Behaviour of rectangular reinforced concrete members confined with GFRP sheets

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ABSTRACT: Practical and economical reinforcement of existing structures can be achieved through external bonding of Glass Fibre Reinforced Polymer (GFRP) sheets to structural components. An experimental programme was developed to investigate strengthening effects of GFRP wrapping on rectangular concrete columns. Test variables included the wrapping scheme, presence of longitudinal sheets and the loading condition. Three types of loadings were considered: pure axial compression, pure flexure and combined flexure and axial compression. Axial compression versus flexure interaction diagrams were constructed. Specimens with and without longitudinal GFRP strips had similar pure bending capacities. The specimens with longitudinal GFRP reinforcement had balanced conditions with higher bending and lower axial compression resistance than specimens without longitudinal GFRP strips. Analysis of the experimental results revealed that the largest influencing factor that increased the compressive strength of the specimens subjected to pure axial compression was the amount of transverse GFRP wrap. The largest contributing factor for increased moment resistance in specimens subjected to flexure and combined flexure and axial compression was the presence of longitudinal GFRP strips.

1 INTRODUCTION

Much of our current infrastructure is constructed of concrete. As time passes, deterioration and change of use requirements facilitate the need for new structures. Demolition of existing and construction of new structures is a costly, time consuming and resource intensive operation. If existing structures could be reinforced to meet new requirements then the associated operating costs of our infrastructure would be reduced.

A practical method for reinforcing existing concrete components is externally bonding reinforcement to the surface of concrete members. Externally bonded steel plates and prestressing strands have been used successfully to reinforce beams, columns and slabs. While steel is an effective material for externally reinforcing members it can be difficult to work with because of its weight and stiffness.

Fibre reinforced polymer (FRP) is a light, flexible, non-corrosive and strong material that can be externally bonded to concrete members. FRP products exhibit different strength characteristics than conventional steel reinforcing. They have higher strengths but lower strains at failure than reinforcing steel. Also, they have an associated purchase cost premium and are an unfamiliar product for many contractors and designers.

The load carrying capacity of concrete columns can be increased by bonding FRP sheets to the concrete surface. FRP sheets wrapped around the perimeter of the column, with fibres oriented transversely to the axis of the column, will confine the concrete and enhance the axial compressive capacity of the column. FRP sheets with fibres oriented longitudinally with the axis of the column will provide additional tensile load carrying capacity and increase the flexural capacity of the member.

Bonding of FRP sheets to provide confinement is more easily achieved on columns with circular cross-sections. Circular sections provide a continuous curvature without abrupt changes. Ideally, the confining stresses will be evenly distributed throughout the circular cross-section and the confining sheet. Rectangular or square sections have four sides with two or four equal lengths. The associated confining stresses will not be equally distributed along the four sides of the cross-section. Furthermore, the corners of the section provide points of stress concentration where the sheets may fail prematurely.

Strength enhancement by FRP wrapping for columns under pure axial compression is well documented in the published literature (ACI 440R-07, 2007). FRP wrapping of columns can provide strength enhancement for a member subjected to combined axial compression and flexure (Chaallal and Shahawy 2000; Iacobucci et al. 2003; Bousias et al. 2004; Sause et al. 2004; Rocca, 2006). Several models have been developed to predict the behaviour of FRP confined concrete columns (Bank 2006, Teng, 2002).

This paper aims to examine the relationship between wrapping arrangements and strengthening effects for rectangular reinforced concrete columns wrapped with GFRP sheets under combined flexure and axial compression (Lankinen, 2003).

2 EXPERIMENTAL PROGRAMME

An experimental programme is undertaken in which a total of 16 reinforced concrete columns are confined with a combination of transversely and longitudinally applied GFRP wraps. The columns are tested in pure compression, pure bending and combined bending and compression to obtain data points for column interaction diagrams.

2.1 *Test matrix*

The loading and wrapping schemes combine to form the test matrix depicted in Table 1.

Table 1: Test Matrix for Experimental Programme

Axial compression (kN) Wrapping scheme	0	100	200	Failure
Intermittent transverse GFRP strips	IT0	IT100	IT200	IT
Continuous transverse GFRP wrap	CT0	CT100	CT200	CT
Intermittent transverse GFRP strips & longitudinal GFRP strips	ITLS0	ITLS100	ITLS200	ITLS
Continuous transverse GFRP wrap & longitudinal GFRP strips	CTLS0	CTLS100	CTLS200	CTLS

The four loading schemes are in terms of the amount of axial compression. Specimens noted with 0kN axial compression are tested to failure in pure flexure. The specimens noted as 100kN and 200kN axial loads are loaded to a constant sustained axial compressive force of 100kN and 200kN respectively and then tested to failure in flexure. Specimens noted as "Failure" are tested to failure in pure axial compression.

