SIZE EFFECTS: THEORETICAL CONCEPTS, EXPERIMENTAL VERIFICATION, AND IMPLICATIONS IN STRUCTURAL DESIGN - CONCLUSIVE REMARKS

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Abstract

This report gives some preliminary conclusions from the discussion in the Conference Workshop III entitled "Size Effects: Theoretical Concepts, Experimental Verifications, and Implications for Design", at the FraMCoS 2 conference. Two main tendencies for the account of size effects are distinguished, one concerned with the structural level, which takes into account size effects in terms of scaling laws, the other concerned with the numerical modeling of size effects. Concerning the scaling laws, the different approaches (global energy release *versus* topological approach) lead to different scaling laws, to be seen in perspective with the different theoretical concepts behind. Finally, concerning the numerical modeling, size effects can be taken into account at the local level of material description through the dependence of the material properties governing cracking on the maximum aggregate size.

1 Origin of Size Effects

It seems now generally admitted that size effects in the cracking of concrete is due to the degree of heterogeneity of the matter constituting concrete: the tensile strength of concrete is mainly related to that of the cement paste, which - in turn - is governed by the presence of voids, microcracks etc. created during the concrete hardening by nun-uniform shrinkage during hydration at the scale of the heterogeneous material, i.e. at the scale of the concrete aggregates. At the level of local material description, these initial defaults are activated during loading in the sense of Weilbull's theory (1939), influence the cracking of concrete and give rise to apparent size effects concerning the nominal strength of the material. The fracture process is thus influenced by these local size effects and with it the nominal strength of the structure. However, at this structural level, the cracking leads to stress re-distributions and activates dissipative mechanisms (such as friction at crack interface), not accounted for in Weilbull's theory which seems thus not appropriate to describe size effects on the nominal strength of structures.

2 Account for Size Effects

The account for size effects depends on the scale of material description, whether structural (nominal strength of structures) or local (nominal material strength and/or tension softening properties). In this sense, two main tendencies for the account of size effects are distinguished, one concerned with the structural level, which takes into account size effects in terms of *scaling laws*, the other concerned with the numerical modeling of size effects.

2.1 Structural level

Concerning the scaling laws, two main approaches can be distinguished to describe size effects on the nominal strength of structures, namely the *global energy release* approach proposed by Bažant and the *topological approach* proposed by Carpinteri and co-workers (see the workshop papers). The different theoretical approaches behind lead to different scaling laws (figure 1), which approximately overlap in the middle of the range.

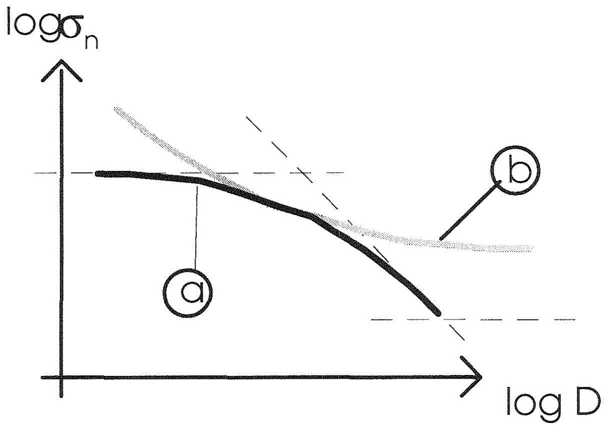

Figure 1 : Universal Scaling Laws; a) global energy release approach, b) topological approach

- The "size effect law" proposed by Bažant is based on energy release arguments and dimensional analysis. It matches the asymptotic cases of very small and very large structures, the first described in terms of the strength theory (horizontal asymptote), the latter described by linear fracture mechanics (oblique asymptote).
- The "multifractal scaling law" proposed by Carpinteri and co-workers is based on a geometrical approach that describes in terms of fractal geometry the microstructural disorder (i.e., the degree of heterogeneity). However, the "mechanics" used in the derivation of the multifractal scaling law seems to be not yet formulated (the tensorial origin of the stresses at the level of the fractal description needs to be stipulated *a priori*; otherwise, stresses are not related via contact forces to the external load).

2.2 Numerical modeling

In contrast to the structural level, size effects can be taken into account at the level of material description, and with this in the numerical modeling of concrete cracking. Since size effects are due to the degree of heterogeneity of the matter constituting concrete, the existing models account for size effects through the dependence of the material properties governing cracking on the maximum aggregate size. We may distinguish (see the workshop papers):

- The "probabilistic approach" proposed by Rossi, where the nominal tensile strength at the level of local material description is given by distribution functions with experimentally determined mean values and standard deviation which depend on the test-specimen size, the size of the coarsest aggregate and the nominal compressive strength. In the FE modeling with a discrete crack-approach, these functions are used by replacing the test-specimen volume by the volume of each singular finite element. The distributed tensile strength thus models the heterogeneity of the matter, depending on the scale of material observation, which -in the FE modeling- corresponds to the finesse of the meshing.
- The "tension softening approach" proposed by Mihashi, which accounts for size effects by the dependence of the tension softening properties of the material on the maximum aggregate size. This allows for the numerical determination of scaling laws at the structural level, which can be compared with the existing scaling laws determined directly at the structural level from experimental data.

Numerical models which account for size effects can therefore be used to verify existing scaling laws, calibrate their parameters or determine their domain of application. In particular, the asymptote for very large structures, i.e. the size of the structure beyond which size effects become negligible, can be determined numerically. In the case of exceptional structures, where it is too expensive to perform experimental tests, the scaling law may be determined from less expensive numerical simulations.

3 Conclusion

This report cannot reproduce the vivid discussion of the workshop on such a hot topic as size effects in concrete cracking and failure. No doubt seems to exist about the (practical) importance of size effects for design and modeling of concrete cracking and failure. While the origin of these size effects seems now settled ("why?"), disagreement still exists "how (?)" to account for them at the structural level. In return, there seems less disagreement in the numerical modeling of size effects. Based upon the physical origin of size effects, the dependence of the material properties governing cracking on the maximum aggregate size at the level of material modeling seems promising for the future.