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STRENGTHENING OF MASONRY COLUMNS WITH SPRAYED GLASS FIBRE REINFORCED POLYMER (SGFRP)

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ABSTRACT

Strengthening masonry columns by spraying them with glass fibre reinforced polymer (GFRP) was investigated experimentally. The study was aimed at assessing the strength and strain increases imparted by the technique. Plain and reinforced columns were tested. Twenty-four columns were constructed with Type S mortar and straight and bull nose masonry units. The columns were one meter high and either 290 mm x 290 mm or 390 mm x 390 mm in cross-section. Two thicknesses of GFRP were attempted, but it was found to be difficult to maintain uniform thickness. Nevertheless, minor increase in strength and large increase in strain were achieved with both the plain and the reinforced columns under concentric axial compression.

KEYWORDS: columns, strengthening, GFRP, spray, compression, concentric loading.

INTRODUCTION

There has been an increasing trend in recent years for restoration, rehabilitation or strengthening of structures to be considered rather than demolition followed by new construction. Increases in permitted loads, additions to a structure or the need for seismic upgrading can all instigate assessment for refurbishment. Fibre Reinforced Polymers (FRP) have been involved in many schemes for repair and strengthening. Columns are a particular problem as failure of a column can have significant consequences for a structure. Wrapping reinforced and pre-stressed concrete columns [1, 2] with FRP has been shown to increase their strength, but similar test data for masonry columns are very limited [3]. The application of FRP sheets is a tedious process. A new option has become available which involves spraying high performance fibres with a durable hybrid polymeric resin onto the surface at high speeds (100 km/h), such that a well compacted and well-bonded composite with high strength and stiffness is formed. With the resulting random distribution of the fibres in 2-D, the FRP layer inherits non-linear stress-strain behaviour and has isotropic in-plane strength performance [4].

EXPERIMENTAL PROGRAM

The purpose of this study was to assess the application of sprayed glass fibre reinforced polymers (SGFRP), on the strength of masonry columns. Twenty four columns were tested concentrically in compression. Reinforced and plain columns were tested both with and without sprayed FRP. All columns were constructed by a skilled mason with Type S (structural) mortar. Joints were finished with a concave finishing tool. 1 metre high columns were constructed with two different cross-sectional sizes with pressed clay masonry units. Ten 50 mm mortar cubes were cast to test for the 28-day compressive strength of the mortar. Cubes were left to cure at room temperature (23° C).

The units included a three-hole perforation pattern and were available in rectangular and bull nose shapes. Rectangular masonry units were 90 mm x 190 mm x 76 mm. The Bullnose units had the same dimensions with a bullnose of 25mm radius on one corner, used to form the column corners (Figure 1). Bullnose units were used to avoid a sharp corner and thus premature rupture of the FRP: the confining forces provided by the SGFRP layer are distributed over the curved surface [5].

