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Use of advanced composite materials in strengthening axially loaded reinforced concrete columns

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Abstract

The present study deals with the analysis of experimental results, regarding of load carrying capacity and strains, obtained from tests on reinforced concrete (RC) columns, strengthened with external carbon fibre reinforced polymer (CFRP) sheets. The experimental parameters include: number of wrap layers, slenderness of the columns (L/a or L/D) and section geometry (circular or square). A total of 48 specimens were subjected to axial compression. All test specimens were loaded to failure. Compressive stress, both axial and hoop strains have been recorded to evaluate the stress-strain relationship, ultimate stress, stiffness, and ductility. First, the effects of test parameters are analysed and compared. Results clearly demonstrate that composite wrapping can enhance the structural performance of RC columns in terms of both maximum strength and ductility.

Keywords: RC column; composite material; CFRP; confinement; slenderness; section shape; strength; ductility.

1. Introduction

During the last decade, advanced composite materials, such as carbon fibre reinforced polymer (CFRP) sheets or plates, have been successfully used for the rehabilitation of concrete structures throughout the world. Their application in civil engineering structures has been growing rapidly in recent years, and is becoming an effective and promising solution for strengthening deteriorated concrete members because of their high strength-to-weight ratio, good fatigue properties and excellent corrosion resistance. They are also quickly and easily applied, their use minimizes labour costs and can lead to significant savings in overall project costs.

Several studies on the performance of FRP wrapped columns have been conducted, using both experimental and analytical approaches [1-6]. This strengthening technique has proved to be very effective in enhancing column ductility and axial load capacity. Most of the available experimental data regarding FRP-confined columns have been generated from tests on small-scale concrete cylinders with standard strength. The data available for columns with square or rectangular cross sections have increased over recent years but are still limited [7-9]. Also the validation of these results and their applicability to large-scale reinforced concrete (RC) columns is of great practical interest. Published work in this field is relatively scarce [10,11]. More research on this subject is needed to study the effect of slenderness for concrete columns with higher strength.

This study presents a comprehensive experimental investigation on the behaviour of axially loaded circular and square reinforced columns strengthened with CFRP wrap. A total of 48 concrete specimens were tested under axial compression. The data recorded included the compressive loads, axial strains,

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and radial strains. The parameters considered are the number of composite layers and slenderness ratio of the column - L/D and L/a, for circular and square cross sections, respectively.

2. Experimental Program

The concrete mix used to prepare testing specimens had an average strength of 50 MPa. The carbon-fibre sheets used were the SikaWrap®-230 C product, an unidirectional wrap. The Sikadur®-330 epoxy resin was used to impregnate and bond the carbon fabrics to the columns. Eight series of experiments were performed to investigate the behaviour of plain concrete (PC) and RC columns confined by CFRP composite. For all RC specimens the diameter of longitudinal and transverse reinforcing steel bars were respectively 12 mm and 8 mm. The longitudinal steel ratio was constant for all specimens and equal to 2.25%. The yield strength of the longitudinal and transversal reinforcement was 500 MPa and 235 MPa, respectively. Table 1 summarizes the specimens involved in the experimental program.

The specimen notations are as follows. The first two letters refer to the cross section shape: C for circular and S for square, followed by type of concrete: PC for plain concrete and RC for reinforced concrete. The next letter indicates the slenderness ratio: x for L/a=2 (or L/D=2), y for L/a=4 (or L/D=5.08) and z for L/a=7.14 (or L/D=6.45). The last number specifies the number of reinforcing layers. With regard to results, f'_{cc}/f_{co} represents the average ratio of concrete strength of confined to unconfined member. The axial strains ε_{cc} and ε_{co} correspond, respectively, to confined and unconfined concrete specimens.

After concrete columns were fully cured, CFRP wrapping was performed according to the procedure specified by the manufacturer. Specimens were loaded under monotonic uniaxial compression up to failure. Load was applied at a rate of 0.24 MPa/s and was recorded with an automatic data acquisition system. Axial and lateral strains were measured using extensometers.

Table 1. Details of test specimens and experimental results (mean values).

Specimen designation	Slender ratio L/D or L/a	Nominal dimensions (D x L or a x a x L) (mm)	Number of layers	Number of specimens	f'_{cc} (MPa)	f'_{cc}/f'_{co}	ε_{cc} (‰)	$\varepsilon_{cc}/\varepsilon_{co}$
CPC. x0	2	160 x 320	0	2	49.46	1.00	1.69	1.00
CPC. x1	2	160 x 320	1	2	56.36	1.14	2.53	1.50
CPC. x3	2	160 x 320	3	2	82.91	1.67	7.27	4.30
CRC. x1	2	160 x 320	0	2	58.24	1.00	3.02	1.00
CRC. x1	2	160 x 320	1	2	77.51	1.33	8.36	2.78
CRC. x3	2	160 x 320	3	2	100.41	1.72	13.58	4.50
CRC. y0	5.08	197 x 1000	0	2	62.68	1.00	2.90	1.00
CRC. y1	5.08	197 x 1000	1	2	88.27	1.40	6.94	2.40
CRC. y3	5.08	197 x 1000	3	2	99.77	1.60	8.67	3.00
CRC. z0	6.45	155 x 1000	0	2	45.00	1.00	1.48	1.00
CRC. z1	6.45	155 x 1000	1	2	65.25	1.45	4.89	3.30
CRC. z3	6.45	155 x 1000	3	2	90.90	2.02	10.51	7.10
SPC. x0	2	140 x 140 x 280	0	2	48.53	1.00	3.39	1.00
SPC. x1	2	140 x 140 x 280	1	2	52.52	1.08	4.01	1.18
SPC. x3	2	140 x 140 x 280	3	2	58.25	1.20	7.11	2.10
SRC. x0	2	140 x 140 x 280	0	2	52.82	1.00	4.08	1.00
SRC. x1	2	140 x 140 x 280	1	2	62.04	1.17	5.42	1.30
SRC. x3	2	140 x 140 x 280	3	2	69.09	1.30	6.89	1.70
SRC. y0	4	140 x 140 x 560	0	2	52.67	1.00	2.11	1.00
SRC. y1	4	140 x 140 x 560	1	2	61.61	1.16	2.82	1.34
SRC. y3	4	140 x 140 x 560	3	2	65.91	1.24	3.17	1.50
SRC. z0	7.14	140 x 140 x 1000	0	2	48.26	1.00	1.38	1.00
SRC. z1	7.14	140 x 140 x 1000	1	2	60.16	1.24	2.07	1.55
SRC. z3	7.14	140 x 140 x 1000	3	2	65.71	1.35	2.86	2.03