CHAPTER 8

SUMMARY AND CONCLUSIONS

The experimental study was conducted on the axial and flexural strengthening of CFST columns and beams with externally bonded CFRP sheets and strips to confirm the effectiveness of strengthening technique and also to study the effects of CFRP fabrics on the ultimate strength of retrofitted beams and columns. The test results described in this research work indicate that the externally bonded CFRP composites can be used significantly to increase the load carrying capacity of CFST columns and beams. From the results of experiments, the following conclusions can be drawn.

- The failure of columns without confined by CFRP fabrics was outward buckling at the top on all four sides of the steel tube and furthermore, the crushing of concrete was not occurred in order that the applied load was decreased slowly after the failure load but favourable enhancement in ductility performance was noticed.

- The columns strengthened by 50mm CFRP strips having a spacing of 20mm, were failed by rupture of fibre which was occurred at top edge of the columns and thereafter delamination of fibre due to outward buckling of steel tube was observed on the sides of the CFST.
When the spacing between the CFRP strips is increased, the unwrapped area will become more and resulted in maximum strain during loading and also the sufficient confining pressure was not provided by the FRP composites and due to that the buckling of steel tube was occurred in the unwrapped zone.

The CFST members confined by CFRP fabrics sustained higher ultimate load and larger axial deformation compared to control column and also reinforcement by CFRP laminates significantly increases the strength capacity of the specimens.

The enhancement in axial deformation control of columns with smaller spacing of CFRP strips such as HS-50-20-T1(2), HS-50-20-T2(2) and HS-50-20-T3(1) compared to control column was 23.28%, 52.66% and 85.05% respectively.

The columns HS-50-30-T1(2), HS-50-30-T2(1) and HS-50-30-T3(2) enhanced their axial deformation control by 19.58%, 34.11% and 66.24% respectively.

The axial deformation control of the confined columns increases as the number of layers increases, but the enhancement in axial deformation control was also not proportional. The above nonlinearity in axial deformation control when increasing the number of layers of fibre may be attributed to crushing of resin lying in between the fibres.

The axial stress-strain behavior of columns having 20mm spacing of CFRP strips was outperformed when compared with that of columns strengthened by CFRP strips having spacing of 30mm and 40mm.
The column HS-50-20-T2(2) enhanced their deformation control by 17.13% and 24.64% compared to columns HS-50-30-T2(1) and HS-50-40-T2(1) respectively.

The columns HS-50-30-T3(2) and HS-50-40-T3(2) have more axial deformation (11.7mm and 11.07mm respectively) than that of column HS-50-20-T3(1) furthermore which was 12.6% and 64.08% more than that of HS-50-30-T3(2) and HS-50-40-T3(2).

The external bonding of CFRP strips considerably enhanced the load carrying capacity of the columns, especially the columns strengthened by three layers of CFRP strips in all spacing were outperformed.

The axial load carrying capacity of the confined columns increases as the number of CFRP layers increases but the enhancement in axial load carrying capacity was not proportional.

When compared with control column (CC1), the enhancement in axial load carrying capacity of columns HS-50-20-T1(3), HS-50-20-T2(1) and HS-50-20-T3(3) was found to be 7.92%, 20.44%, and 28.69% respectively.

The specimens HS-50-30-T1(2), HS-50-30-T2(1) and HS-50-30-T3(2) enhanced their axial load carrying capacity by 6.10%, 14.56% and 28.47% respectively when compared to the control column.
In similar manner, the column having 40mm spacing of CFRP strips such as HS-50-40-T1(3), HS-50-40-T2(1) and HS-50-40-T3(2) having 5.88%, 10.59% and 19.05% respectively more load carrying capacity than the control column.

The specimens strengthened by CFRP strips with smaller spacing have more axial load carrying capacity and the increase in axial load mainly depends upon proper designed spacing of CFRP strips.

When compared with the columns HS-50-30-T2(1) and HS-50-40-T2(1), the column HS-50-20-T2(1) is having 5.1% and 8.90% more load carrying capacity respectively.

The increase in load of column HS-50-20-T3(3) was 2.11% and 8.69% more than that of columns HS-50-30-T3(2) and HS-50-40-T3(2) respectively.

The external bonding of CFRP fabrics did not much affect the ductility of the CFST section in addition ductility of the CFST section increases as the number of CFRP layers increases and also the effect of increase in spacing between the CFRP strips on ductility enhancement was not obvious.

