CHAPTER 7

CONCLUSIONS

7.1 GENERAL

Experimental, theoretical and numerical investigations were conducted to gain increased knowledge on the cumulative damage of CFT and SFRCFT columns subjected to variable and constant lateral cyclic load combined with constant axial load. To simulate the actual behaviour, a simplified numerical model was developed based on finite element package ABAQUS and was validated against the experimental results. The effect of in-fill and diameter to thickness ratio on the ductility factor, energy absorption capacity and damage index of the in-filled columns was studied. A simplified displacement based damage model has been proposed which was validated against the test results available in the literature. Based on the experimental, numerical and theoretical investigations carried out the following conclusions are drawn.

7.2 BEHAVIOUR OF IN-FILLED COLUMNS

In this study, the behaviour of in-filled columns adding steel fibres to the filled concrete in various volume fractions viz. 0.75%, 1.00% and 1.25% was analysed. A detailed experimental programme was carried out. Various loading patterns were adopted to study the behaviour elaborately.
7.2.1 Axial Load Tests

In order to understand the behaviour of CFT and SFRCFT columns under pure compression, axial load tests were carried out. From these tests the following conclusions were drawn.

- There is a uniform increase in ultimate load, ductility factor and initial stiffness with increase in percentage of steel fibres upto 1.00%. However, when the percentage of steel fibres is increased to 1.25%, there is a drastic reduction in ultimate load, ductility factor and initial stiffness. This is due to the balling effect of steel fibres.

- Due to effective confinement and high compressive strength, initial stiffness increases by 1.6 times irrespective of the D/t ratio with increase in volume fraction of in-fill from 0.75% to 1.00%.

- Compared to all other columns, 1.00% SFRCFT columns exhibit significantly improved performance with large ductility, initial stiffness and load carrying capacity.

- Commencement of yielding is much prolonged in SFRCFT columns compared to CFT columns.

- D/t ratio governs the failure mode with local buckling progressing aggressively in thinner tubes compared to thicker tubes.

- EC4 is capable of predicting the theoretical loads conservatively within a margin of 2%.
7.2.2 Variable Amplitude Tests

The conclusions drawn from the tests maintaining a constant axial load and variable amplitude lateral cyclic loading is given below

- All the in-filled columns failed in a ductile manner and showed plump hysteresis loops.
- Major factors affecting the hysteresis behaviour and load carrying capacity of in-filled columns are D/t ratio and mechanical properties of materials.
- Irrespective of the D/t ratio 1.00% SFRCFT columns show enhanced performance exhibiting enhanced ductility, energy absorption capacity, ultimate load carrying capacity and also plumper hysteresis loop.
- With increase in the volume fraction of fibres from 0.75% to 1.00%, more than 60% improvement in ductility and energy absorption capacity of CFT columns can be achieved.
- Specimens with D/t ratio 38 exhibit 1.2 times more ductility and 2 to 2.5 times more energy absorption capacity than specimens with D/t ratio 57 irrespective of the type of in-fill.

7.2.3 Constant Amplitude Tests

From the tests carried out maintaining constant axial load and constant amplitude lateral cyclic loading, the following conclusions are drawn.

- Specimens subjected to lateral drift of 2%, showed virtually no signs of damage or deterioration even upto 50 load cycles,
whereas specimens subjected to lateral drift of 6.0%, failed in less than 15 cycles.

- It is concluded that external forces that impose displacement ductility demands of less than 2.0, in-filled columns can survive a series of similar events without undergoing any significant structural damage. When the ductility demand approaches 4.0, the likelihood of moderate to severe damage is high and this depends on the number of inelastic cycles experienced by the structures.

- In-filled columns with D/t ratio 57 subjected to predominantly high amplitude inelastic cycles, undergo rupture of the steel tube. It is found that threshold low amplitude cycle is approximately 2 to 4 percent drift, while high amplitude cycles are those in excess of 4%.

- The energy absorption capacity of a member at failure is dependent on the drift amplitude. The energy absorption capacity decays with the drift amplitude.

### 7.2.4 Cumulative Damage Model

The following observations are made based on the simplified cumulative damage model developed.

- The simplified displacement based cumulative damage model proposed to predict the damage index of the specimens is found to give reasonably accurate results.

- Damage index of the in-filled columns depends on the type of in-fill and D/t ratio of the steel tube.
• The application of Miner’s linear damage accumulation rule in conjunction with the cumulative damage model of in-filled columns tested in this study provides a reasonable estimation of the damage index of in-filled columns.

• There is good agreement between the energy based damage index and damage index calculated based on the proposed displacement based damage model.

7.2.5 **Failure Modes of Columns Subjected to Lateral Cyclic Loading**

From the cyclic loading tests carried out on CFT and SFRCFT columns, the following observations are drawn regarding the failure modes of in-filled columns.

• All in-filled columns buckled outwardly at the bottom due to crushing of in-fills at the verge of failure.

• The failure mode of the specimens depends on the D/t ratio and is independent of the type of in-fill and loading pattern.

• Rupture of steel tubes is found to occur in the thinner tubes and outward buckling occurs in the thicker tubes.

• Commencement of yielding of the steel tube is very much prolonged in SFRCFT columns as compared to CFT columns.

• Pinching effect is totally absent in SFRCFT columns.

• Irrespective of D/t ratio the location of plastic hinge from the base progressively moves up in columns subjected to constant axial load with constant amplitude lateral loading with increase in the drift ratio.
7.2.6 Numerical Study

A numerical model using ABAQUS was developed to simulate the behaviour of CFT and SFRCFT columns subjected to lateral cyclic loading. From the numerical study carried out the following conclusions are drawn.

- The numerical model developed using ABAQUS software is found to closely simulate the behaviour and failure modes of both CFT and SFRCFT columns.
- The lateral load – deformation behaviour predicted using the finite element model agreed well with the experimental loads with a margin of 1.50%.
- Since the ductility factor, energy absorption capacity and load carrying capacity predicted by the ABAQUS model closely simulate the experimental values, the FE model truly represents the actual behaviour of CFT and SFRCFT columns.

7.3 CONTRIBUTIONS

This study contributes to the area of composite steel-concrete structures in the following ways.

- A simplified displacement based damage model has been proposed for the evaluation of damage index of in-filled circular columns.
- Extensive experimental data has been generated for the strength, stiffness, ductility, energy absorption capacity and damage index of CFT and SFRCFT columns.
The advantages of SFRC in place of PCC as an in-fill for composite columns have been clearly brought out.

A numerical model has been developed using ABAQUS package which closely simulates the actual behaviour.

7.4 SCOPE FOR FURTHER WORK

- Similar experiments can be conducted on sections with different types of fibres, various end conditions and section configurations.

- Behaviour of these elements in the assemblies of frames can also be studied.