Bažant's Scientific Accomplishments **March 2008**

A salient property of the classical theories of elasticity and plasticity is that the nominal strength of a structure (understood as the maximum load divided by the characteristic cross section area of structure) is independent of structure size. However, for materials lacking ductility, it decreases with the structure size. This is known as the size effect. Until the 1980s, all the experimentally observed size effects were generally attributed to material strength randomness. The idea was that, at increasing structure size, the strength of the weakest material element governing structure strength is statistically likely to decrease. This statistical theory (suggested in 1684 by Mariotte and mathematically first formulated in 1939 by Weibull) worked superbly for fatigue-embrittled metals and fine-grained ceramics, but not for quasibrittle materials. These are materials in which the inhomogeneity size (or fracture process zone size) is not negligible compared to the structure size. They include concrete (as the archetypical case), polymer-fiber composites, tough ceramics, rocks, stiff soils, sea ice, snow slabs, rigid foams, wood, bone, many high-tech and bio-materials, and most materials on approach to nano-scale.

Bažant revolutionized the theory of scaling of structural failure beginning with his 1984 discovery of a stronger type of size effect which dominates in quasibrittle structures, is non-statistical, and is caused by the release of stored energy due to stable growth of large fractures or large damage zones prior to reaching the maximum load. Noting that, in the case of geometric similarity, the energy consumed by fracture increases with structure size linearly and the energy released from the structure quadratically, he concluded that, to preserve energy balance for all sizes, the nominal strength must decrease. Using ingenious asymptotic matching arguments, Bažant derived in 1984 a deceptively simple law which bridges the power scaling laws of classical fracture mechanics and of plasticity, and has surprisingly broad applicability to all quasibrittle materials. With his assistants, he verified his law by experiments on many materials, and by nonlocal numerical simulations. He showed how to use his size effect law for identifying the cohesive fracture characteristics from experiments (which became an international standard), and how to exploit it to simplify computer failure analysis.

Early in the computer era, cracking and other distributed damage in quasibrittle materials was simulated in terms of the stress-strain relations. In 1976 Bažant changed the practice by demonstrating that such computer simulations are unobjective since they exhibit spurious mesh sensitivity and strain localization, converge at mesh refinement to a wrong solution with zero energy dissipation, and exhibit a spurious size effect. To overcome such pathological behavior, Bažant pioneered, beginning with his landmark 1976, 1983 and 1984 papers, distributed damage models with a finite material characteristic length. These models include his energy-consistent crack-band model (1976, 1983), today widely used in practice, and his nonlocal and gradient models for damage (1984), which stimulated an avalanche of papers and are today used in most research on quasibrittle failures. Bažant justified the nonlocality by heterogeneity and micromechanics of interacting growing crack systems. In 1991, using extreme value statistics, he formulated a probabilistic extension describing the transition from the energetic size effect in small structures to the classical statistical size effect in large structures failing at fracture initiation. Further he extended his size effect law to compression fracture (including kink band propagation in fiber composites), to safe design code procedures for R.C. (under shear) and for dams, and to metal-composite joints and sandwich shells for large ship hulls and aircraft.

It may be noted that Bažant also made major contributions to structural stability (correlation among various 3D stability criteria at finite strain, stability of crack systems, thermodynamic analysis of inelastic structure stability, stability of sandwich plates and other soft-in-shear, delamination buckling, stability of large regular frames), theory of creep and hygrothermal effects in concrete (model B3 for design; age-adjusted effective modulus method for creep structural analysis, standard by now; nonlinear diffusion model; solidification and microprestress models for creep and aging; exponential algorithm; high-temperature creep and diffusion; thermodynamics of creep mechanism; finite-strain damage), constitutive modeling of concrete, rocks, etc. (microplane model M4), effects of alkali-silica reaction or microwave heating on concrete, 3D elastic stress singularities, size effects in micrometer-scale thin metallic films, crashworthiness of braided composites, etc. He presented the first (and later complete) explanation of 9/11 WTC collapse, and clarified the response of nuclear concrete structures to reactor core accidents. In 1959 he patented a successful safety ski binding, in 1961 designed a highly curved prestressed box girder remarkable for those times, etc.

Nevertheless, Bažant is best known for his world leadership in research on the scaling of structural failure.