CS 62 BEM ANALYSIS OF CRACK PROPAGATION IN PULL-OUT TESTS

A. H. CHAHROUR Graduate School of Kumamoto University
M. OHTSU Dept. Civil & Environmental Eng., Kumamoto Univ.

1. INTRODUCTION

Stress state in a pull-out of an anchor bolt embedded in concrete block is so complex [1] that the round-robin analyses and tests of anchor bolts by RILEM Technical Committee for Fracture Mechanics provide quite a scatter in the results [2]. The authors have applied a two-domain boundary element method (BEM) successfully to mixed-mode fracture of center-notched concrete beams [3]. In the present paper, crack propagation in pull-out tests of anchor bolt is simulated by a two-domain BEM approach, based on the criterion of linear elastic fracture mechanics (LEFM).

2. ANALYTICAL PROCEDURE

In the analysis, the initial model is divided into two domains, of which the interface boundary is joining the anchor head with the reaction support. A constant element is adopted for traction and a linear element is assigned for the displacement on the boundary elements. The numerical integration over each element is performed by using 6-point Gaussian quadrature.

The stress intensity factors at the crack tip are determined by Smith's one point formulae [4]. K_I and K_{II} are determined from displacement u_i in the X-direction and displacement v_i in the Y-direction at the crack tip element. The direction of crack propagation is determined, based on the criterion of the maximum circumferential stress of LEFM,

$$K_I^* \sin\phi + K_{II}^*(3\cos\phi - 1) = 0, \qquad (1)$$

$$\cos(\phi/2)[K_I^* \cos^2(\phi/2) - 3K_{II}^* \sin(\phi/2)] = 1, \qquad (2)$$

where $K_I^* = K_I/K_{IC}$ and $K_{II}^* = K_{II}/K_{IC}$. ϕ is taken to be the angle corresponding to the bigger maximum tensile stress. Crack propagation is modeled by creating new boundaries along the direction determined from eq. 1 where the boundary is initially stitched on the common interface. Automatic remeshing of the boundary is accommodated with the increment of crack growth.

3. ANALYTICAL MODELS

An analytical model of dimension 450 mm wide and 900 mm high represents a half portion of a two-dimensional concrete plate. The depth of an anchor head is 165 mm. In one case the load-supporting point is located at 75 mm apart from the anchor head and 300 mm apart in the other. The fracture toughness of concrete is 0.548 MPa.m$^{1/2}$.

A crack is assumed to start propagating from the upper edge corner of the bolt to the reaction support node. When the criterion of eq. 2 holds, a crack propagates. The node at the tip is separated into two nodes, creating two new crack tip elements of which directions are determined from eq. 1. This results in the increase of the total number of nodes. A new stitching boundary is made as the straight line joining the new crack tip elements to the reaction support on the top of the concrete block. An element length is adopted as 1. 5 cm on the external surface of the concrete block, and the crack increment is taken to be 1 cm.

4. ANALYTICAL RESULTS AND DISCUSSION

Figs. 1 and 2 show analyzed crack trajectories of the two analytical models. It is observed that crack trajectories dominantly depend on the ratio 'a/d' of the distance 'a' from the anchor bolt to the support and the depth 'd' of anchor bolt. Cracks propagate directing to the reaction support in the case a/d = 0.5. This is the case well known in the pull-out test. In contrast, when the ratio a/d is equal to 2, cracks seem to propagate almost horizontally. Particularly, the crack trajectory is so tortuous that an inflection point is found.

Load versus anchor-head displacement curves are shown in Figs. 3 and 4. Essential feature of the curves is observed in a long descending branch after the maximum load. In the case of Fig. 1 : the ratio a/d = 0.5, the load- displacement curve analyzed decreases gradually. For the case of Fig. 2 : the ratio a/d = 2, the failure curve is not smooth with an abrupt increase or a decrease which is obviously associated with the inflection point of the crack trajectory. It suggests the change of fracture mechanisms in the process of the pull-out failure.

