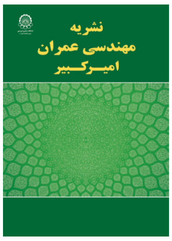


Amirkabir Journal of Civil Engineering

Amirkabir J. Civil Eng., 50(1) (2018) 31-34
DOI: 10.22060/ceej.2017.11366.5012

Effect of Crack Cohesive Stresses on the Load-Deformation Response of Reinforced Concrete Beams

V. Broujerdian*, A. Sherafati, H. Karimpour

Department of Civil Engineering, Iran University of Science and Technology, Tehran, Iran

ABSTRACT: It is well known that the behavior of concrete is extensively affected by the initiation of cracks and their propagation. Among these cracks, diagonal or shear cracks have more complicated and less known behavior. In spite of extensive research in this field, current codes of practice do not provide a uniform margin of safety against shear failure of reinforced concrete yet. To simulate the non-elastic behavior of concrete in the fracture process zone, the distribution of cohesive forces through the crack sides have been used by researchers. The aim of this study is to evaluate the effect of the crack's tip cohesive forces on the load-deflection response of reinforced concrete beams using fracture mechanic. In the numerical analysis used in this study, the non-linear behavior of concrete in the compression field is simulated by damage-plasticity model. To simulate the non-linear behavior of concrete in the tension area and simulating the onset and evolution of cracking, non-linear fracture mechanics based on cohesive crack model is used. Using finite element software of ABAQUS, a step by step approach is used. In the presented approach, the probability of possibility of crack evolution in beams is considered. Comparing the calculated load-deflection curves for several reinforced concrete beams with the experimental ones showed a good consistency.

Review History:

Received: 9 February 2016
Revised: 8 December 2016
Accepted: 2 January 2017
Available Online: 14 January 2017

Keywords:

Reinforced Concrete Beams
Finite Element Method
Crack
Cohesive Stresses
Fracture Mechanics

1- Introduction

Since the behavior of reinforced concrete structures is affected by crack initiation and propagation, understanding the crack tip fracture process zone not only helps to understand the failure mechanism, but also it is important to find and predict real crack paths in real structures [1].

The first serious study on the concrete cracks and failures caused by them was done in 1928 by Richardt, Brandzaeg and Brown. Kaplan [2] tried to use linear fracture mechanics principles for concrete. A number of researchers such as Shah and Mc Garry [3] showed that linear fracture mechanics leads to incorrect results for concrete structures. By understanding the nonlinear behavior of concrete, different nonlinear models were introduced over time. Researchers have shown that to simulate inelastic response of material at the fracture process zone in the crack tip, a cohesive stress distribution closing the crack surfaces can be used [4], [5]. Cohesive crack model initially was introduced by Barenblatt [4, 5] and Dugdale [6]. Although BarenBlatt applied cohesive crack model to brittle fracture analysis, Dugdale introduced it to model the behavior of ductile material. Under the discrete crack method [7], Hillerborg et al. [8] were the first researchers who applied the cohesive crack model for simulation of concrete structure failure. Initially, they found that even if the use of large finite element analysis, the analysis of onset and evolution of cracks as well as failure analysis can be done with the cohesive crack model. Hereby, this method put an end to mesh sensitivity. After, cohesive crack method was modified and used over time by researchers.

In this study, a step by step approach provided, with which the behavior of the load-deformation of empirical reinforced concrete beams using damage-plasticity model and non-linear fracture mechanic based on cohesive crack model are investigated. Several softening functions to investigate the effect of different cohesive forces at the crack tip are used in the method provided with discrete crack model. Finally, the load-deflection diagrams of reinforced concrete beams obtained from numerical analysis are compared with experimental results.

2- Numerical Modeling

For numerical simulation of reinforced concrete beams, ABAQUS finite element software is used. In the proposed stepwise approach, the simultaneous creation and growth of several cohesive cracks are considered. One of the basic assumptions in this study is neglecting the slip between concrete and rebar. The method used in this research is based on the concept of discrete crack model. The steps of the proposed numerical algorithm are in Figure 1.

