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Research on non-linear structural behaviors of prestressed concrete beams made of high strength and steel fiber reinforced concretes

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Abstract

The flexural behaviors of fully and partially prestressed concrete beams made of high strength and steel fiber reinforced concretes are studied by experiment and non-linear finite element method. Three levels of partial prestress ratio (PPR) are considered, and for each PPR, a pair of two-span continuous beams with box-section are designed. In each pair of the test beams, one is constructed by the high strength concrete completely, and for the other one the steel fiber reinforced concrete is used in the negative moment zone (the mid-support zone). Such structural behaviors as the deflection of beam, the formation and the development of crack, the strain of concrete and reinforcement bar, and the moment redistribution are investigated. A non-linear finite element analysis program is developed and applied. The constitutive behavior of concrete is modeled by the microplane theory. A four-nodal six-DOF (degree of freedom) degenerated shell element is adopted to simulate the structural behaviors of the box-section beam. To obtain the ultimate limit state of the structure, the arc-length method is introduced in the non-linear solution. The analytical results agree well with test ones. The influences of the steel fiber reinforced concrete used in the negative moment zone on the structural behaviors are mainly concerned.

Keywords: High strength concrete; Steel-fiber reinforced concrete; Prestressed concrete; Continuous beam; Non-linear finite element analysis

1. Introduction

With technological development, application of high strength concrete into civil engineering has attracted more and more attention during the past twenty years. Compared with normal concrete, high strength concrete possesses such advantages as higher compressive strength and modulus of elasticity, less creep and shrinkage deformation, and so on. Due to these merits, high strength concrete is preferred in long-span and high-rise structures [1].

To improve the ductility of concrete, addition of steel fiber into concrete matrix has been demonstrated to be an effective way [2]. Generally, through arresting and intersecting crack in concrete matrix, the bridging effect of the random distributed steel fiber can effectively absorb fracture energy and slow down propagation of crack. In the previous studies, the mechanical properties and application of steel fiber reinforced concrete have been investigated intensively [3–6].

Fully and partially prestressed concrete structures have been widely used in railway and highway bridge engineering. Through adopting high strength concrete, prestressed concrete bridge can increase span, decrease self-weight, reduce prestress loss, and so on [7]. Although high strength concrete and steel fiber reinforced concrete are extensively applied to reinforced concrete structures, these applications to prestressed concrete structures seem to be quite few. Padmarajaiah and Ramaswamy studied the flexural behaviors of 15 pieces of simply supported fully and partially prestressed high strength concrete beams containing steel fibers by experiment and non-linear finite element analysis

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[8]. In their studies, the major involved parameters include the level of prestressing force, fiber volume fraction, and fiber location (full depth, partial depth over full length and half depth over the shear span only). Padmarajaiah and Ramaswamy studied the flexural strength of prestressed steel fiber reinforced high strength concrete beam [9]. However, to the best knowledge of authors, work about applying the high strength concrete and fiber reinforced concrete into prestressed concrete continuous beam is rare. In the present paper, the structural behaviors of two-span prestressed concrete continuous beams with varying height of box-section are investigated. The concrete of the test beams have the cubic compressive strength of 80 MPa. The major parameters involved in the test beams include PPR and fiber location. Three levels of PPR are considered. To investigate the influence of the steel fiber on the structural ductility, two beams are designed for each PPR, in which one beam is cast with high strength concrete in the full length, and the fiber reinforced high strength concrete is used in the mid-support zone (the negative moment zone) for the other one.

2. Experiment program

The program consists of six pieces of two-span continuous beams with box-section as shown in Fig. 1. Considering that the prestressed concrete continuous beams adopted in bridge engineering generally have the varied section, therefore, the height of the test beams is 50 cm and 30 cm for the mid-support and the mid-span section, respectively, and a linear variation of the section height is adopted between the mid-support and the mid-span section.

