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COMPUTING QUASIBRITTLE FAILURE PROBABILITY: FROM NANO TO MACRO

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ABSTRACT

In civil, aeronautical and naval engineering, in protection from natural hazards, and in micro-electronics and MEMS, and one must ensure an extremely small failure probability, $< 10^{-6}$. How to do that is adequately understood only for the limiting special cases of perfectly brittle or ductile behaviors, for which the structural strength distribution is necessarily Weibullian or Gaussian, respectively. Presented is a computational approach to do that for the broad class of quasibrittle structures, which have brittle constituents with material inhomogeneities of non-negligible size, and include structures made of concrete (as the archetypical case), rocks, fiber composites, wood, toughened ceramics, rigid foams, sea ice, stiff soils, snow slabs, etc., as well as metals and ceramics on approach to nano-scale. It is shown that, for such structures, the strength distribution is transitional, having a Weibull asymptote (with zero threshold) on the left and a Gaussian (normal) asymptote on the right, with the transition center shifting from left to right as a function of structure size and geometry. The consequence is that, for quasibrittle structures, the understrength partial safety factor must also be computed as a function of size and geometry. Computing merely the mean and standard deviation of structural strength is insufficient, while a purely computational evaluation of the far-out distribution tail for any given structure size and geometry is beyond reach. Therefore, computational mechanics must be combined with a physically based model of the distribution, to anchor the tail to the mean and standard deviation, both of which can be computed easily, e.g., by combining finite elements or discrete elements with Latin hypercube sampling. It is shown how the transitional distribution of strength of a representative volume element (RVE) of material can be derived from the interatomic potential, Maxwell-Boltzmann distribution of atomic energies and stress dependence of the activation energy, how (for failures occurring at crack initiation) the RVE distribution can be scaled up with structure size, considering its geometry, and how asymptotic matching techniques can overcome computational challenges. Using Morse interatomic potential, the theory is further extended to predict the distribution of lifetime of quasibrittle structures and show how it depends on structure size and geometry. The theory is verified by comparisons with experimental strength histograms and size effect tests of concrete, ceramics and fiber composites. Finally, as an example, it is shown that the tolerable abutment displacement of the Malpasset dam, catastrophically breached in 1959, would today have to be about 4-times smaller than assumed at the time of design.

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