Random field realization and fracture simulation of rock with angular-bias in microcrack orientation

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Realistic fracture simulations in rock as a heterogeneous brittle material require the use of models that incorporate its inhomogeneities and statistical variability. The statistical variation at the meso and micro scales not only propagate to macroscopic fracture measures such as ultimate load and fracture energy, but also affect the modes of fracture pattern observed. Statistical Volume Elements (SVEs) homogenize material properties at scales below the so-called Representative Volume Elements (RVEs) to maintain material inhomogeneity and randomness, which as mentioned are important in quasi-brittle fracture modeling. The SVE size has a major impact on homogenized material property fields. For example, the mean value and standard deviation of fracture strength generally decrease as the SVE size increase. At the same time, for a macroscopically isotropic material its response at SVE limit may tend to an anisotropic material if the material is built from anisotropic units (e.g. grains) or contain features such as microcracks.

For a macroscopically homogeneous and isotropic material, volume element (VE)-based homogenized properties tend to their macroscopic homogeneous and isotropic limits as the VE tends to infinity (or practically to the RVE limit). However, for a macroscopically anisotropic medium such as rock with bedding planes, the homogenized material fields are expected to remain highly anisotropic irrespective of SVE size. Herein, we propose an approach for a domain with microcracks to derive various angle-dependent fracture strengths. In this approximate approach, the interaction of microcracks is ignored. Eventually, fracture strength field is characterized as a function of not only position but also on the angle of loading. We formulate a Karhunen-Loeve (KL) method for this augmented problem and demonstrate that it can be formed by the KL eigenvalue solutions at certain angles. Next, we demonstrate that for a specific class of rocks where covariance function in angle direction only depends on angle difference (e.g. isotropic rocks), we can decouple the eigen-problem. Sample random fields for fracture strength will be presented for the general and specific cases where covariance function in the angle differences is not and is a function of angle difference, respectively. Finally, we demonstrate the effect of including the angle-dependency of fracture strength in macroscopic rock dynamic fracture simulations with a spacetime discontinuous Galerkin finite element method [2]. The main difference of the proposed work and [1] is that in [1] in all stages of SVE characterization, random field realization, and macroscopic fracture simulation, fracture strength was assumed to be isotropic as opposed to the proposed work.

References:

[1] P.L. Clarke and R. Abedi, "Fracture modeling of rocks based on random field generation and simulation of inhomogeneous domains" In: Proceeding 51th U.S. Rock Mechanics/Geomechanics Symposium, San Francisco, California, USA – June 25-28, ARMA 17-0643 (11 pages), 2017.
[2] R. Abedi, R.B. Haber, S. Thite, and J. Erickson, "An h–adaptive spacetime discontinuous Galerkin method for linearized elastodynamics", Revue Européenne de Mécanique Numérique, special issue on adaptive analysis, 15(6):619 – 642, 2006.