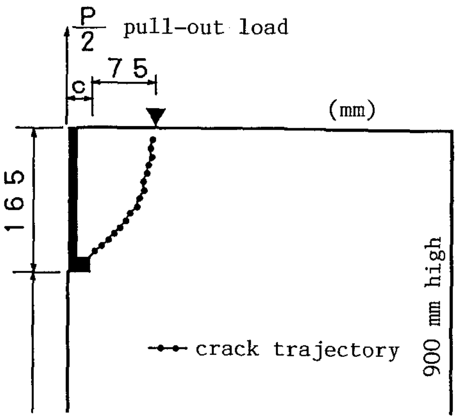

Fig. 1 Crack trajectory in the case a/d=0.5.

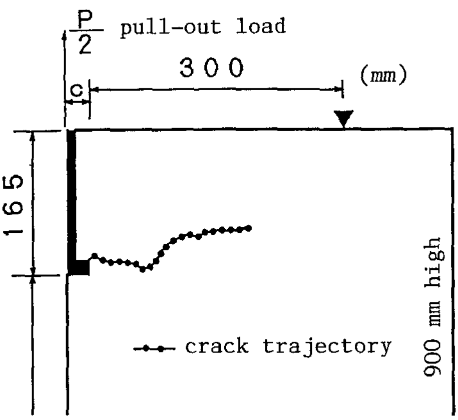

Fig. 2 Crack trajectory in the case a/d=2.0.

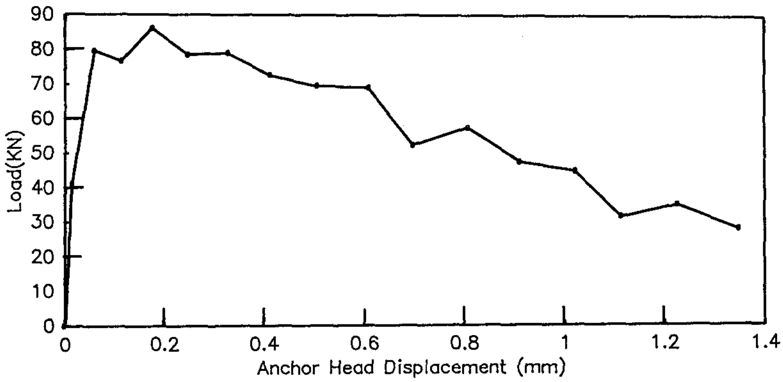

Fig. 3 Load–displacement curve (a/d = 0.5).

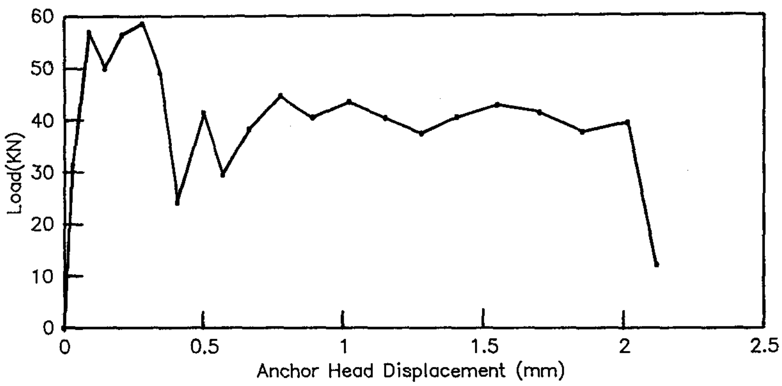

Fig. 4 Load–displacement curve (a/d = 2.0).

REFERENCES

[1] R. Ballarini and S. P. Shah, Analysis of Concrete Structures by Fracture Mechanics, edited by Elfgren & Shah, Chapman and Hall, RILEM, 1991, pp. 245–280.
[2] L. Elfgren, Fracture Mechanics of Concrete Structures, edited by Z. Bazant, Elsevier Applied Science, 1992, pp. 865–869.
[3] A. H. Chahrour and M. Ohtsu, 2nd International Conference on Fracture and Damage of Concrete and Rock, Vienna, 1992.
[4] R. N. L. Smith and J. C. Mason, Boundary element methods in engineering, edited by Brebbia, Springer, Berlin, 1982, pp. 472–484.