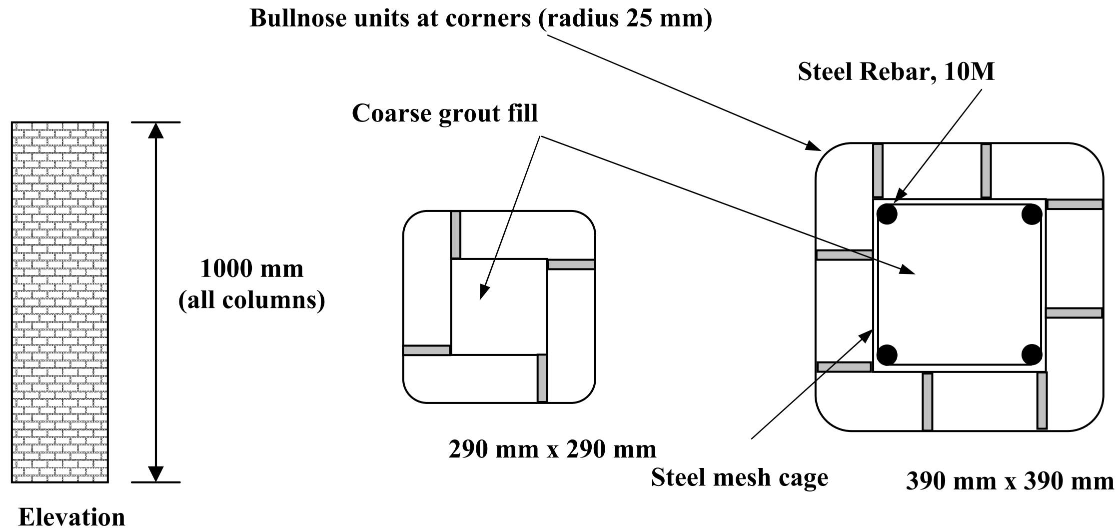


Figure 1 – Column Details

Only large columns were reinforced with steel bars. Four steel bars were placed in the inner cavity with a column shaped wire steel cage (Figure 2). The cavity was filled with coarse grout, having the proportions shown in Table 1 (CSA A179) [6]. Ten cylinders (101.6 mm diameter x 203.2 mm high) were cast to determine coarse grout compressive strength. All columns were cured for at least 28 days. After curing four columns of each type were sprayed with GFRP as per Table 2: 2 columns to a nominally 2 mm thick layer and 2 others with nominally 4 mm. The columns were left to cure for a further 7 days before testing began. A continuous roll of high performance glass fibre was fed through a spray gun equipped with a nozzle for resin spray and a time regulated chopper (cutter). The chopper cut the fibre to 30 mm lengths. The GFRP was sprayed in stages until the desired thickness was nominally reached. It was difficult to maintain consistent thickness in the sprayed layer. A brass embossed roller was used to compact each sprayed layer and flatten in any extruding fibres.

Table 1 - Coarse-grout mix proportions (by cement weight)

Materials	Relative value
Portland cement	1
Hydrated lime	0
Fine aggregate	2.63
Coarse aggregate	1.5
Water	1.2

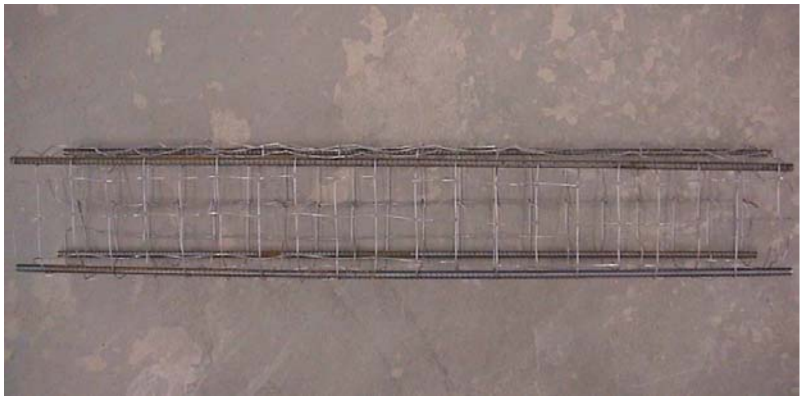


Figure 2 – Type 10 steel rebar and steel mesh cage assembly

Table 2 - Designation of specimens (A and B are replicas)

290 mm x 290 mm Columns		
Plain	**A**	**B**
Plain with SGFRP 2mm	**A2**	**B2**
Plain with SGFRP 4mm	**A4**	**B4**
390 mm x 390 mm Columns		
Plain	**AP**	**BP**
Plain with SGFRP 2mm	**AP2**	**BP2**
Plain with SGFRP 4mm	**AP4**	**BP4**
Plain, steel reinforced	**AR**	**BR**
Steel reinforced with SGFRP 2mm	**AR2**	**BR2**
Steel reinforced with SGFRP 4mm	**AR4**	**BR4**

Spraying is shown in Figure 3. After the FRP had cured, the columns were trimmed to remove excess GFRP, and the columns capped using Plaster of Paris.

Figure 3 – GFRP spray process

After testing, sections of the FRP were delaminated from the columns, the thickness of the layer was measured at several points and tension specimens cut out. Properties determined for all materials are shown in Table 3.

