Statistical volume elements for the characterization of angle-dependent fracture strengths

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Realistic fracture simulations in rock 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.

We obtain certain fracture strengths of interest including uniaxial and biaxial tensile strengths, shear strength, and uniaxial compressive strength. These strengths are characterized for different angles of loading, thus rock with anisotropic fracture strength can be characterized. This enables modeling a rock with bedding planes. We compare the statistics of the characterized strengths in terms of their probability distribution function, mean value, and standard deviation as the size of volume elements increases. Further, we study the auto- and cross-correlation functions of these random fields to shed light on the length scales, relative to the volume element size, at which homogenized properties vary. While crack interaction is not included in our model, the analysis provides insight on the distribution and correlation of different strengths. Finally, the spacetime discontinuous Galerkin (SDG) method is used for macroscale rock fracture analysis where fracture strengths are obtained by the aforementioned homogenization approach. The SDG method permits nucleation of cracks from weak points in the domain and their propagation along the most preferable angle which is determined based on local stress field and angle-dependent fracture strength.