2.2 *Specimens*

Specimens consisting of rectangular cross-section (100mm breadth x 150mm height with 10mm radii rounded corners) are used in this study. While columns of this size cross-section are not used in construction, cross-sections of this size are more easily handled and have lower compressive failure loads than columns of larger cross-sections. The ability to fail the columns in pure compression was a major factor in determining the cross-section size.

Two sets of column lengths are used. Columns subjected to pure axial compression are 500mm in length with the other columns 1700mm in length. A 1700mm length allows for a span of 1500mm with two transverse point loads applied at 500mm from either support of the specimen (see Fig. 1). The 500mm long "stub" columns were tested in a vertical arrangement subjected to pure compression (not shown).

Steel reinforcement in the specimen consisted of 6mm diameter smooth bars. To meet the minimum requirements of CSA Standard A23.3-94 the following reinforcement was used; four longitudinal bars, shear ties at 50mm with 500mm of the supports for the beams, and ties at 100mm between the loads. Fig. 1 shows the geometry and reinforcement details for the test specimen.

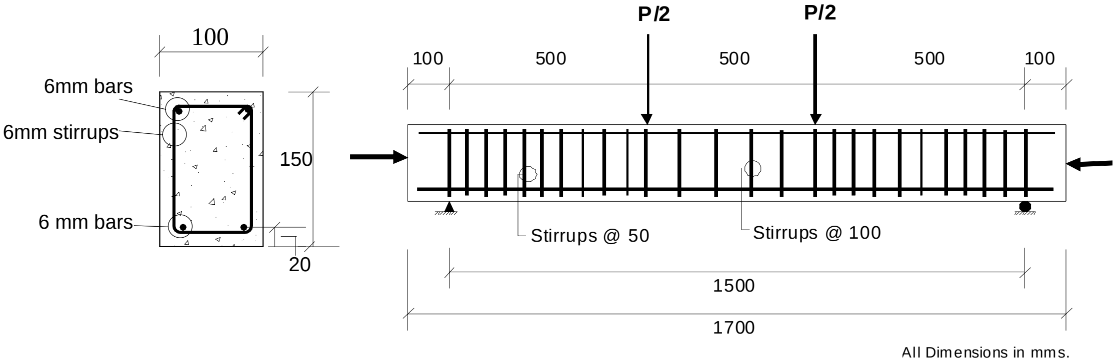


Figure 1. Test specimen and loading configuration for combining axial compression & flexure

2.3 *Wrapping schemes*

Glass fibre reinforced polymer (GFRP) sheets are used to transversely and longitudinally confine the concrete specimens. Four wrapping schemes are applied to the test specimens as follows:

- <u>Intermittent transverse GFRP strips (IT):</u> 75mm wide GFRP transverse strips spaced at 150mm on centre.
- <u>Continuous transverse GFRP wrap:</u> A continuous GFRP transverse sheet specimen.
- <u>Intermittent transverse GFRP strips and longitudinal GFRP strips:</u> 75mm wide GFRP strips are oriented longitudinally along the 100mm sides of specimen, 125mm wide GFRP strips are oriented longitudinally along the 150mm sides of specimen and 75mm wide strips are oriented transversely to the axis of the specimen spaced at 150mm centre to centre over the longitudinal strips.
- <u>Continuous transverse GFRP wrap and longitudinal GFRP strips:</u> 75mm wide GFRP strips are oriented longitudinally along the 100mm sides of specimen, 125mm wide GFRP strips are oriented longitudinally along the 150mm sides of specimen and a continuous GFRP sheet is oriented transversely to the axis of the specimen over the longitudinal strips.