Table 3 - Material properties

Test	***Rectangular Masonry Units***	***Bullnose Masonry units***	***SGFRP***	***Type-S mortar cubes***	***Coarse Grout***
Masonry Compressive strength. Five-High prism stacks (MPa)	21.6	19.2	-	-	-
Unit Compressive Strength (fc)	29.5	40.4	-	9.4	28.8
Initial Rate of Absorption IRA (%)	0.64	1.7	-	-	-
Total Absorption (%)	5.87	5.97	-	--	-
Tensile Strength (MPa)	-	-	43	-	-
Young's Modulus (GPa)	-	-	63.3	-	-
Elongation at break (%)			2.1		

To avoid premature crushing of top and bottom column ends during testing, two sets of steel brackets were fixed at the top and bottom ends of each column, with a padding of fibre board between the steel and the column surface. The brackets were held together by four threaded pins. The pins were tightened using a torque wrench, set at 54.3 N.m (40 ft. lb) torque. The brackets were designed to confine the first 100 mm of column height at each column end. The columns were instrumented with four displacement transducers, each attached at a column corner, measuring over a gauge length of approximately the central third of the total column length (333 mm).

Displacement was monitored at the beginning of each test and a series of loading, un-loading and spherical seat adjustments were performed until the displacements increased similarly in all transducers, indicating concentric loading. An extra transducer was attached underneath the bottom platen to measure the total deformation of the column. The deflections recorded from the four transducers, were averaged in order to plot load-deflection curve for each column. Data were collected using a data acquisition board feeding a PC. The vertical deflection for each transducer and axial load was recorded at 1 s intervals. Load was increased until cracking was observed. Cracks developed vertically through masonry units and perpend joints in the mid-side of each column. No vertical cracking was observed along the column corners. Load-deflection curves were plotted for each column as the test proceeded to identify first cracking and ultimate loads. The test was usually stopped when cracking and reduced stiffness at peak load were observed, but some columns were tested to complete failure.
Failure of plain (un-sprayed columns) was explosive, while that of SGFRP columns was not. Vertical cracking was observed in the SGFRP laminates, typically near the corners and along the mid-side of the columns.

RESULTS AND DISCUSSION

Unsprayed Columns

Six un-sprayed specimens were tested and all (plain or reinforced) behaved in a similar manner. Vertical cracks initiated at the four column sides, at mid-height (Figure 4). Cracks then propagated vertically through the masonry units and perpend joints. For plain columns, spalling of masonry units developed until failure was complete and columns were totally destroyed. Inspection of the grout core showed that cracking was also initiated in the core, as shown in Figure 5. Reinforced columns behaved similarly, and no buckling of the steel rebars was observed. Greater deformations were obtained with reinforced columns, compared to plain columns.

Figure 4 – Cracking in a plain column

Figure 5 – Cracking in the grout core of a plain 390 x 390 mm column

Table 4 - Test results

Column Size 1m height (mm x mm)	*Plain*				*SGFRP*				*Comparisons*		
	Specimen No.	*Peak Load (KN)*	*Average Stress (MPa)*	*Max Strain (ue)*	*Specimen No.*	*Peak Load (KN)*	*Average Stress (MPa)*	*Max Strain (ue)*	*Load Increase (%)*	*Stress Increase (%)*	*Strain Increase (%)*
290 x 290	A	1216.02	14.5	1934.5	A2	1467.42	17.6	3726.5	21	22	93
290 x 290	B	1193.42	14.3	2034.5	B2	1419.5	17	3698.8	19	19	82
290 x 290					A4	1490.2	17.8	3802.3	23	23	97
290 x 290					B4	1520	18.19	3420.5	28	28	69
390 x 390	AP	1887.8	12.5	898.5	AR	2262.7	14.9	1027	20	20	15
390 X 390	BP	1852.4	12.2	1038.7	BR	2510.2	16.6	1119.3	36	37	8
390 x 390					AP2	2149.4	14.2	2681.8	14	14	199
390 X 390					BP2	2144.3	14.2	2140.8	16	17	107
390 x 390					AP4	2187.5	14.4	2537	16	16	183
390 X 390					BP4	2366.2	15.6	2311.8	28	28	123
390 x 390					AR2	2645.7	17.5	3087.3	41	40	244
390 X 390					BR2	2532.8	16.7	2687.8	37	37	159
390 x 390					AR4	2645	17.5	3432.8	41	40	283
390 X 390					BR4	2701.4	17.8	3749	46	46	261

