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Influence of Shear Transfer on Cracking Localization

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1. Introduction

Shear transfer is the process that is mobilized with the occurrence of crack sliding displacements along the crack plane. These crack sliding displacements begin to exist after the formation and opening of cracks. In this study, a pullout test specimen with lateral confinement is analyzed to examine the influence of shear transfer on the phenomenon of cracking localization in curved Mode-I fracture in concrete structures. The FEM with cracked element is considered as a suitable method for the analysis. The tension-softening behavior with unloading path is considered. A general model for the shear transfer across the crack surfaces is established, and incorporated into the computer program. The restrained pullout test specimen is analyzed without and with the consideration of shear transfer across crack surfaces, and the results are also compared with the available experimental data.

2. Model for Shear Transfer

It was noted that crack sliding displacements begun to exist after the formation and opening of cracks by the inspection of the numerical results obtained from the analysis of the specimen as shown in Fig. 2. However, the size of such displacements was not significant in the present study. The relationships between crack opening displacements and crack sliding displacements (usually called displacement paths) obtained from numerical analysis were compared with those used by Hassenzadeh [1] in his experiments. These displacement paths for a typical element are depicted in Fig. 1a. From the comparison a simple model for shear transfer across the crack surfaces is established as shown in Fig. 1b.

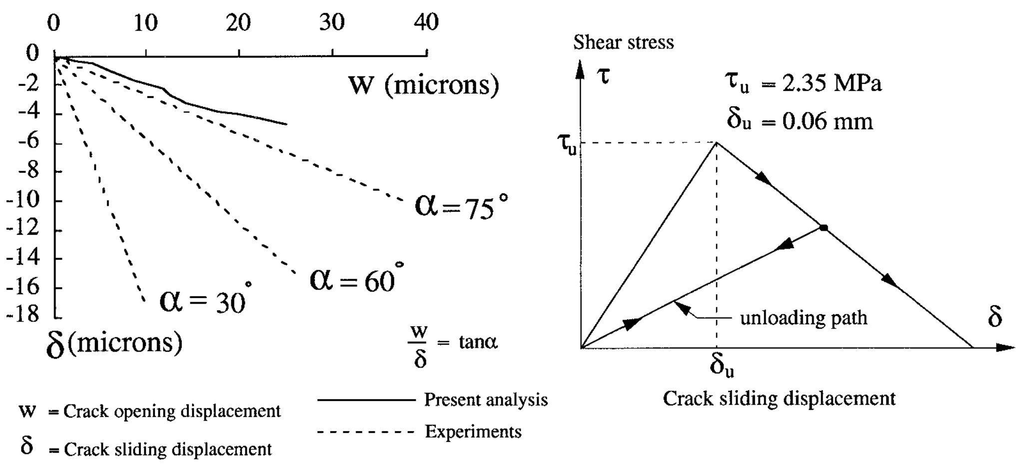

Fig. 1 (a) Displacement paths (b) General model for shear transfer

3. Method of Analysis

Following formulation of tensile fracture phenomena, and piecewise polynomial basis functions for a cracked element over two separate regions, the finite element equations for the 4-node cracked element, with embedded displacement discontinuity in its interpolation functions, were established [2]. A finite element code was developed by implementing these finite element equations for the cracked element into the computer program. The input of this program consists of the geometry of the specimen, the notch depth (if any), thickness, Young's modulus, Poison's ratio, the tensile-softening parameters, and shear transfer parameters.

The load increment analysis is conducted by controlling the load increment so that one element cracks or a change in slope of tension-softening relation occurs in one step. In this method, at every step, a unit load is applied as the testing load, and for every uncracked element, the exact amount of load increment necessary for cracking the element, or, for change in slope of tension-softening curve for the cracked element is established in advance [2]. The magnitude of load factor is determined as the minimum value for the next element to be cracked or for the change in the slope of the tension-softening curve. The uncracked element stiffness is replaced with the cracked element stiffness in case element cracks, or the next slope of tension-softening relation is used in case of cracked element. This process is continued until complete piecewise linear load-displacement response is established.