Corresponding author, E-mail: broujerdian@iust.ac.ir

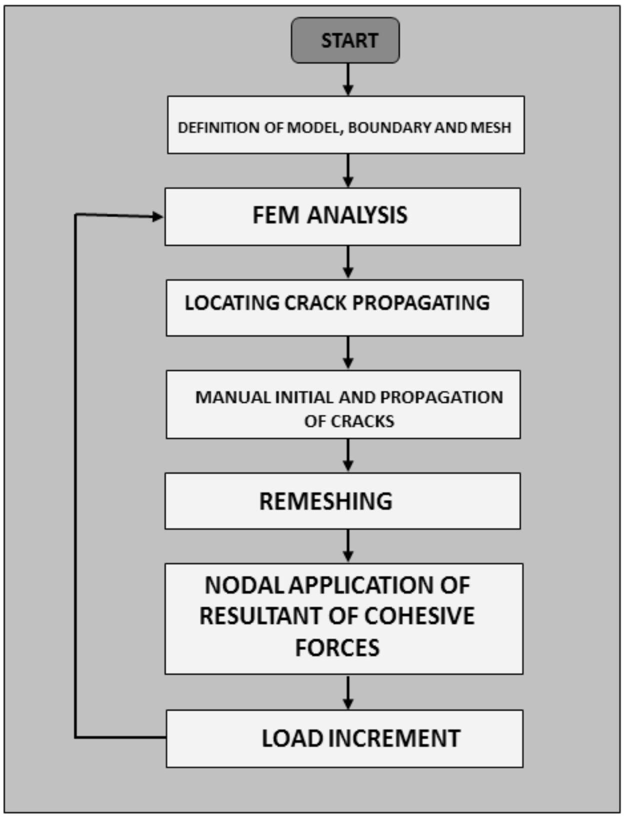


Figure 1. Flowchart of the proposed analysis algorithm

It should be noted that load-controlled loading was applied to the middle span of beams. The criterion of crack onset and evolution in concrete was reaching the tensile stresses to the tensile strength of concrete. Also, the direction of crack growth has considered perpendicular to the normal stress.

Generally, it is assumed that steel reinforcements which are embedded in concrete bear only axial force and their behavior merely is describe by an axially stress-strain relationship. In many studies to model the behavior of bars embedded in the concrete, conventional bilinear elastic full plastic model is used. Of course the steel tensile behavior of a single rebar is different from the behavior of a steel rebar embedded in concrete. After the first failure occurred in rebar, the stress-strain curve of reinforcement embedded in concrete shows a gradual decrease in stiffness which continuous up to complete failure of rebar.

So in order to simulate the behavior of compressive and tensile behavior of steel in reinforced concrete beams, plastic plateau is considered by taking a gentle slope. Also a bilinear relationship with strain hardening for steel reinforcement is taken into account. The behavior of reinforcing bars which is embedded in concrete obeys from a bilinear stress-strain curve.

In this study, to simulate the non-linear behavior of concrete in the compression zone, damage-plasticity theory and the stress-strain relationship provided by Hsu [9] is used. On the other hand, to simulate the non-linear behavior of concrete in the tensile area and crack propagation, non-linear fracture mechanics based on cohesive model is used.

To simulate the non-elastic response of the material considering the fracture process zone of the crack is essential and would be applied with a series of forces to the two sides of the crack.

The distribution of stresses applied to the two sides of crack, conforms concrete softening curve that is one of the most essential basics of cohesive crack model and is defined by the stress-mouth opening displacement curve of the crack, unique for each type of concrete. In recent years, researchers have proposed a variety type of softening curve. Distribution of cohesive stresses in terms of distance from the crack tip, as much as three times the size of the largest aggregate concrete, in the two sides of crack are linear, bilinear and non-linear . In this study, for the linear softening curve of Hillrborg model [8], for the bilinear softening curve Shilang Xu model [10] and for non-linear softening curve Reinhardt and colleague's model [11] is used.

To evaluate the proposed method and compare with the results of some tests which has done on reinforced concrete beams, a series of tests conducted by Bresler and Scordelis [12] which has high quality and sufficient documentation, were selected as benchmark tests. All beams were subjected to monotonic center-point loading, with a force-controlled loading procedure employed.

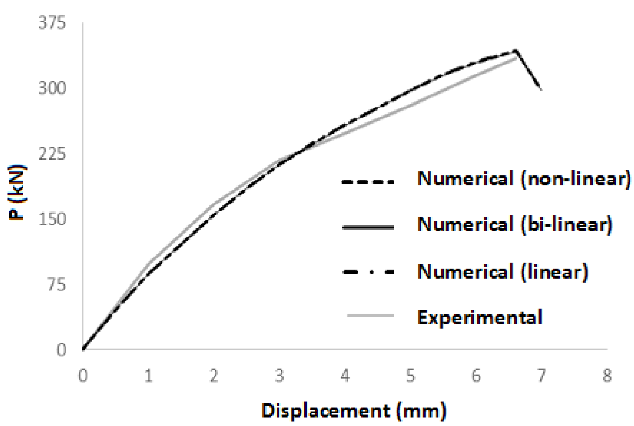
In this study, six beams of Bresler–Scordelis beams are modeled with three different distributions of cohesive stresses at the crack tip including concrete beams without shear reinforcement named OA1, OA2 and OA3 and reinforced concrete beams with shear reinforcement, named A1, A2 and A3 respectively.

to apply non-linearity behavior of concrete at the crack tip, bilinear and nonlinear distribution of the cohesive stresses at the 2 sides of crack is used. The load–deformation responses based on numerical analysis are followed below using three types of softening curves, linear, bilinear and non-linear.