The failure loads, average stresses and strains at failure for all specimens are listed in Table 4. Plots of applied load versus average deflection for each column show linear behaviour up to cracking. A typical load versus deflection graph for plain masonry column is shown in Figure 6. Reinforced columns had failure strains 8-15 % higher than plain specimens.

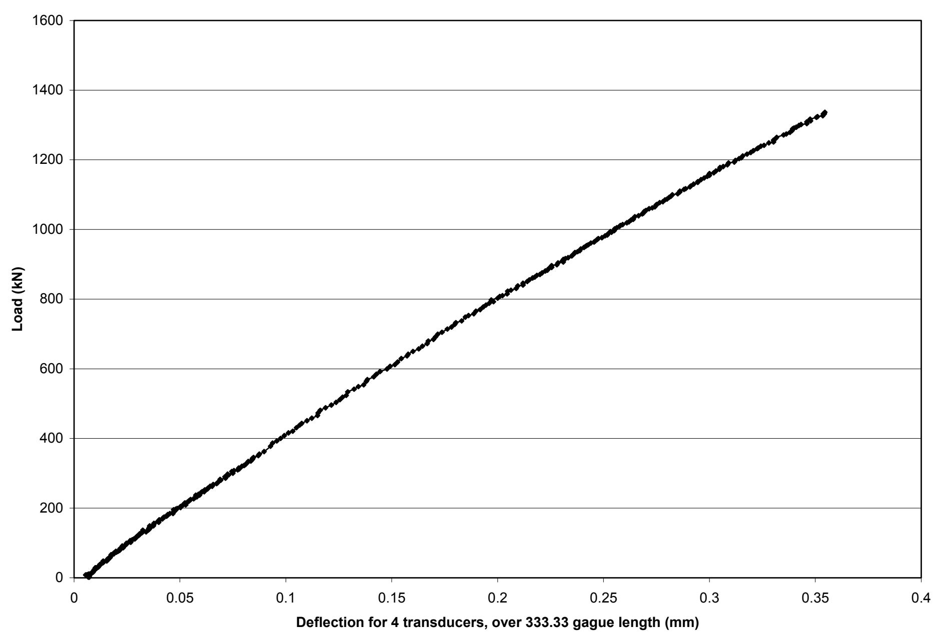


Figure 6 – Typical initial Load-deflection behaviour

SGFRP Columns

All GFRP sprayed columns failed similarly. The SGFRP started to debond before failure, followed by tearing of the laminate as the masonry tried to punch out. The tearing of the SGFRP was a combination of Mode I and Mode III cracking, as shown in Figure 7. Failure loads, stresses and strains are given in Table 4. Overall there was marginal increase in strength between columns with 2 mm and 4 mm thick SGFRP, the small difference being related to the inconsistency in the spraying process.

Figure 7 –Failure of SGFRP laminate in AP2 (above) showing a mix of Mode I and Mode III cracking and BP4 (below) showing only Mode III

The GFRP increased the load capacity of the larger specimens by 14-16 % for Plain/SGFRP 2 mm specimens, 16-28 % for Plain/SGFRP 4 mm, 37-41 % for Steel-Reinforced/SGFRP 2 mm and 41-46 % for Steel-Reinforced/SGFRP 4 mm. A slight increase in load capacity was obtained from thicker sprayed layer of GFRP, and higher load bearing capacity was observed for steel-reinforced specimens. Much higher increases were observed in strain capacity. The increase ranged from 107-199 % for Plain/SGFRP 2 mm specimens, 123-244 % for Plain/SGFRP 4 mm, 159-244 % for Steel-Reinforced/SGFRP 2 mm and 261-283 % for Steel-Reinforced/SGFRP 4 mm specimens.

