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Size effect in quasibrittle failure: Analytical model and numerical simulations using cohesive zone model

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ABSTRACT

The recent rewriting of the Bažant's size effect law (Morel, 2008) which has suggested the existence of an additional asymptotic regime for intermediate structure sizes is now compared to numerical simulations of fracture of geometrically similar notched structures of different sizes extending over 2.4 decades. The quasibrittle fracture behavior is simulated through cohesive zone model (bilinear softening) using a constant set of cohesive parameters whatever the specimen size D is. The R-curves resulting from the load–displacement responses are estimated and appear as size-independent. On this basis, the different asymptotic regimes expected for the size effect on fracture properties at peak load such as the relative crack length, the resistance to crack growth and the nominal strength are shown in fair agreement with the size effect observed on the results obtained from numerical simulations.

1. Introduction

It is nowadays firmly established that the size effect of quasibrittle materials such as concrete, mortar, rocks or wood is an *energetic* size effect and not a *statistical* one in the sense of the Weibull's statistics (Weibull, 1939). Indeed, during the failure of quasibrittle materials, the development of a fracture process zone (FPZ) leads to a stable crack growth prior to the attainment of the peak load. Thus, if the notion of statistical distribution of the local strength exists in quasibrittle materials, the statistical effects are supplanted by release of the stored energy engendered by the stress redistributions which take place in the FPZ. This characteristic of stable crack growth in quasibrittle materials is well described within the framework of equivalent linear elastic fracture mechanics (eq. LEFM) through the resistance curve, commonly called R-curve. The R-curve is at the source of the size effect law (SEL) proposed by Bažant and co-workers (Bažant, 1984, 1997a,b, 2000) which describes the size effect on nominal strength of geometrically similar notched structures of different characteristic sizes D. The nominal strength of a structure of characteristic size D is defined as:

$$\sigma_N(D) = c_N \frac{P_u}{bD}, \tag{1}$$

where P_u is the maximum external load applied to the structure (commonly called the peak load), b is the thickness of the specimen and c_N is a coefficient introduced for convenience. In the last evolution of the SEL, Bažant (1997b) has shown, from an energy-based asymptotic analysis founded on the assumption of a size-independent R-curve, that the size effect on nominal strength σ_N can be estimated, in a first order asymptotic approximation, as:

$$\sigma_N(D) = \frac{Bf_t}{\sqrt{1+\frac{D}{D_0}}}, \tag{2}$$

where f_t [Pa] can be considered as the tensile strength of the material, B is a constant and D_0 [m] is the crossover size between two extreme asymptotic behaviors.[1] Note that the size effect defined in Eq. (2), qualified as 'type 2' size effect (Bažant, 2004), occurs in the case of a large initial notch or preexisting stress-free (fatigued) crack and if the geometry of the specimen is positive (i.e., such that P_u occurs while the FPZ is still attached to the notch tip).

According to Eq. (2), the size effect on the nominal strength of geometrically similar notched structures is expected to be transitional between two extreme asymptotic behaviors as shown in Fig. 1. In the case of small structure sizes (i.e., $D \ll D_0$), $\sigma_N \simeq B$

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[1] The constant B is linked to D_0 and both constants are geometry-dependent.

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