Random field realization and fracture simulation of rocks with angular bias for fracture strength

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Abstract

Realistic fracture simulations in rock as a heterogeneous brittle material require the use of models that incorporate its inhomogeneities and statistical variability. In quasi-brittle materials, the same geometry and loading condition can give quite different fracture patterns. In the present work, we propose an approach based on statistical volume elements (SVEs) to characterize rock fracture strength at the mesoscale, based on the distribution of microcracks at the microscale. The use of SVEs ensures that the material randomness is maintained upon "averaging" of microscale features. By choosing the center of SVEs at a given spatial position on these random realizations and using the moving window approach, where the center of SVE translates in these random realizations, we obtain first and second moments of the target random field. Subsequently, the point-wise probability distribution function and spatial covariance function are used to generate consistent realizations of random fields based on Karhunen-Loeve (KL) method.

There are several differences between [1] and the proposed work herein. First, in [1] fracture strength was assumed to follow a log normal distribution, a restriction relaxed in the present work. Second, in [1] fracture strength was assumed to be isotropic and independent of the angle of loading, conditions that are unrealistic in rock fracture, especially if bedding planes exist. Herein, we add the angle dimension to the spatial domain to deal with a fracture strength field that varies in space and angle directions. We formulate the 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, 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. Third, we demonstrate the importance of incorporating randomness in fracture strength as the angle of loading varies. In uniaxial compressive tests, whether a maximum shear strength or Mohr-Coulomb failure criteria are used, failure occurs on two directions symmetric with respect to the angle of loading. This can result in an unrealistic fracture response where checkerboard fracture patterns occur at almost all points under a highly dynamic loading. We demonstrate that by incorporating randomness of strength in the angle direction, the checkerboard patterns reduce and at different spatial locations different angles of fracture are preferred.

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.