

Fracture mechanics of concrete: Structural application and numerical calculation

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Mechanics of fracture and progressive cracking in concrete structures

1.1 Introduction

Cracking is an essential feature of the behavior of concrete structures. Even under service loads, concrete structures are normally full of cracks. Clearly, cracking should be taken into account in predicting ultimate load capacity as well as behavior in service.

To fracture mechanics specialists, it appears natural that concrete structures should be designed according to fracture mechanics. Yet, none of the existing code provisions are based on fracture mechanics. The reason is not ignorance on the part of concrete engineers. Fracture mechanics analysis was tried, and was found to yield predictions that deviate from measurements, on the average, at least as much as those based on the tensile strength approach. These were, however, predictions of the classical, linear fracture mechanics.

In various recent studies, especially those at the Technical University of Lund, Northwestern University and Politecnico di Milano, it became apparent that fracture mechanics does work for concrete, provided that one uses a proper, nonlinear form of fracture mechanics in which a finite nonlinear zone at the fracture front is taken into account. This may be done in various ways. In the first part of the present work, an exposition of one particularly efficient approach will be given. In this approach [8], which is based on the work recently pursued with success by a group of researchers at Northwestern University and Politecnico di Milano, cracking is modeled in a continuous, or smeared manner, and fracture is treated as a propagation of a smeared crack band through concrete. Continuous modeling of cracks in concrete, introduced by Rashid [119], has become popular in finite element analysis, not just because it reflects the reality of densely distributed cracks, but mainly because it is computationally convenient.

In the present engineering practice, tensile strength is used as the cracking criterion. This criterion, however, does not give objective results and does not agree with fracture tests. Remedy can be obtained by

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introducing an energy criterion. This approach will be described in detail, along with the finite element implementation, comparisons with fracture tests, and some examples of application. Considered will be the consequence for the structural size effect, and how this effect should be manifested in code formulas for brittle failures, such as the diagonal shear failure of beams. Furthermore, the stability aspects of fracture will be analyzed focusing attention on the strain localization instability as well as crack spacing. Finally, the conclusion will center on a more fundamental study of strain-softening triaxial constitutive relations for the fracture process zone.

The principal intent of this work* is to highlight various new research directions, rather than present a systematic review and description of all the existing knowledge.

1.2 Blunt crack band theory

Basic hypothesis. The analysis which follows is based on the hypothesis that fracture in a heterogeneous material such as concrete can be modeled as a band of parallel, densely distributed microcracks having a blunt front [1-5]. This hypothesis may be justified as follows.

For the purpose of analysis, a heterogeneous material is approximated by an equivalent homogeneous continuum. One must then distinguish the continuum stresses and strains (macrostresses and macrostrains) from the actual stresses and strains in the microstructure, called the microstresses and microstrains. In the theory of randomly inhomogeneous materials, the homogenized continuum stresses and strains are defined as the averages of the microstresses and macrostrains over a certain representative volume (Figure 1.1). Its size must be sufficiently large compared to the size of the inhomogeneities. Even for a crude description, this size must be considered to be at least several times the size of inhomogeneities, i.e., several times the maximum aggregate size.

In the usual analysis, only the average elastic (or inelastic) material properties are considered and the geometry of the microstructure with the differences in the elastic constants between the aggregate and the cement matrix is not taken into account. The detailed distribution of stress or

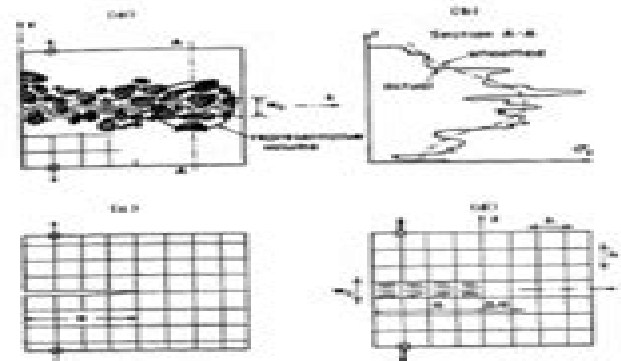


Fig. 1.1. Random microstructure, smear of microcracks, and crack band or blunt crack model.

strain is assumed, it makes no sense to consider concentrations of stress (or of microcrack density) within volumes less than several aggregate sizes (Figure 1.1).

Similarly, a straight-line crack is an approximation. The actual crack path in concrete is not smooth but highly tortuous, since the crack tends to pass around the hard aggregate pieces and randomly ways to the side of a straight path by distances roughly equal to the aggregate size (Figure 1.1). Therefore, the actual stress (microstress) variation over such distances cannot be relevant for the macroscopic continuum model.

In view of the foregoing arguments, one should not subdivide the

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Katrin Zwirgmaier



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