Table 1
The material properties of concrete

	$f_{cu,k}$ (MPa)	$f_{split,k}$ [a] (MPa)	E_c (MPa)
High strength concrete	84.55	6.55	38405
Steel fiber reinforced high strength concrete	81.90	7.56	38193

[a] $f_{split,k}$ represent the split strength of concrete.

The design mix of concrete is determined by trial and error. To improve the workability of concrete, a high-efficiency water-reducing admixture (superplasticizer) is used, and the final mix of concrete is 1:0.35:0.98:2.52:0.012 (cement:water:sand:coarse aggregate:superplasticizer). The steel fiber used in the present study has a shape of hooked-end. The basic material properties of concrete are given in Table 1. The basic material properties of the prestressing tendon and reinforcement bar are listed in Table 2.

The definition of PPR is given as

$$\mathrm{PPR} = \frac{f_{py}A_p}{f_{py}A_p + f_y A_s} \tag{1}$$

where f_{py} and f_y are the tensile strength of the prestressing tendon and the reinforcement bar (MPa). A_p and A_y are the area of the prestressing tendon and the reinforcing bar, respectively (mm^2). For the fully prestressed concrete, the value of PPR equals 1.0, and for the partially prestressed concrete, this value will be less than 1.0. Three pairs of test beams with different values of PPR are designed, in which one pair of test beams is fully prestressed, and the other two are partially prestressed. To simulate the practical behaviors of the continuous beam in bridge engineering,

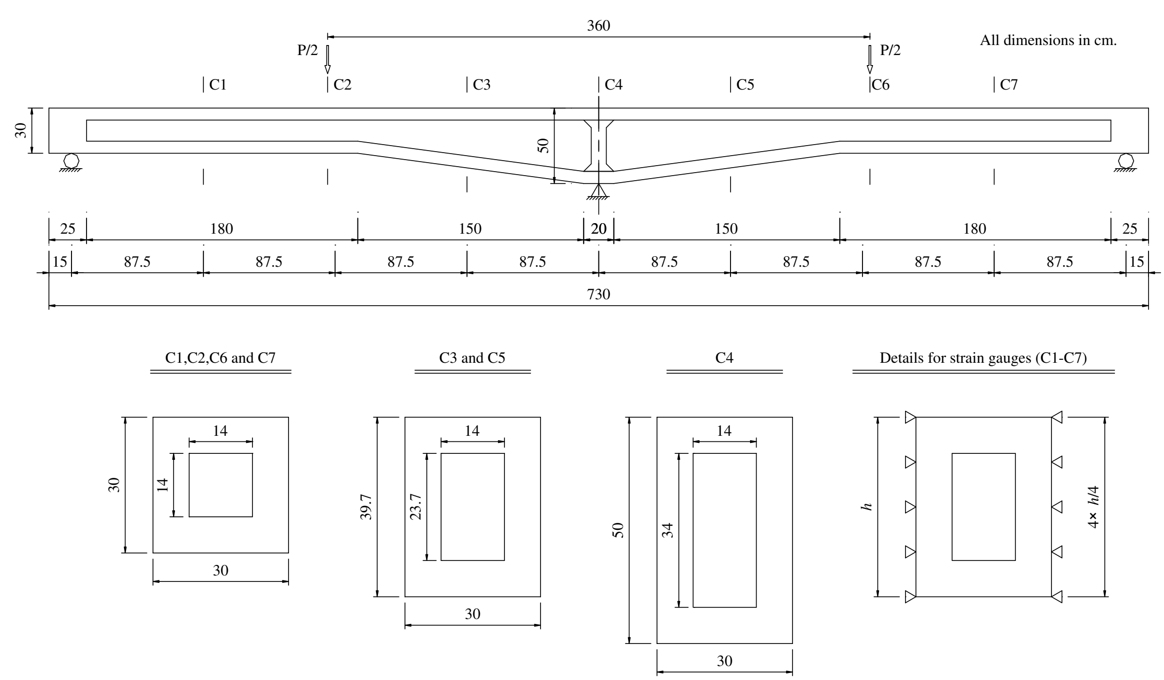

Fig. 1. Geometrical configuration of the test beam.