STATISTICAL MECHANICS OF SAFETY FACTORS: FROM NANO TO MACRO

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In civil, naval and aeronautical engineering, in protection from natural hazards, and in micro-electronics and MEMS, failure probability less than about one in a million is required. How to achieve that is adequately understood only for the limiting special cases of perfectly brittle or ductile behaviors. Presented is a theory to achieve that for the broad transitional class of quasibrittle structures, having brittle constituents with material inhomogeneities of non-negligible size (concrete, rock, fiber composites, wood, tough ceramics, foams, etc). It is shown that the probability distribution of strength of a small representative volume element (RVE) of material is governed by the Maxwell-Boltzmann distribution of atomic energies and stress-dependence of interatomic activation energy barriers, and that it must be statistically modeled by a hierarchy of series and parallel couplings. The strength distribution of one RVE must have a broad Gaussian core with a grafted far-out power-law tail having a zero threshold and amplitude depending on temperature, loading rate and load duration. The tail governs the strength distribution of a quasibrittle structure according to the weakest-link model for a finite chain of finite RVEs. The Weibull distribution must have a zero threshold and is approached only for structures far larger than one RVE (which must be redefined in terms of extreme value statistics). The theory can capture experimentally observed deviations of strength histograms from Weibull, and of the mean scaling law from a power law. These deviations can be exploited for verification and calibration.

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