For the small masonry columns, the spraying of GFRP increased load capacity 19-21 % for Plain/SGFRP 2 mm specimens, and 23-28 % for Plain/SGFRP 4 mm. Again a slight increase in load capacity was obtained for the thicker layer of GFRP, and higher capacity was observed for steel-reinforced specimens. As with the larger specimens, strain capacity was increased for all specimens, compared to control ones. The increase was in the range of 82-93 % for Plain/SGFRP 2 mm specimens and 69-97 % for Plain/SGFRP 4 mm. A typical load-deflection curve for a SGFRP specimen is shown in Figure 8. Increases are shown in Figure 9.

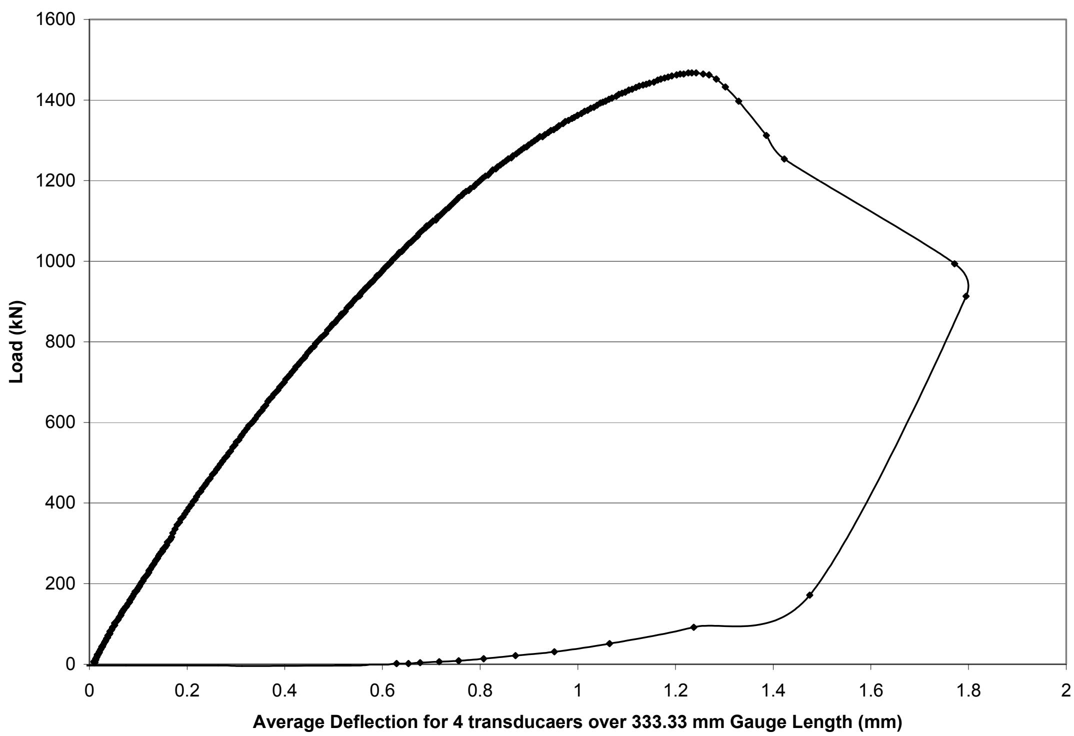
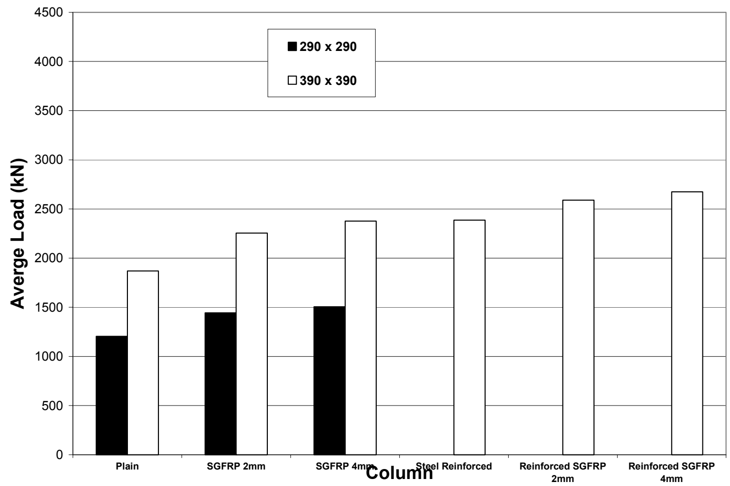
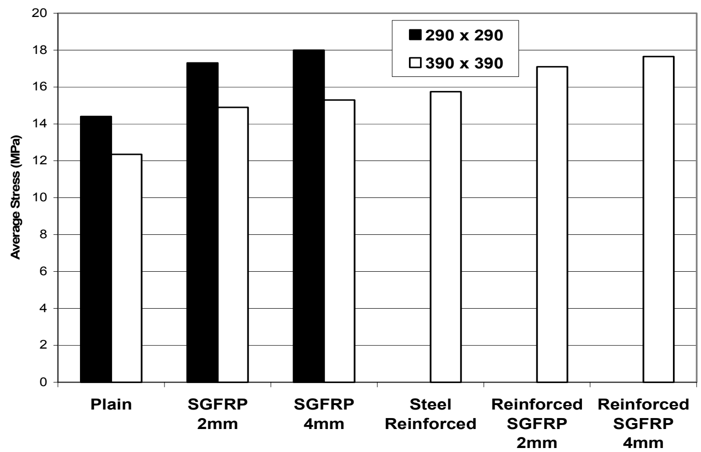