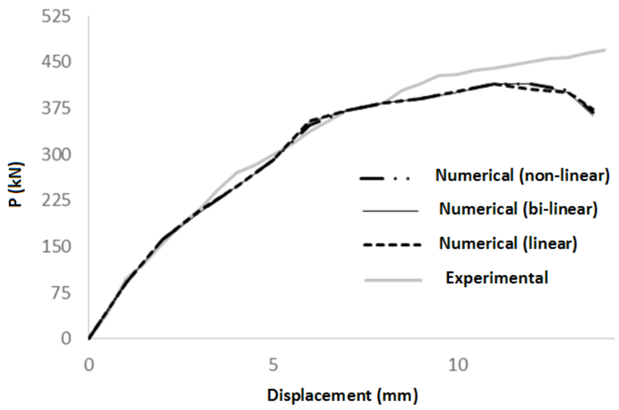
With comparison between results of the numerical and experimental results can be seen that the proposed method used in this study, can predict the load-deformation responses in reinforced concrete beams with and without stirrups.

3- Results and Discussion

The results of numerical modeling for the load-deformation curves of Bresler-Scordelis beams were compared to the experimental ones. For each beam, three numerical curve were obtained corresponding to three softening law of linear, bi-linear, and non-linear ones. The results for beam OA1 (without stirrups) and beam (A1) with stirrups are presented in Figure 2.



(a)



(b)

Figure 2. Comparison of experimental and predicted load-deformation curves: a) beam OA1, b) beam A1

4- Conclusions

This study examines diagonal cracking of reinforced concrete beams subjected to three-point bending test. The classical finite element method based on discrete crack approach is used in this study. The behavior of cracks is simulated based on cohesive crack model. Three different softening laws of linear, bi-linear, and non-linear curves were considered to simulate the cohesive zone of cracks. A stepwise approach is proposed to analyze crack propagation.

The results showed that there is a little difference between load–deformation curves derived based on different softening laws. In other words, the type of traction-separation function used in numerical study is not very important in the results.

The comparison of the predictions of the proposed method for reinforced concrete beams with test results indicates good accuracy in the evaluation of the load-deformation curves of the beams.

References

[1] Hu, S.W., Mi, Z.X. and Lu, J., 2012. A study on the crack propagation process in concrete structures using energy method. In Applied Mechanics and Materials (Vol. 204, pp. 3151-3155). Trans Tech Publications.

[2] Kaplan, M.F., 1961, November. Crack propagation and the fracture of concrete. In Journal Proceedings (Vol. 58, No. 11, pp. 591-610).

[3] Shah, S.P. and McGarry, F.J., 1971. Griffith fracture criterion and concrete. Journal of the Engineering Mechanics Division, 97(6), pp.1663-1676.

[4] Barenblatt, G.I., 1959. The formation of equilibrium cracks during brittle fracture. General ideas and hypotheses. Axially-symmetric cracks. Journal of Applied Mathematics and Mechanics, 23(3), pp.622-636.

[5] Barenblatt, G.I., 1962. The mathematical theory of equilibrium cracks in brittle fracture. Advances in applied mechanics, 7, pp.55-129.

[6] Dugdale, D.S., 1960. Yielding of steel sheets containing slits. Journal of the Mechanics and Physics of Solids, 8(2), pp.100-104.

[7] Ngo, D. and Scordelis, A.C., 1967, March. Finite element analysis of reinforced concrete beams. In Journal Proceedings (Vol. 64, No. 3, pp. 152-163).

[8] Hillerborg, A., Modéer, M. and Petersson, P.E., 1976. Analysis of crack formation and crack growth in concrete by means of fracture mechanics and finite elements. Cement and concrete research, 6(6), pp.773-781.

[9] Hsu, T.T. and Zhang, L.X., 1996. Tension stiffening in reinforced concrete membrane elements. ACI Structural Journal, 93(1), pp.108-115.

[10] Xu, S., 1999. Determination of parameters in the bilinear, Reinhardt's non-linear and exponentially non-linear softening curves and their physical meanings. Werkstoffe und Werkstoffprüfung im Bauwesen, Hamburg. Libri Bod, 15, pp.410-424.

[11] Reinhardt, H.W., Cornelissen, H.A. and Hordijk, D.A., 1986. Tensile tests and failure analysis of concrete. Journal of Structural Engineering, 112(11), pp.2462-2477.

[12] Bresler, B. and Scordelis, A.C., 1963, January. Shear strength of reinforced concrete beams. In Journal Proceedings (Vol. 60, No. 1, pp. 51-74).

Please cite this article using:

V. Broujerdian, A. Sherafati, H. Karimpour, Effect of Crack Cohesive Stresses on the Load-Deformation Response of Reinforced Concrete Beams. *Amirkabir J. Civil Eng.*, 50(1) (2018) 89-96.

DOI: 10.22060/ceej.2017.11366.5012