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Cement and Concrete Research 35 (2005) 384–392

CEMENT AND CONCRETE RESEARCH

Experimental and theoretical investigation on the postcracking inelastic behavior of synthetic fiber reinforced concrete beams

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Received 24 February 2004; accepted 12 July 2004

Abstract

A realistic method of analysis for the postcracking behavior of newly developed structural synthetic fiber reinforced concrete beams is proposed. In order to predict the postcracking behavior, pullout behavior of single fiber is identified by tests and employed in the model in addition to the realistic stress–strain behavior of concrete in compression and tension. A probabilistic approach is used to calculate the effective number of fibers across the crack faces and to calculate the probability of nonpullout failure of fibers. The proposed theory is compared with test data and shows good agreement. The proposed theory can be efficiently used to predict the load–deflection behavior, moment–curvature relation, load–crack mouth opening displacement (CMOD) relation of synthetic fiber reinforced concrete beams.

Keywords: Fiber reinforcement; Microcracking; Pullout strength; Structural synthetic fiber; Tensile properties

1. Introduction

Fibers have been used in many applications, including tunnel linings, impact-resistant structures, and repair/rehabilitation of damaged structures. However, the most important application of fibers would be to prevent or control the tensile cracking occurring in concrete structures [1–13]. It is, therefore, necessary to realistically model the postcracking behavior of fiber-reinforced concrete (FRC) members.

Recently, structurally efficient synthetic fibers have been developed by authors and coworkers [10]. Here, structural synthetic fibers mean that they exhibit structurally effective properties, such as increase of toughness and/or loading carrying capacity after cracking. These synthetic fibers have advantages compared to steel or other fibers in that they are corrosion-resistant and exhibit high energy-absorption capacity.

The purpose of the present study is to explore experimentally and theoretically the cracking resistance and postcracking behavior of newly developed structural synthetic fiber reinforced concrete beams. To this end, the pullout tests of fibers were conducted which simulate pullout behavior of fibers at crack surfaces. The arbitrarily oriented fibers at the crack surface have been considered by introducing a probabilistic concept. The load–deflection and moment–curvature curves were generated from the theory derived in this study and compared with test data.

2. Models for postcracking behavior

2.1. Concept of analysis

A fiber-reinforced concrete beam as shown in Fig. 1 has been considered for the analysis of postcracking behavior. Fig. 1 shows the failure mode of a beam with the crack mouth opening displacement (CMOD). Fig. 2 depicts the strain and stress distributions along the depth of normal reinforced concrete (RC) beam. These stress distributions can be redrawn as shown in Fig. 3 for fiber-reinforced concrete (FRC) beams. In Fig. 3, the pullout forces of fibers in tensile region depend on the crack opening displacements along the depth from neutral axis.

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doi:10.1016/j.cemconres.2004.07.019

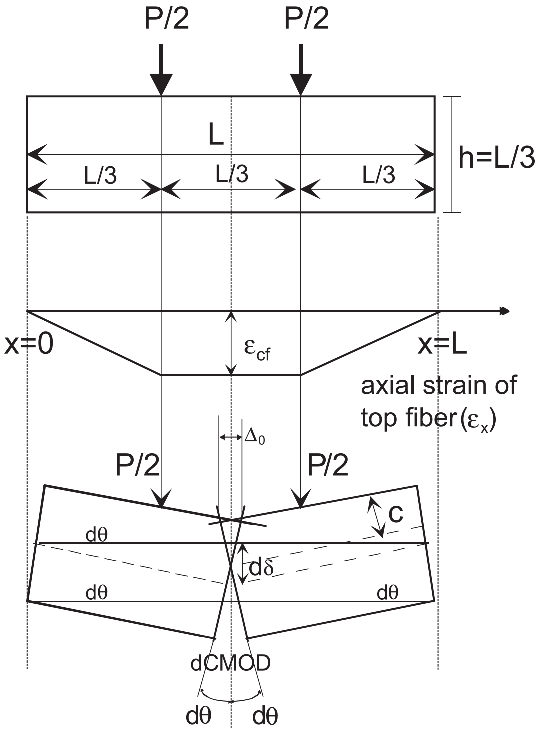

Fig. 1. Failure mode of FRC beam under load.

In order to obtain the postcracking behavior of FRC beams, the stress–strain relations of concrete in compression and tension, and the stress–crack width relation after cracking must be properly defined. This will be clarified in the next section.

