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INVESTIGATION OF FIBRE REINFORCING THE COVER OF CONCRETE COLUMNS

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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 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: RC Columns, Fibres, Ductility

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INTRODUCTION

Over the past twenty years, research of and improvements to concrete mix design have resulted in an increase of three to four-fold 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. 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 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.

FIBRES WITHIN CONCRETE COLUMNS

A number of researchers over the years have conducted research on using fibres to enhance the properties of concrete. To name a few, Adepegba and Regan [4] carried out tests on steel fibre reinforced concrete columns with 2.4 m height and made of concrete with 32 to 44 MPa compressive strength. The columns were tested in axial compression. The central 0.8 m had a square cross section of 200 mm whilst outside this region the section was enlarged gradually and reached a cross-section size of 200 mm x 500 mm at both ends. The main variable in the experiment was the fibre content of each column which ranged from 0% to 2%. 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 [5] studied the effect of varying the amount of lateral reinforcement on steel fibre-reinforced and non-fibre-reinforced concrete columns. The columns were 200 mm square and 1000 mm high, consisted of concrete in the range 20 MPa to 30 MPa, and were subject to a concentric axial load. The fibrous columns contained 1.5% (by volume) steel fibres. 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.

Foster [1] investigated the mechanics behind early cover spalling and improvements gained through the addition of steel fibres to high strength concrete columns. Using previous and current research he concluded that two processes were necessary for cover spalling to take place. The first involved cracking between the cover and core concrete (due to the expanding cover separating from the confined core) and the second he described as a driving force to push the cover concrete away from the column (including buckling of the cover or outward bending and/or expansion of the longitudinal reinforcement, although further research was recommended to determine which of these driving forces was more significant). Cover spalling was found to be an inevitable consequence of confinement of the core but early spalling could be prevented through the use of steel fibres (which also improved the ductility of the column).

Sarker [3] studied the effect of adding synthetic fibres to high strength concrete columns. The fibres used were 3M Polyolefin (25/38) fibres which were added to 175 mm square columns with a concrete strength of 62 MPa. The columns were subjected to single and double curvature bending and it was found that the inclusion of fibres increased the ductility of the columns and arrested the early spalling of the cover. It was also proposed that longer fibres at a higher percentage content would produce better column performance.

EXPERIMENTAL PROGRAMME

Selection of the optimum fibre quantity was critical to this study. Firstly, it was important to construct a column with 0% fibres (Column C1) to provide a reference point to which results could be compared. Secondly, it was decided that the recommended manufacturers dosage of 0.9 kg/m^3 (0.1% fibres) should be used to provide information as to whether the minimum recommended dosage for shrinkage was sufficient for strength and ductility (Columns C2, C3 and C4). Finally, as for the amount of fibres which would be sufficient for this study, 0.1% was considered the minimum for strength and ductility purposes and 0.5% was considered the maximum for placement purposes. Hence a value between these two of 0.3% fibres (2.7 kg/m^3) was chosen (C5, C6 and C7).

From each batch of fibres three columns were proposed. One containing a uniform fibrous cross-section (C2 and C5), one containing fibres in the cover extending into the core (C3 and C6) and one containing fibres located only in the cover (C4 and C7). The fibre content and location for each column are shown in Table 1 and details and diagrams of the columns are presented in the following sections. The reinforcement of all columns consisted of 6N12 bars (12 mm deformed bars with 500 MPa tensile strength) and R10 (10 mm plain bars with 250 MPa tensile strength) at 50 mm helices.

Casting Procedure

The high strength concrete (HSC) was placed into two wheelbarrows so casting of Column C1 could begin. In order to create the fibrous high strength concrete (FHSC) the HSC was placed directly from the concrete chute into the concrete mixer. The fibres were added evenly to the concrete by hand as it descended the chute. The mixing drum was filled to the correct predetermined height so that a total volume of 0.125 m^3 was present. The mixer was switched on for 1.5 to 2 minutes until the fibres were dispersed evenly throughout the mix. The quantities of fibres added to the concrete were 0.11 kg for the 0.1% mix and 0.34 kg for the 0.3% mix.