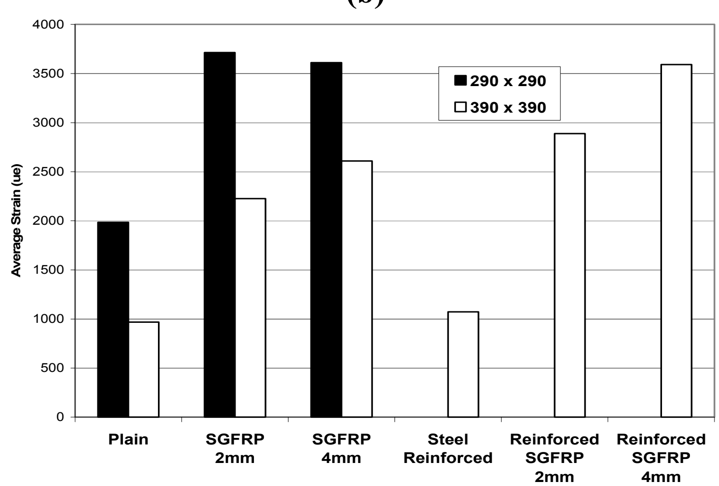
Figure 8 – Typical Load-deflection behaviour for a sprayed specimen (A2)



(a)



(b)



(c)

Figure 9 – Average ultimate load, stress, and strain for all columns.
(a) Ultimate load for plain, reinforced, and SGFRP;
(b) Ultimate stress for plain, reinforced, and SGFRP;
(c) Ultimate strain increase for plain, reinforced, and SGFRP.

CONCLUSIONS AND SUGGESTIONS

The load-displacement curves of all columns showed an initial approximately linear phase followed by strain softening. In general, external spraying of the masonry columns with GFRP resulted in a remarkable increase in ultimate strain, a decrease in stiffness, and slight increase in strength and ductility. Despite the difficulty controlling the degree of cracking in each test, the following trends can be deduced from Figure 9:

- The ultimate loads of columns sprayed with GFRP did not increase substantially except in the case of 390 x 390 mm columns with a nominal 4 mm thick SGFRP.
- Loads increase with increasing SGFRP thickness, and with the use of steel-reinforcement.
- Average stress decreases with increasing column cross-sectional area.
- Large increases in ultimate strain were obtained for all specimens with SGFRP confinement.
- Spraying GFRP is a relatively easy technique of providing significantly increased strain capacity and small strength increases to concentrically loaded masonry columns.
- Further tests need to be performed to determine if the same benefits are observed under eccentric loading.

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