The Hognestad's stress–strain relation (Eqs. (1) and (2)) of concrete in compression is employed in this study, which is one of the most generally used equation to model the constitutive behavior of concrete. Fig. 4 exhibits the typical stress–strain relation of concrete in compression [14].

$$f_c = f_c' \left[2\frac{\varepsilon_c}{\varepsilon_0} - \left(\frac{\varepsilon_c}{\varepsilon_0}\right)^2 \right] \quad \text{for } 0 \le \varepsilon_c \le \varepsilon_0 \tag{1}$$

$$f_c = f_c' \left[1 - \frac{0.15}{0.004 - \varepsilon_0}(\varepsilon_c - \varepsilon_0) \right] \quad \text{for } \varepsilon_0 \le \varepsilon_c \le 0.003 \tag{2}$$

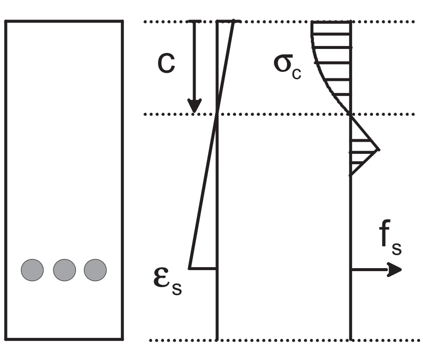

Fig. 2. Stress and strain relation of RC beam.

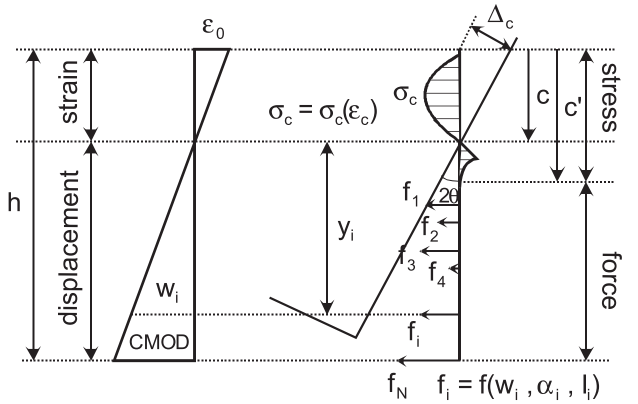

Fig. 3. Schematic view of forces and stresses acting on cracked section of FRC beam.

in which f_c' =compressive strength of concrete and ε_0=the strain at peak stress (see Fig. 4). The force C in compression zone can be written as follows.

$$C = \alpha f_c' bc \tag{3}$$

where α=the factor for average stress, b=width of beam, and c=the depth of neutral axis from the top face of a beam. The factor α can be considered as a conversion factor from actual stress–strain curves to a rectangular stress block. This can be obtained by equating the area under actual stress–strain curve to the area under rectangular stress block as follows [14].

$$\int_0^{\varepsilon_{cf}} f_c d\varepsilon_c = \alpha f_c' \varepsilon_{cf}; \qquad \text{Then } \alpha = \frac{\int_0^{\varepsilon_{cf}} f_c d\varepsilon_c}{f_c' \varepsilon_{cf}} \tag{4}$$

The location of the compression force, γc, from the top fiber can be obtained as

$$\gamma = 1 - \frac{\int_0^{\varepsilon_{cf}} \varepsilon_c f_c d\varepsilon_c}{\varepsilon_{cf} \int_0^{\varepsilon_{cf}} f_c d\varepsilon_c} \tag{5}$$

where γ=centroid factor for compression force.

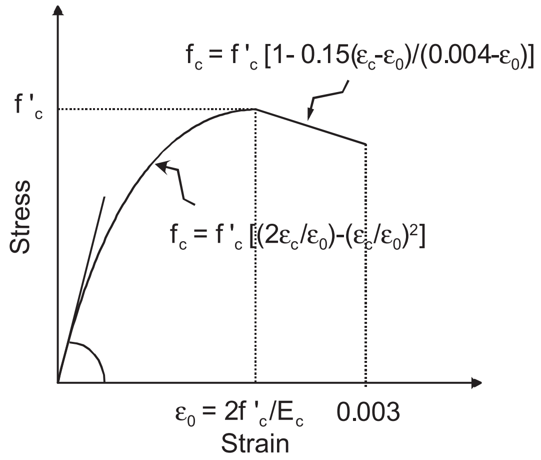

Fig. 4. Hongnestad's stress–strain curve for concrete in compression.