Table 1 Column number by fibre content and location.

COL	FIBRE CONTENT	FIBRE LOCATION
C1	0%	N/A
C2	0.1%	Entire Cross-Section
C3	0.1%	Cover + Extending into Core (outer 45mm)
C4	0.1%	Cover Only (outer 22.5mm)
C5	0.3%	Entire Cross-Section
C6	0.3%	Cover + Extending into Core (outer 45mm)
C7	0.3%	Cover Only (outer 22.5mm)

In order to determine the properties of both the HSC and FHSC, sample cylinders and beams were cast. For each of the three batches (0%, 0.1% and 0.3%) six small cylinders were made for compressive tests (three for 7-day strength and three for 28-day strength), three large cylinders were made for indirect tensile tests at 28 days, and three beams were made for flexural tests at 28 days. Each of the samples was cleaned and lubricated prior to casting.

For the columns which had uniform cross-sections, pouring and vibrating were conducted in three stages. The concrete was scooped into the columns for 1/3 of the height before being vibrated with an electric vibrator. The middle and top 1/3 were poured in the same manner and finally the surface was finished with a wet trowel. No problems were encountered in pouring Column 1 (0%), Column 2 (0.1%) or Column 5 (0.3%).

The columns which were to have a smaller HSC core (Column 3 and Column 6) were constructed with a PVC pipe located inside the steel reinforcement (see Figure 1). The HSC was scooped into the PVC pipe whilst the FHSC was placed around the outside of the PVC pipe. The FHSC was pushed with 6 mm bars and the sides of the formwork were tapped with a mallet to ensure the FHSC dropped to the bottom of the column. The column was filled in this way until the HSC inside the PVC pipe and the FHSC outside the PVC pipe were equal and at roughly 1/3 the column height (see Figure 2a). The PVC pipe was then lifted until it was roughly 50 mm inside the concrete (see Figures 1 and 2b). The vibrator was then placed down the centre of the PVC pipe to vibrate the core whilst the cover was rodded with 6mm bars and tapped with a mallet. This process was then repeated for the middle and upper 1/3 of the column (see Figures 2c, 2d and 2e) and the top surface was finished with a wet trowel.

The columns which were to have a larger HSC core, or fibres only located in the cover (C4 and C7) were constructed with a Perspex sheet fabricated into a tube with diameter 163 mm located outside, but in contact with, the steel reinforcement (see Figure 3). The HSC was placed in the centre of the Perspex tube whilst the FHSC was placed around the outside of the tube in the gap between the Perspex and the formwork. Although the gap in which to place the FHSC was smaller than the gap for the PVC pipe, the concrete dropped to the bottom of the column with ease as there were no obstructions and pushing with 6 mm bars was not required. The column was filled in this way until the HSC inside the Perspex tube and the FHSC outside the Perspex tube were equal and at roughly 1/3 the column height (see Figure 2a). The Perspex tube was then lifted until it was roughly 50 mm inside the concrete (see Figures 3 and 2b). The vibrator was then placed down the centre of the Perspex tube to vibrate the core whilst the cover was rodded with 6 mm bars and tapped with a mallet. This process was then repeated for the middle and upper 1/3 of the column (see Figures 2c and 2d), although the upper 1/3 was not vibrated immediately. The final 40 mm was not placed straight away (see Figure 2e) in order to allow for the strain gauge wires to be threaded through the hole in the side of the formwork. Once this was carried out, the Perspex tube was replaced in the column, the final 40 mm was cast and vibration of the top 1/3 took place. Finally, the top surface was finished with a wet trowel.