When compared to CC1, the columns HS-50-20-T1(3), HS-50-20-T2(1) and HS-50-20-T3(3) enhanced their ductility index by 17.10%, 29.56%, 36.60% respectively.

Until reach the failure load of control beam, all the strengthened beams under three wrapping schemes exhibited
linear elastic behavior followed by inelastic behavior when increasing the load further.

- A good composite action exist between two components were confirmed in the case of beams with full wrapping at the bottom and U-wrapping schemes and no apparent debonding of fibre was identified whereas the beams with partial wrapping exhibited delamination of fibre and were failed even before attaining the ultimate load of control beam.

- The external bondings of CFRP significantly reduce the deflection and also enhance the stiffness of the beam compared to the control beam. The increase in thickness of CFRP fabrics provides considerable tensile strength and that restraining effect control the deflection of the beam.

- The percentage increase in deflection control of beams FWB-L1(3), FWB-L2(3) and FWB-L3(2) are 150%, 166% and 260% respectively when compared to control beam (CB2).

- The specimens PWB-L1(2), PWB-L2(1) and PWB-L3(1) enhanced their deflection control by 130.35%, 153.38% and 200.90% respectively compared to the control beam (CB2) and their axial deformation at the respective failure load of control beam (CB2) was 25.77mm, 23.44mm and 18.78mm respectively.

- The enhancement in deflection control of beams FUW-L1(3), FUW-L2(2) and FUW-L3(1) by 134%, 150% and 256% respectively when compared to the control beam.
The enhancement in deflection control due to an increase in the number of layers was not proportional. The above non-linearity in deflection control may be attributed to crushing of resin lying in between the beam and FRP fabrics.

Out of three wrapping schemes, the beams strengthened by U-wrapping scheme showed better improvement in deflection control compared to the beams strengthened by full wrapping and partial wrapping at the bottom.

The beams FUW-L1(3), FUW-L2(2) and FUW-L3(1) enhanced their deflection control by 4%, 2% and 3% respectively only at the respective failure load of beams FWB-L1(3), FWB-L2(3) and FWB-L3(2) respectively and the beams FUW-L1(3), FUW-L2(2) and FUW-L3(1) were increased their deflection control by 15%, 2% and 17% compared to the beams PWB-L1(3), PWB-L2(3) and PWB-L3(2) respectively.

In all strengthened sections, the presence of CFRP has significantly contributed to the moment carrying capacity and stiffness of the CFST sections, except the beams strengthened by PWB, especially for three layers. And also flexural strength of the strengthened beams increases as the thickness of the CFRP increases.

When compared with control beam (CB2), the increase in moment carrying capacity of beams FWB-L1(3), FWB-L2(3) and FWB-L3(2) were 10.1%, 12.84% and 35.77% respectively.
When comparing the behaviour of beams PWB-L1(2) and PWB-L2(1) to that of control beam CB2, only 6.4% and 4.58% respectively of moment carrying capacity were enhanced.

In all strengthened specimens, the beams strengthened by FUW were sustained higher strength than that of others. The increased strength is attributed to the presence of fibres at the web of the CFST member to resist the applied load initially and delayed the load transfer to the fibre at the bottom and as a result the rupture of fibre was postponed.

The beams FUW-L1(3) and FUW-L2(2) enhanced their moment carrying capacity by 3% and 10.5% compared to beams FWB-L1(3) and FWB-L2(3) respectively.

The beam FUW-L3(1) exhibited 8.1% increase in moment carrying capacity compared to beam FWB-L3(2) even though their load deflection behavior was same.

The control specimens exhibited more ductile nature compared to CFRP strengthened beams and also the ductility of the strengthened specimens decreased when the number of FRP layers increased. This decrease in ductility is due to the sudden rupture of CFRP fabrics and its brittle nature. The beams strengthened by FRP fabrics at the bottom showed better ductility response than that of beams with U-wrapping scheme.

The load deflection curve obtained by numerical simulation for all strengthened beams exhibited linear elastic behavior.
until reach the failure load of control beam followed by inelastic behavior when increasing the load further. In addition to that, behavior of those had good agreement with the experimental results.

From the above observations, it is suggested that those beams subjected to large bending, the partial wrapping is not suitable for strengthening because of sudden delamination of fibre rather than rupture and at the same time, if any appropriate anchorages like bolting or riveting will be provided to avoid debonding of fibre, then it will be turned in to a fine and economical method for strengthening of CFST members.