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ScienceDirect
Construction and Building Materials 21 (2007) 118–125
Construction and Building MATERIALS
www.elsevier.com/locate/conbuildmat

Using fibres to enhance the properties of concrete columns

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Received 20 January 2005; received in revised form 16 June 2005; accepted 30 June 2005
Available online 19 August 2005

Abstract

This paper explores the effects of adding synthetic reinforcing fibres to high-strength reinforced concrete columns and in particular only to the cover of the columns. An experimental program was conducted where seven circular reinforced concrete columns were tested with varying fibre content – one contained no fibres, two contained fibres throughout the cross-section and four contained fibres only in the outer concrete. The other column properties were kept the same for all the seven columns. All seven columns were tested by the application of a concentric, axial compression force. It was found that although only minor improvements were noticeable for a fibre content of 0.1%, the addition of 0.3% polypropylene fibres increased the load at which cover spalling took place. It was also found that the columns containing both fibrous high strength concrete (FHSC) in the outer concrete and HSC in the core exhibited higher levels of ductility than the columns containing FHSC throughout the entire cross-section.

Keywords: Fibre; RC columns; Ductility

1. Introduction

Over the past 20 years, research of and improvements to concrete mix design have resulted in an increase of three to fourfold in available concrete strengths. With respect to columns, a larger compressive strength means a smaller cross-sectional area required, resulting in better utilisation of available space and materials. These higher-strength columns, however, have been shown to contain weaknesses. As the compressive strength increases so too does the brittleness and while increasing the amount of lateral reinforcement reduces this brittleness, it also increases the column's susceptibility to early cover spalling [1]. In order for high-strength concrete (HSC) columns to be effective and superior to normal strength concrete columns, these weaknesses need to be overcome.

Early spalling of the cover concrete arises due to the confinement effect provided by the reinforcement. When a column is axially compressed, material is pushed outwards resulting in increased cross-section dimensions. The core concrete is confined by reinforcement, but the unconfined cover concrete outside the reinforcement continues to be pushed outwards, placing it in tension, and forcing it to separate from the core concrete. Once this cover has spalled the column has less cross-sectional area and hence has a reduced load-carrying capacity. Research has shown that the addition of fibres to the concrete helps to arrest the onset of early cover spalling [1–3]. This research has also shown that ductility of the HSC columns can be improved through the addition of fibres.

One of the problems associated with using fibres is that the fibres may not be uniformly distributed throughout the member. In particular, fibres may clump together in the core of the column, thus the density and compressive strength at that section may be reduced. These problems may be overcome by locating fibres only in the cover concrete, to prevent early cover spalling whilst having the core of the column containing only

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doi:10.1016/j.conbuildmat.2005.06.028

non-fibrous concrete to maintain sufficient compressive strength. This process, although laborious, would result in more efficient use of materials.

This study of fibre reinforced concrete columns investigates a new method of column construction which results in fibrous high strength concrete (FHSC) being located only in the cover concrete while plain HSC is located in the remaining core concrete. It is proposed that this new type of column will perform in a superior manner to columns which contain FHSC throughout the entire cross-section as problems such as the movement of fibres towards the centre of the column, away from the cover, during vibration will be overcome. This new type of column also provides a more efficient use of materials as fibres are located in the cover to prevent early cover spalling, while the remainder of the column contains only plain HSC so the integrity and density of the core remain unaffected.

The aim of this study is to find a more efficient design for fibre reinforced high strength concrete columns.

2. Literature review

2.1. High strength concrete columns

Foster and Attard [4] tested 68 concrete columns by varying load eccentricities, concrete strengths and the amount of reinforcement. It was found that increasing the amount of longitudinal reinforcement and/or decreasing tie spacings will reduce the ultimate capacity for combined bending and compression for all concrete strengths, as the reinforcement formed a natural plane of separation between the core and cover concrete.

Pessiki and Pieroni [5] conducted studies on eight spirally reinforced concrete columns. The study found that ductility decreased with increasing concrete strength and the columns with higher amounts of longitudinal reinforcement maintained peak load for longer but displayed less ductility than the columns with less longitudinal reinforcement.

Razvi and Saatcioglu [6] studied the effect of varying reinforcement on 20 high-strength concrete columns. It was found that high-strength concrete columns displayed extremely brittle behaviour unless confined by suitable transverse reinforcement. Also, the presence of longitudinal reinforcement improved the performance of the columns due to a better confining effect.

2.2. Early cover spalling in high strength concrete columns

Foster et al. [7] used finite element modelling to investigate the effect of cover spalling for both high-strength (>60 MPa) and normal-strength concrete columns subject to concentric compression loads. It was found through the model, and verified through experimental testing, that as the amount of tie reinforcement increased, the ultimate column strength (or the load at which early cover spalling took place) decreased while the ductility of the column increased.

Liu et al. [8] conducted tests on 12 high strength concrete columns to investigate the issue of early cover spalling. It was found that the column strength was the greater of the column spalling load and the capacity of the confined core and that the study provided further evidence that the design load can be taken as 0.85 times the capacity of the entire concrete section.

2.3. Fibres within concrete columns

Adepegba and Regan [9] carried out tests on steel fibre reinforced concrete columns. It was found that the addition of steel fibres at any of the tested fibre contents did not increase the ultimate load of the column. It was noted, however, that the experiments did not investigate the post-failure behaviour improvements gained by the addition of steel fibres.

Ganesan and Murthy [10] studied the effect of varying the amount of lateral reinforcement on steel fibre-reinforced and non-fibre-reinforced concrete columns. It was found that as the amount of lateral reinforcement increased, larger strength increases were obtained from the fibrous columns compared with the non-fibrous columns and the addition of steel fibres resulted in better strength and ductility.

Campione [11] presented a mathematical model which determined the stress–strain relationship for fibre reinforced concrete columns. The analytical expressions allowed the determination of the maximum strength and strain capacity of circular or square, high-strength or normal-strength, fibrous or non-fibrous concrete columns. Explanations were also given regarding the region of the column cross-section which could be considered effectively confined by the reinforcement. It was also noted that the model was verified through experimental testing.

Foster [2] presented a design model for calculating the ductility of fibre reinforced high strength concrete columns. It was demonstrated through design examples that the spacing of reinforcement ties could be increased with the inclusion of steel fibres in the concrete for a given level of ductility.

Sarker [3] studied the effect of adding synthetic fibres to high strength concrete columns. It was also proposed that longer fibres at a higher percentage content would produce better column performance.

3. A new casting technique for concrete columns

As discussed above, fibres increase ductility and also help to arrest the onset of early cover spalling (ECS). As