CHAPTER 1

INTRODUCTION

1.1 GENERAL

Concrete – filled steel tube (CFT) columns are extensively used in modern structures, mainly due to the combined advantages of the steel tube and the concrete core. However, many researchers cast doubt on the use of plain concrete as in-fill material in steel tubes, due to the extremely disastrous effects of the 1995 Kobe earthquake in Japan on steel and concrete composite structures. This prompted a change of seismic design perspective from the previous emphasis on structural strength to emphasis on structural ductility and energy absorption capacity. Accordingly, the in-fill material inside steel tubes is required to be of the quality as to increase the ductility and energy absorption capacity of composite columns. Many kinds of in-fill materials are used to improve ductility of composite columns. Among the various in-fill materials, steel fibre is gaining attention due to its high flexural strength, tensile strength, lower shrinkage, and better fire resistance.

Recently studies on the behaviour of steel fibre reinforced concrete -filled steel tube (SFRCFT) columns are gaining prominence. Applications have also introduced the use of steel fibre reinforced concrete combined with high strength thin-walled steel tubes with much success. When high strength concrete and thin-walled steel tubes are used together, the more brittle nature of high strength concrete is partially mitigated by the confinement due to the steel tube, and local buckling of the thin steel tube is delayed by the support offered
by the concrete. These structural members are designed to develop a certain amount of inelastic deformation in the event of severe earthquake. However, the members must be able to withstand strong earthquakes without collapse. Compared to static studies, research work on the hysteretic behaviour of in-filled columns is lacking. Until now, studies on the influence of volume fraction of steel fibres on the behaviour of SFRCFT columns have not yet been comprehended.

Further, experimental investigations to study the behaviour of CFT and SFRCFT columns under lateral cyclic load combined with constant axial load are necessary to develop a damage criterion for in-filled columns. With this background, the present study has been initiated to investigate the hysteretic behaviour of in-filled columns under lateral cyclic load combined with constant axial load and the results are discussed in the light of improvement of ductility and energy absorption capacity and development of cumulative damage index of CFT and SFRCFT columns. The study also focuses on the distribution of damage index throughout the loading history by using transmitted energy during loading sequences.

1.2 STEEL - FIBRE REINFORCED CONCRETE (SFRC)

When steel fibres are added to the concrete mix, they are randomly distributed and act as crack stemmers. Concrete being a brittle material, has low tensile strength and ductility, whereas steel fibre reinforced concrete, a two phase composite material, having uniformly distributed steel fibres, has better resistance against cracking, improved strength in shear, tension, compression and flexure with better toughness and ductility properties.

The weak matrix in concrete, when reinforced with steel fibres, uniformly distributed across its entire mass, gets strengthened enormously, thereby rendering the matrix to behave as a composite material with properties significantly different from conventional concrete. The randomly-oriented steel fibres assist in controlling the propagation of micro-cracks
present in the concrete matrix, first by improving the overall cracking resistance of the matrix itself, and later by bridging across even smaller cracks formed after the application of load on the member, thereby preventing their widening into major cracks.

The addition of randomly distributed fibres improves the fracture strength, toughness, impact resistance, flexural strength and fatigue resistance of concrete. Furthermore, debonding and pulling out of fibres requires more energy, resulting in considerable increase in resistance and toughness under static and dynamic, monotonic and cyclic loading respectively. SFRCFT columns also present better fire resistance than CFT columns because of the active confinement of the concrete due to the steel fibres.

The amount of fibres added to a concrete mix is measured as a percentage of the total volume of the composite (concrete and fibres) and is termed as volume fraction ($V_f$). Fibres with a non-circular cross-section use an equivalent diameter for the calculation of aspect ratio (ratio of the length of the fibre, $l_f$ to the diameter of fibre, $d_f$). Increase in the aspect ratio of fibres usually increases the flexural strength and toughness of the matrix. However, fibres which are too long tend to “ball” in the mix and create workability problems. The effectiveness of the steel fibres in arresting the cracks in the concrete matrix are shown in Figures 1.1 and 1.2.

![Figure 1.1 Cracks in PCC](image1.png)  ![Figure 1.2 Absence of Cracks in SFRC](image2.png)
1.3 COMPOSITE ACTION

The composite action between steel and concrete results from the mechanical interlock, friction and adhesion. During low level compressive loading, the Poisson’s ratio of concrete is 0.15 to 0.20, which is lower than that of steel, which is around 0.30. Hence initially the steel tube has no confining effect on the concrete core. However as the load increases, the longitudinal strain increases and the Poisson’s ratio of concrete increases to 0.50.