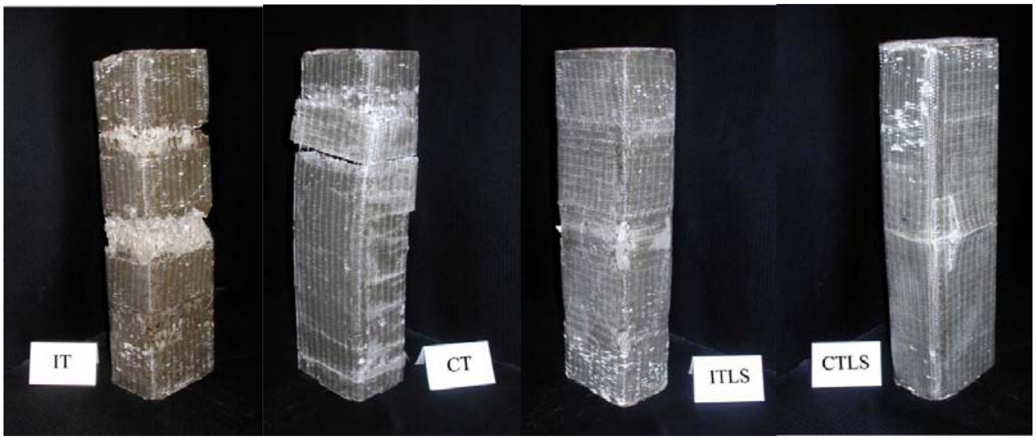
2.4 *Materials*

Concrete used had a 28 day compressive strength of about 20MPa. The use of a low compressive strength allows confining effects that could more than double the capacity of the specimen while still permitting testing to failure with the laboratory equipment.

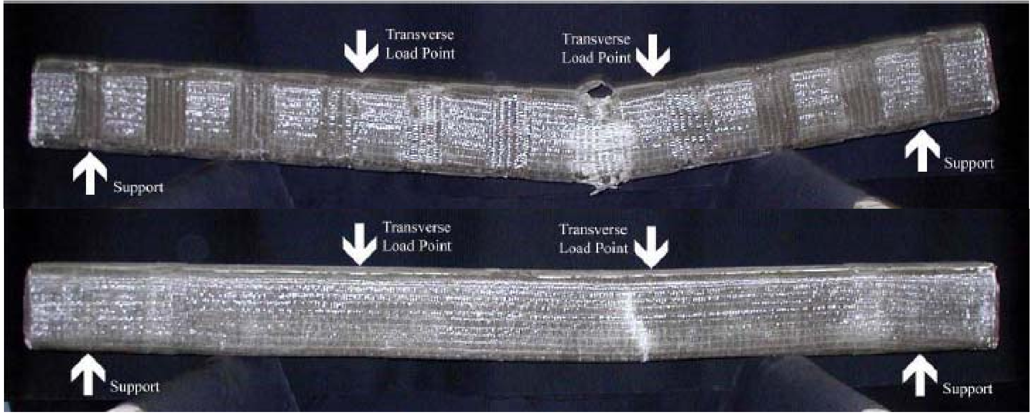
The steel reinforcement had a yield strength of 400 MPa. The GFRP system used was donated by the Sika Corporation: SikaWrap Hex 100G glass fibre sheets in conjunction with Sikadur Hex 300/306 epoxy resin. The GFRP sheets had a thickness of 1 mm (composite), ultimate strength of 600 MPa, an elasticity modulus of 26 GPa, and an ultimate elongation of 2.24% (Sika, 2000).

3 RESULTS & DISCUSSION

The details of individual test results can be found elsewhere (Lankinen 2003). The typical failure modes of the specimens are shown in Fig. 2. Specimens under pure axial load failed by crushing of the concrete with rupture of the GFRP sheets where applicable. Specimens under combined compressive and flexural loading failed by tensile rupture of the GFRP strips followed, in some cases, by crushing of concrete.



a) specimens (stub columns) under pure axial load



b) specimens under combined axial + bending

Fig. 2. Failure modes: a) specimens under pure axial loads, and b) specimens under combined axial + bending

Interaction diagrams for all the specimens are depicted in Figure 2 using the measured data. Four curves are shown in Fig 3. Each curve is plotted using four specimens per group (e.g. Specimen IT0, IT 100, IT200, and IT). The specimens tested can be divided into two groups with similar traits. One group consists of specimens with only transverse GFRP wraps. The other group consists of specimens with transverse and longitudinal GFRP strips. Specimens within each of these groups have similar behaviour. The curves of specimens IT(x) and CT(x) both have a similar moment resistance at 0kN axial load with specimens CT(x) having a greater moment resistance at a given axial compressive load. This relationship is the same for specimens ITLS(x) and CTLS(x), where x=0, 100kN, 200kN. The presence of longitudinal strips increases the moment resistance and decreases the axial load resistance at the balanced condition. Continuous transverse wrap gives higher axial compression resistances than the specimens with intermittent transverse wrap.