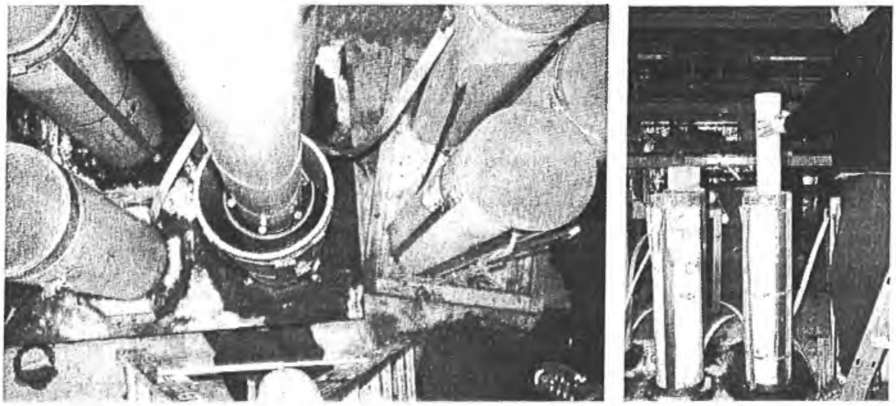

Figure 1 Columns 3 and 6 - small HSC core

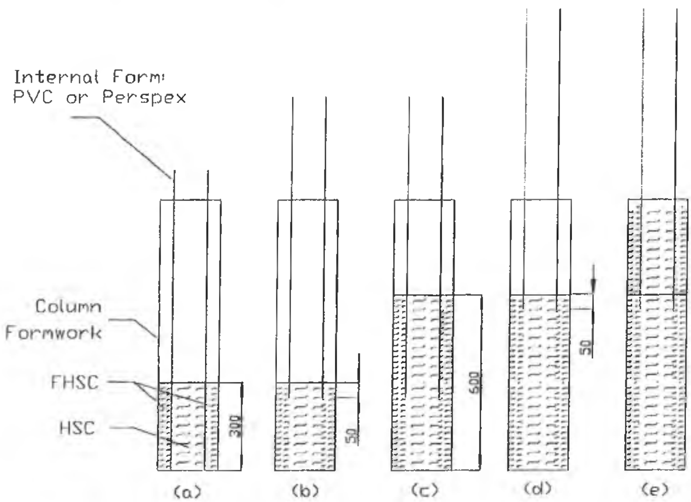

Figure 2 Column casting procedure

At the conclusion of casting, all specimens were covered with wet hessian and plastic sheets to prevent moisture loss. The cylinder and beam samples were stripped and placed in a curing tank whilst the columns were stripped after 7 days and placed under wet hessian and covered with plastic sheets.

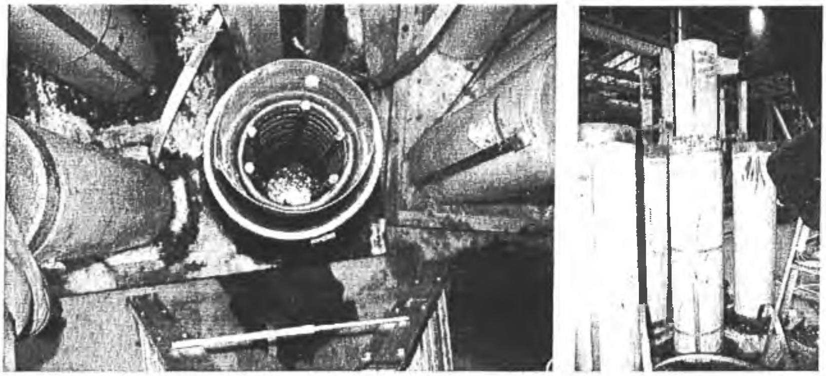

Figure 3 Columns 4 and 7 - large HSC core

COLUMN TESTING

The following procedure was employed to test the column specimens. Each column was capped at the base with high-strength plaster and once the plaster had set, the column was inverted, lifted into the testing machine and capped at the opposite end, under a preload of around 14 kN provided by the testing machine. While the high-strength plaster was allowed to set a galvanised safety cage was placed around the column to minimise any potential damage caused by flying debris. Once sufficient time was allowed for the plaster to set, testing of the column took place.

The columns were tested under displacement controlled loading regime. The rate of loading was varied depending on the response of the column but a value of 0.3 mm/min was found to be ideal for speed and accuracy. During testing, deflection readings were taken by hand every 20 kN so that load-deflection curves could be created.

RESULTS

Testing the concrete for its compressive strength revealed that it had a value of 62 MPa. Table 2 shows yield load, corresponding displacement, ultimate load and the maximum displacement of the seven tested columns.

