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A comparative study of fracture parameters in notched concrete beams*

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The object of this contribution is to focus attention on the parameter γ_R as described by Equation (2) of the paper. The formulation adopted has some novel features which invite comment and further investigation.

The modified effective fracture energy γ_R is determined from the energy dissipated in a cycle of loading. In the Appendix to the paper, it is suggested that during an increment of loading energy is dissipated in three ways, viz,

- (1) in creating new traction-free surfaces corresponding to the extension of an open crack by an amount Δc ,
- (2) in extending the microcracked zone (which exists ahead of the stress-free crack) into previously uncracked material, and
- (3) in increasing the amount of microcracking in regions where microcracks already exist before the increment is applied.

The energy in category (1) is of the kind envisaged by Griffiths and is the material input to Linear Elastic Fracture Mechanics. The component (2) has a counterpart in Hillerborg's⁽¹⁾ fictitious crack model for crack propagation with its traction/crack separation relation giving the work of fracture. Component (3) is additional and does not fit the normal pattern in that,

although the increment of energy dissipated depends on the length of the previously microcracked zone, it does not depend on the amount the crack advances. Because of this, Equation (2) is not homogeneous and terms of a size determined by incremental quantities appear with others that are not.

To see the implications of this, consider a cycle of loading in which the crack does not advance. If energy is dissipated in such a cycle of loading, a value of γ_R can be calculated from Equation (2) using the length of material previously subject to microcracking. Moreover, the equation suggests that repeated cycles of loading would lead to an increase in microcracking, without necessarily any corresponding crack extension. Accordingly, it seems that the energy component (3) is more related to hysteresis and damping than crack extension.

In work on concrete in compression, Spooner and Dougill⁽²⁾ separated the energy dissipation in a cycle of loading into components on the assumption that damage occurred only when acoustic emission could be detected and this occurred only during the first passage over a particular strain range. It is suggested that a similar approach might have some application in analysing the results of the notched beam tests reported in the paper.

REFERENCES

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*Pages 50 to 58 of MCR 142.

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Reply by the authors

The main issue in the points raised by Dr Dougill concerns the occurrence of continued microcracking in already microcracked regions under further cycles of load. If such a phenomenon is absent, then Dr Dougill's arguments are entirely correct, which would allow Equation (2) to be reformulated. However, these seem to be a number of pointers to the continued microcracking phenomenon.

(1) If during a given cycle of loading, energy is consumed solely in the extension of the microcracked zone (ΔZ_{n1}) and in the creation of new stress-free crack surfaces (Δc), then this implies that the region of material lying between these incremental lengths experiences no microcracking. It would seem inconsistent that a region of material between two other regions in which energy is being consumed, would itself contribute nothing to the energy term, especially since the global stress field must be continuous in these regions.

It would seem more logical to consider all three regions as being subject to a similar microcracking phenomenon throughout the loading cycle. Then, the extension of the microcracked zone is the initia-

tion of new microcracking in previously undamaged material, the previously microcracked zone experiences continued microcracking, and the creation of new stress-free crack surfaces is little more than the final stage in the process of microcrack development and coalescence. Hence the Δc component should be thought of in microcracking terms rather than in classical Griffith terms.

(2) The question of whether energy can be dissipated during a cycle of zero main crack growth by the mechanism of continued microcracking is interesting. According to SEM work in progress by a colleague, Dr Tait, of this University, continued microcracking (in the form mainly of microcrack extension) does occur in previously microcracked material during a cycle of loading. What is not clear, is whether this phenomenon occurs when there is no extension of the main crack.

However, zero extension of the main crack during a load cycle is not necessarily synonymous with zero extension of the microcracked zone. Is there in fact not a possibility that what we call hysteresis/damping may at least partly be related to microcrack development? This problem bears further study.

Having made the above points, it is to be acknowledged that Equation (2) is not entirely satisfactory at this stage. The component of energy (c) in the discussion does depend partially on the amount that the crack advances in that crack advance reduces the lengths of the region in question. On the assumption that the continued microcracking phenomenon is valid, then another form for Equation (2) may have to be found. Clearly, further phenomenological studies of microcrack development are required before this question can be properly resolved.