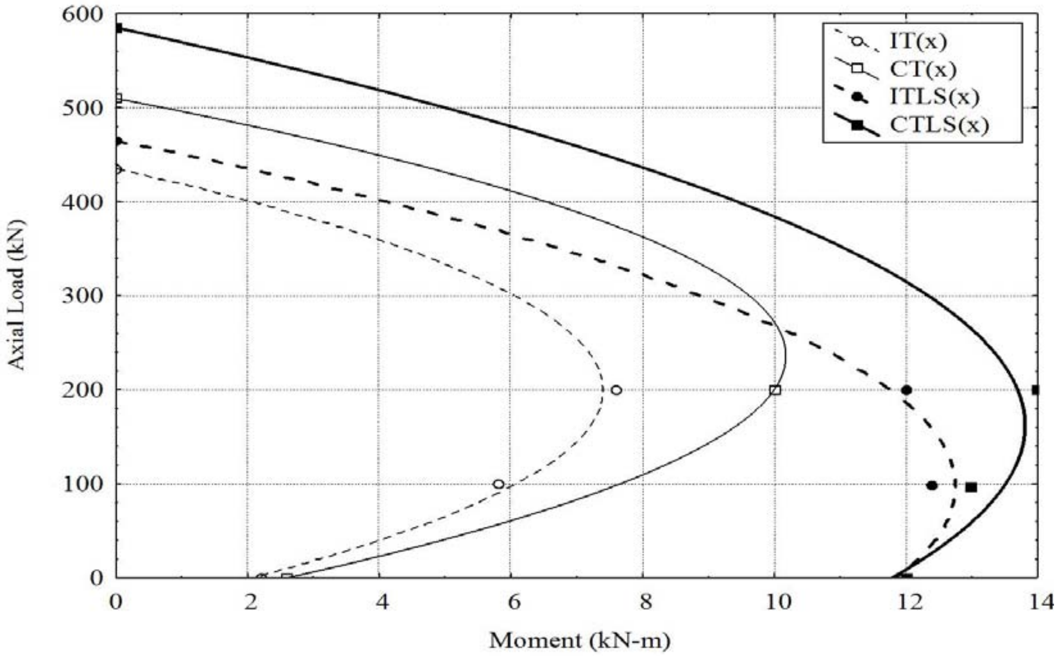


Figure 3. Interaction Diagram for Test Specimens using Measured Data

It is clear that the factor that has the greatest impact on the axial compressive resistance is the presence of transverse wrapping and longitudinal GFRP strips. Continuous transverse wrapping has the greatest impact on axial compressive strength followed by longitudinal GFRP strips. Longitudinal strips slightly increase the compressive resistance due to the restraining effect on the shear plane of the specimen. Specimens with continuous transverse wrap have higher compressive resistances than specimens with intermittent transverse wrap due to the greater confining affect. The longitudinal GFRP strips act to reduce the balanced condition axial resistance since these strips add more tensile resistance during flexure thereby creating a condition where compression failure is most likely.

It is apparent that the factor that has the greatest impact on the moment resistance is the presence of longitudinal strips. Specimens with longitudinal strips have higher moment resistances than specimens without. The next contributing factor is the degree of transverse confinement. Specimens with continuous transverse wrap have higher moment resistances than the specimens with intermittent transverse wrap.

4 CONCLUSIONS

The following conclusions can be drawn:

- Specimens with and without longitudinal GFRP strips have similar pure bending capacities. The specimens with longitudinal GFRP reinforcement have curves with balanced conditions that have higher moment capacities and lower axial compressive resistances than specimens without longitudinal GFRP strips.
- Specimens CT(x) (where x=0, 100 and 200) had the highest axial compressive resistance at the balanced condition of 230kN followed by IT(x), CTLS(x) and ITLS(x) with axial compressive resistances at the balanced condition of 200kN , 160kN and 97kN respectively. The largest influencing factor that increased the axial compressive resistance at the balanced condition was the lack of longitudinal GFRP strips. Specimens with more transverse GFRP confinement had higher axial compressive resistance at the balanced condition.
- Specimen CTLS(x) the highest bending resistance at the balanced condition of 14kN m followed by ITLS(x), CT(x) and IT(x) with bending resistances of 13kN m , 9.2kN m and 7.4kN m respectively. The largest influencing factor that increased the bending resistance at the balanced condition was the presence of longitudinal GFRP strips. Specimens with more transverse GFRP confinement had higher bending resistances at the balanced condition.

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