Due to this, the rate of lateral expansion of unconfined concrete becomes greater than that of steel and a radial pressure gradually develops at the steel-concrete interface. As a result, the concrete core gets confined and hoop tension develops in the tube at this phase. Thus, the steel tube is stressed bi-axially and the concrete core is stressed tri-axially. Hence, for hollow steel columns with in-filled concrete, the load carrying capacity increases significantly. Thus, the corresponding ultimate load becomes higher than the sum of the ultimate loads that can be achieved by steel and concrete acting independently.

1.4 CYCLIC BEHAVIOUR

Experimental and analytical work carried out to understand the cyclic behaviour of columns has been primarily limited to more common and deleterious effects of cyclic shear and bending rather than cyclic axial compressive loads. When a circular concrete in-filled steel section is subjected to bending in one direction, the part of the section under compression develops local buckling outwards.

As the moment is increased, the local buckling spreads along the circumference of the tube, due to the absence of the web to arrest the spread like in rectangular concrete in-filled steel sections. If a moment is applied in
the opposite direction, a similar local buckling develops and finally merges with the previously developed local buckling to form what is known as a ring type local buckling. The formation of a ring type local buckling not only enhances the ductility of circular concrete-filled steel sections but also causes progressive collapse under moderate but long duration earthquakes. This is because, when cycled at small amplitudes, the side, which buckles first, tends to have a lesser strength as compared to the opposite side. As a result, the deformations on that side increase progressively leading to collapse.

1.5 SCOPE OF THE INVESTIGATION

Cyclic loading studies on in-filled columns so far have focused on standard loading protocols with varying drift amplitude to obtain the cyclic behaviour, without considering the effects of amplitude and number of cycles on damage accumulation. The overall buckling of in-filled columns is relatively simple, but the complexity increases with failure modes under the combination of axial load and lateral cyclic load and due to the properties of the in-fill material.

For the design of concrete in-filled sections, Eurocode 4 is widely used. The present design methods and approaches are limited with respect to the property of in-fill as well as to their accuracy. Though design rules are available for specific situations regarding local and post buckling behaviour of hollow and Plain Cement Concrete (PCC) in-filled steel columns, enhanced knowledge and design approach for in-filled columns subjected to lateral cyclic loading seems to be lacking. Addition of steel fibres to the concrete will enhance the ductility property, which is an added advantage for structures to be used in seismic prone zones.

Studies are needed to assess and quantify the ductility enhancement and cumulative damage accumulation process when fibres are added to the
concrete in-fill. The process of developing a test program that addresses these concerns is a challenge in itself. Hence tests on CFT columns and SFRCFT columns under variable and constant lateral cyclic loading combined with constant axial load is required for the complete understanding of the cumulative damage process.

Therefore issues related to correlation of observed hysteretic behaviour to damage of in-filled columns are found to be necessary to model and calibrate the cumulative seismic damage. The effort described here is an initial step in this direction in which the system variables and measured response were tailored to model and calibrate the cumulative seismic damage.

1.6 OBJECTIVE OF THE INVESTIGATION

CFT and SFRCFT columns under constant axial load with variable amplitude as well as constant amplitude lateral cyclic loading have been tested to failure. The following are the objectives of this investigation

- To study the hysteretic behaviour and compare the effect of diameter to thickness ratio and the influence of SFRC as in-fill on the ductility and energy absorption capacity of in-filled columns.

- To develop a numerical model using finite element method to simulate the behaviour of in-filled columns under cyclic loading.

- To review the existing codal recommendations and compare them with the experimental results.

- To propose a simplified cumulative damage model for the evaluation of damage index of CFT and SFRCFT columns.
1.7 ORGANISATION OF THE THESIS

The thesis consists of seven chapters.

**Chapter 1 Introduction** presents the problem under investigation in detail. The need for the present investigation, the scope of the investigation and organization of the thesis are presented.

**Chapter 2 Literature Review** reviews the experimental, theoretical and numerical investigations carried out in the past two decades on in-filled columns subjected to various load conditions.

**Chapter 3 Theoretical Investigation** discusses the various codal recommendations for concrete in-filled sections under axial compression.

**Chapter 4 Experimental Investigation** provides the details of the experimental investigation carried out.

**Chapter 5 Numerical Investigation** presents the details of finite element modeling carried out using the finite element package ABAQUS version 6.5 (2005).

**Chapter 6 Results and Discussion** documents the results and discussions of the entire experimental, theoretical and numerical work carried out.

**Chapter 7 Conclusions** summarizes the detailed summary of the conclusions drawn from the present work, contributions and scope for further work. The list of references is given at the end of the thesis.