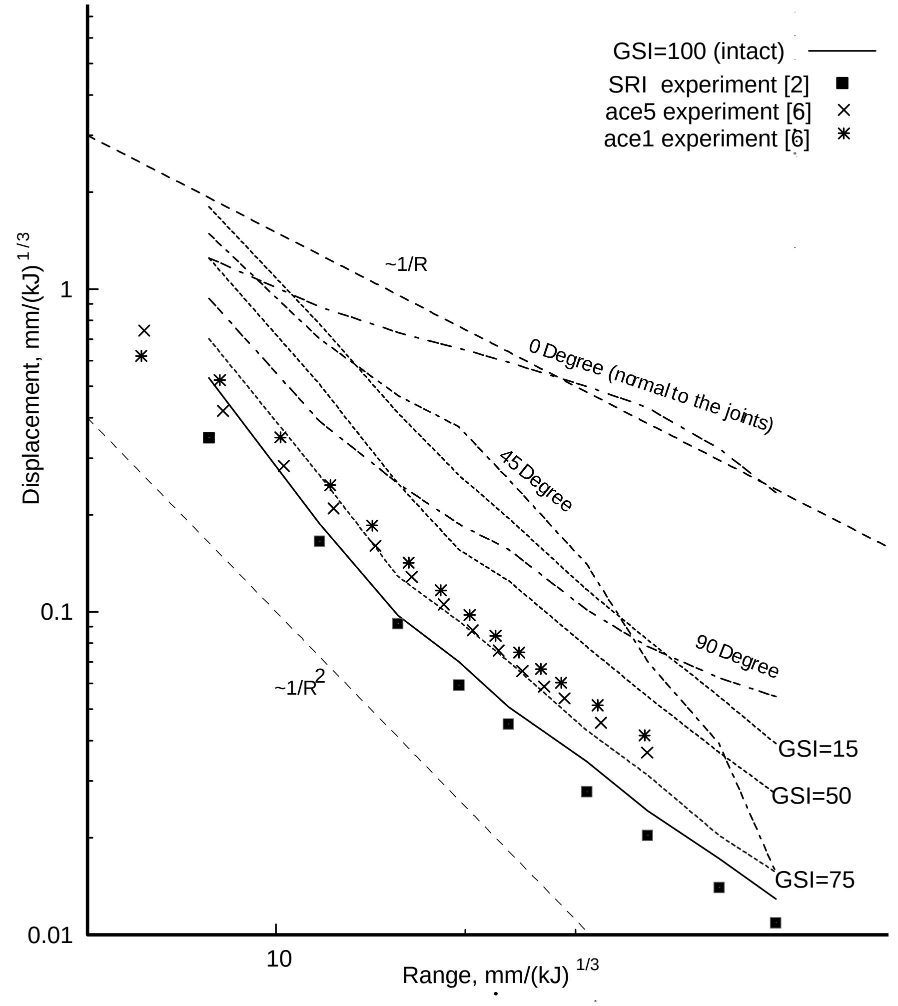

Figure 2: Maximum displacement vs distance from the source for limestones with different GSI

ACE experiments [6] were done for slightly different limestone than one used in [2] which we used to calibrate our model. As it is seen from Fig.2, they can be described by reducing the GSI index.

Also shown are the results of calculations with explicitly introduced joints. All joints were normal to the axis of symmetry. The joint spacing was 6 mm. Results show strong anisotropy in wave attenuation. The normal-to-joint momentum attenuates slower than in the media without joints whereas in the direction of 45 degree to the axis the wave attenuates much faster. It is clear that such a media cannot be successfully modeled in the frame of isotropic approach by scaling down the yield properties for the jointed material.

5 CONCLUSIONS

- We have developed a nonlinear model which describes both static and dynamic measurements in intact rock samples and allows scaling the properties for heavily jointed rock masses.
- Explicit modeling of the joints is important if the joint spacing is comparable with the wave length or if the joints have a preferred orientation (as in the case shown above).
- For larger wave lengths and randomly oriented joints the implicit approach seems to be more practical. More study in 3D is required to establish correlations between the explicit and implicit approaches for this case.

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