Ductility of each of the tested columns was calculated and are shown in Table 3. These ductilities were calculated as a ratio of the ultimate displacement to the yield displacement as one measure and as the ratio of the maximum displacement to the yield displacement as a second measure. The ductility of the C1 was used as a reference value for the remaining columns.

In order to assess the benefits of varying the fibre content, C1, C2 and C5 were compared. All three columns had uniform cross-sections with fibre contents of 0.0%, 0.1% and 0.3%, respectively. Figure 4 shows that cover spalling in both C2 and C5 occurred at a higher load than C1 indicating better performance due to the presence of fibres. The percentage of fibres present also had an effect as cover spalling for C5 occurred at a higher load than for C2.

Table 2 Results of testing the columns

COL.	YIELD LOAD (kN)	DISPL. AT YIELD LOAD (mm)	ULT. LOAD (kN)	DISPL. AT ULT. LOAD (mm)	MAX DISPL. (mm)
C1	1580	3.6	1780	9.5	14.8
C2	1780	2.9	1849	3.0	11.2
C3	1660	3.3	1830	9.2	13.6
C4	1520	4.2	1669	9.0	> 19.5
C5	1725	3.7	1935	5.1	> 78.0
C6	1937	4.1	2009	4.8	> 39.0
C7	1774	4.0	1885	8.9	28.5

Table 3 Calculated ductility of the tested columns

COL.	DUCTILITY: ULT. DISP./ YIELD DISP.	DUCTILITY RELATIVE TO C1	DUCTILITY: MAX. DISP./ YIELD DISP.	DUCTILITY RELATIVE TO C1
C1	2.7	1.0	4.2	1.0
C2	1.1	0.4	3.9	0.9
C3	2.8	1.0	4.1	1.0
C4	2.2	0.8	> 4.6	> 1.1
C5	1.4	0.5	> 21.1	> 5.1
C6	1.2	0.4	> 9.5	> 2.3
C7	2.2	0.8	7.1	1.7

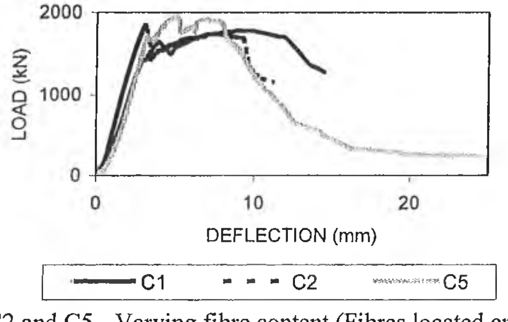

Figure 4 C1, C2 and C5 - Varying fibre content (Fibres located entire cross-section)

The effect of varying the percentage of fibres on cover spalling can also be shown through the comparison of C3 and C6. The columns contained both high-strength concrete (HSC) and fibrous, high-strength concrete (FHSC) in the same locations but C3 contained 0.1% FHSC while C6 contained 0.3% FHSC. Figure 5 shows C6 reached a load of 2000 kN before cover spalling took place while C3 only reached a load of 1660 kN again indicating that increased fibre content yields better results.

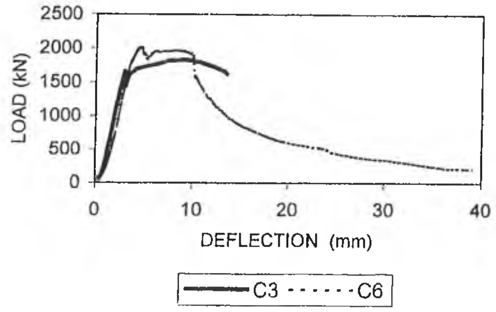

Figure 5 C3 and C6 - Varying fibre content (Fibres located in cover plus extending into the core)

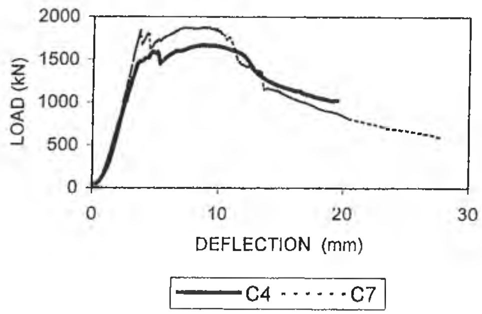

Figure 6 C4 and C7 - Varying fibre content (Fibres located in cover only)

