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Quasibrittle Failure Probability and Scaling

given by

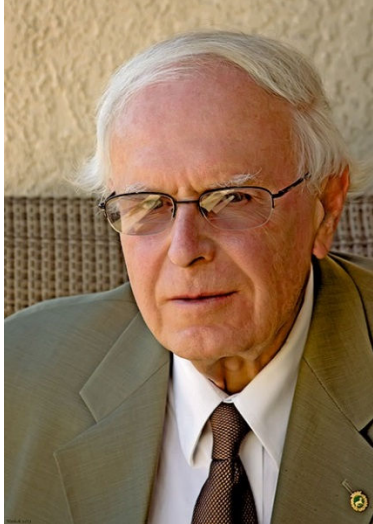
Prof. Zdeněk P. Bažant

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The size effect on structural strength and its probability distribution function (pdf) is a complex problem for quasibrittle materials because their failure behavior transits from quasi-plastic at small sizes to brittle at large sizes. These are heterogeneous materials with brittle constituents in which the size of inhomogeneity, or representative volume element (RVE), is not negligible compared to the structure size. Aside from concrete, the archetypical example, they include fiber composites, coarse-grained ceramics, rocks, sea ice, snow slabs, wood, bone, foam, stiff soil, dry snow, ccarton, etc., and on the micro- or nano-scale, all brittle materials become quasibrittle. Since the break probability is known exactly only for interatomic bonds (being equal to frequency), Kramer's rule of transition rate theory is applied to nano-crack jumps. Based on proving the rules of multiscale transition of tail probabilities of break to material scale, the probability distribution function (pdf) of strength of one macro-scale representative volume element (RVE) is shown to have a Weibullian tail, calibrated to reach to probability circa 0.001, the rest being Gaussian. On the structure scale, only Type 1 failure is considered, i.e., the structure fails as soon as the first RVE fails. Hence the weakest-link model applies on the structure scale. But, crucially, the number of links is finite, because of non-negligible RVE. For increasing structure size, the Weibullian portion gradually spreads into the Gaussian core. Only in the infinite size limit the distribution becomes purely Weibull, but, importantly, with a zero threshold. Based on an atomistic derivation of the power law for subcritical macro-crack growth, a similar Gauss-Weibull transition is shown to apply to structure lifetime. The theory is then extended to the size dependence of Paris law and Basquin law for fatigue fracture, to statistics of fatigue lifetime, and to residual strength after a period of preload. The theory is shown to match the existing experimental results on the monotonic strength, residual strength after preload, static and fatigue crack growth rates, and static and fatigue lifetimes, including their distributions and size effects on the distributions. There are three essential consequences: 1) The safety factors must depend on structure size and shape; 2) To predict the pdf of strength, the size effect tests of mean strength suffice; 3) To predict the static and fatigue lifetimes, it suffices to add tests of initial subcritical crack growth rate. An interesting mathematical analogy predicting the lifetime of nano-scale high-k dielectrics is also pointed out. Finally, a new "fishnet" statistics for strength of biomimetic nacre-like lamellar structures, modelled as a square fishnet pulled diagonally, is presented. This simple model differs from the weakest-link model as well as the fiber bundle model. The pdf is found again to transit from Gaussian to Weibullian, but in a different way.



Bio-Sketch: Born and educated in Prague (doctorate 1963), Bažant joined Northwestern in 1969, where he has been W.P. Murphy Professor since 1990 and concurrently McCormick Institute Professor since 2002, and Director of Center for Geomaterials (1981-87). He was inducted to NAS,



NAE, Am. Acad. of Arts & Sci., Royal Soc. London; to the academies of Italy (lincei), Austria, Spain, Czech Rep. and Lombardy; to Academia Europaea, Eur. Acad. of Sci. & Arts. Honorary Member of: ASCE, ASME, ACI, RILEM; received 7 honorary doctorates (Prague, Karlsruhe, Colorado, Milan, Lyon, Vienna, Ohio State); Austrian Cross of Honor for Science and Art 1st Class from President of Austria; ASME Timoshenko, Nadai and Warner Medals; ASCE von Karman, Newmark, Biot, Mindlin and Croes Medals and Lifetime Achievement Award; SES Prager Medal; ČSM Medal, Šolín, Bažant Sr. and Stodola Medals, RILEM Medal; Exner Medal (Austria); Torroja Medal (Madrid); etc., Hon. Mem. of 8 societies. Was President of SES, IA-FramCoS, IA-ConCreep. He authored seven books on Concrete Creep, Scaling of Structural Strength, Inelastic

Analysis, Fracture & Size Effect, Stability of Structures, Concrete at High Temperatures, and Probabilistic Quasibrittle Strength. H-index: 112, citations: 55,000 (one Google Jan. 2017, incl. self-cit.), i10 index: 550. In 2015, ASCE established ZP Bažant Medal for Failure and Damage Prevention, and; ČSM ZP Bažant Prize for Eng. Mech. He is one of the original top 100 ISI Highly Cited Scientists in Engrg. (www.ISIhighlycited.com). His 1959 mass-produced patent of safety ski binding is exhibited in New England Ski Museum. Home: <http://cee.northwestern.edu/people/bazant/>

Selected References:

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The lecture will be held on Wednesday, June 15, 2017 at 10:00 in the building of the Institute of Thermodynamics (lecture room B), Dolejškova 5, 182 00 Prague 8

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