Modeling anisotropic damage using a reconstruction by rational covariants of the elasticity tensor obtained by Discrete Element tests

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When submitted to mechanical loading, quasi-brittle materials such as concrete are degraded. This degradation leads to a decrease in stiffness and a loss of isotropy. In the literature, different anisotropic damage models account for those phenomena. However, anisotropic damage models usually require complex experimental identification procedures.

This study aims at deriving a 2D anisotropic damage model from discrete beam-particle simulations. This work is the continuation of previous studies [1, 2].

A virtual beam-particle [3] unit cell is loaded with multi-axial proportional and non-proportional loadings until failure. Those simulations explicitly represent micro-cracking and describe its impact on the effective elasticity tensor. During the loadings, there are two phases of failure: diffuse nucleation of micro-cracks, which then coalesce as macro-cracks. We construct a dataset of effective elasticity tensors using the measurements during each loading.

The formulation of the anisotropic damage state model is done in two parts. We start by defining a damage variable and then model the effective elasticity tensor from this damage variable using the dataset. To achieve those objectives, we analyze the dataset under the light of two mathematical tools. The first is the (exact) distance to a symmetry class (here, to orthotropy). Using this tool, we show that most of the effective elasticity tensors in the dataset are indeed not isotropic. An anisotropic damage model is therefore required to represent the impact of micro-cracking on the elastic properties. We also show that most tensors are close to being orthotropic, so we next assume that the elasticity tensor is at most orthotropic. The second mathematical tool is the harmonic decomposition of an elasticity tensor coupled with a reconstruction by rational covariants. It decomposes any elasticity tensors into two invariants (shear and bulk modulus), a 2nd-order tensor covariant and a 4th-order tensor covariant. Both covariants are harmonic, i.e., traceless and totally symmetric. This decomposition enables us to introduce a damage variable to recover exactly the bulk modulus and the 2nd-order covariant from the damage variable and initial elastic properties. Then, we propose different models to express the shear modulus and the 4th-order harmonic tensor from damage. Thanks to the orthogonality property of harmonic decomposition terms, the models for each part are independent. This procedure enables us to obtain a satisfying state model requiring the introduction of only one parameter up to high levels of damage.

The damage yield surface associated with the beam-particle is analyzed in the second step. We show that a Drucker-Prager criterion fits the discrete model yield surface. Finally, we propose an evolution model based on invariants of the damage variable.

To summarize, we propose a 2D anisotropic state model that accurately represents the impact of micro-cracking on the effective elastic properties up to a high level of damage. We also propose a damage evolution model. A similar methodology could be applied in the 3D case in future studies. Another perspective is adding the effect of crack closure (with contact and friction).

References

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