4. Results

To observe the influence of shear transfer on tensile crack growth phenomena in curved Mode-I fracture, the pullout test problem (Plane stress case) tested by Lun [3] was selected for the investigation (see Fig. 2). Figure 2 also provides full details of the geometric characteristics of the specimen. The finite element mesh represents only half the specimen, utilizing the symmetry of the structure and the stress state. Four-node cracked square elements are used for the fracture zone as shown in Fig. 3. Outside this fracture zone, four-node ordinary plane stress elements are used. The load-displacement response established from the present analysis without considering the shear transfer is shown in Fig. 2. The experimental results from test carried out by Lun [3] are also depicted in Fig. 2. Crack pattern obtained from the present analysis is shown in Fig. 3. Many cracks form and open, eventually close and open again. At this moment, however, it cannot be assumed that the tensile fracture phenomenon under mixed-mode loading conditions is exactly reproduced from this analysis; the localization of microcracking that occurs in mode-I loading condition [2] is not obtained.

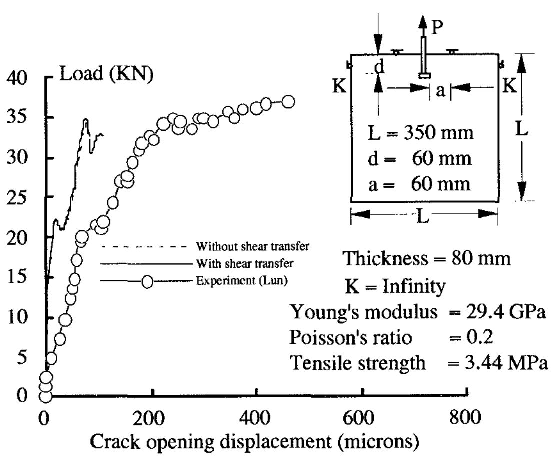

Fig. 2 Load-displacement response

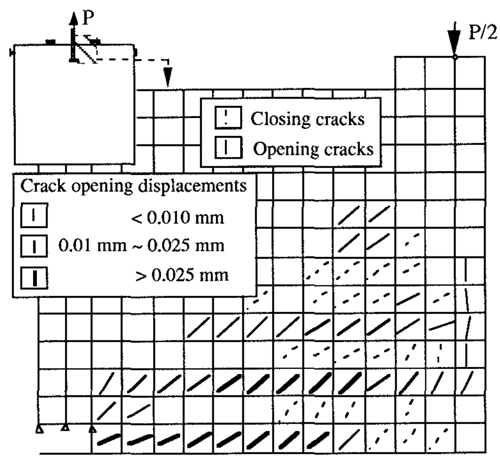

Fig. 3 Crack pattern at final loading step

To examine the influence of shear transfer on cracking localization the same restrained pullout test problem is analyzed by incorporating the model for shear transfer (see Fig. 1) in the program, and the response established from the analysis is depicted in Fig. 2. The cracking pattern in this case is almost similar to that without considering shear transfer across the crack surfaces. It is concluded, therefore, that the response of the specimen subjected to mixed-mode loading can be predicted reasonably well by neglecting the effect of aggregate interlock, while shear transfer across crack surfaces does not appear to affect cracking localization in this analysis. These results are supported by recent experimental observations made by Slowik et al. [4] showing that the cracks in such specimens propagate predominantly in a crack opening mode rather than in a crack sliding mode.

5. Conclusions

From the analysis of restrained pullout test concrete specimen subjected to mixed-mode loading conditions, it is shown that the influence of shear transfer during crack growth in curved mode-I fracture is not significant. However, in order to arrive at a general conclusion regarding shear transfer across crack surfaces, further research is required.

6. References

[1]. Hassanzadeh, M. (1990), "Determination of fracture zone properties in mixed Mode I and II", *Engrg. Frac. Mech.,* **35**(415), 845-853.

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