Columns C4 and C7 were also compared in a similar manner as both contained fibres in identical locations but C4 contained 0.1% FHSC while C7 contained 0.3% FHSC. Figure 6 shows the cover spalling load of 1840 kN for C7 was higher than the cover spalling load of 1570 kN for C4 again indicating that high strength concrete containing 0.3% fibres performs much better than high strength concrete containing only 0.1% fibres.

In order to assess the benefits of varying the location of the fibres, Columns C2, C3 and C4 were compared. All three columns contained FHSC from the same batch but C2 consisted of a uniform cross-section with FHSC throughout, C3 contained FHSC in the cover concrete extending through the region of the steel reinforcement into the core which contained plain HSC and C4 contained FHSC only in the cover concrete, ie only the outer 22.5 mm, and HSC throughout the remainder of the cross-section. As can be seen in Figure 7, cover spalling took place at a higher load for C2 than for C3 and C4 indicating that reducing the amount of fibre present in the cross-section reduces the load at which cover spalling takes place for a low fibre content of 0.1%.

Columns C5, C6 and C7 contained fibres located in identical regions to C2, C3 and C4, respectively, but at three times the fibre dosage, ie 0.3%. However, as shown by Figure 8, varying the location of the fibres did not have a significant effect on the load at which cover spalling took place. Cover spalling of C7 occurred at a slightly lower load than that for C5 but cover spalling of C6 occurred at a slightly higher load than that for C5. It was concluded that at the 0.3% fibre content, all of the three different cross-sections performed in a similar manner, regarding cover spalling, indicating that selection of a cross-section containing FHSC in the cover and plain HSC in the core, would result in a more efficient use of materials.

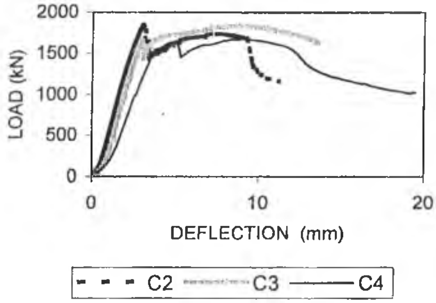

Figure 7 Columns C2, C3 and C4 – Varying fibre location (Constant fibre content of 0.1%)

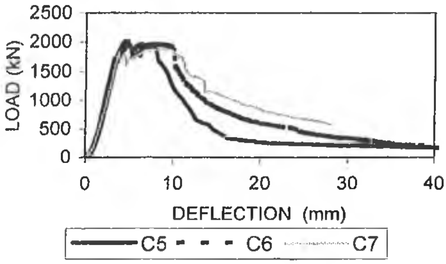

Figure 8 Columns C5, C6 and C7 – Varying fibre location (Constant fibre content of 0.3%)

CONCLUSIONS

This study of fibre reinforced concrete columns involved the testing of seven high strength concrete columns with varying fibre contents and fibre locations. The main aim of this study was to determine whether placing fibrous concrete only in the outer cover, would be sufficient to maintain, or enhance, the desirable properties of high strength concrete columns. The following is a list of the conclusions drawn from this study.

- Introducing 19 mm polypropylene fibres to the concrete increases the load at which cover spalling takes place.
- Increasing the fibre content from 0.1% to 0.3% results in higher strengths being reached before cover spalling takes place.
- Although previous studies suggested otherwise, the findings of the current study suggest that the addition of the fibres did not increase the ductility of the columns.
- The method used to place the fibres in the cover is new and was found to be very effective for casting the columns but laborious.
- Placing the fibres in the cover only ensured that the fibres were evenly distributed, the integrity of HSC core was maintained and the tendency of the fibres to vibrate away from cover into the core was reduced.
- Placing 0.3% fibres in both the cover concrete and through the steel reinforcement into the core increases the load at which cover spalling takes place.

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