CHAPTER 1

INTRODUCTION

1.1 GENERAL

The recent earthquakes in different parts of the world revealed the importance of the design of reinforced concrete structures with high ductility. Strength and ductility of structures mainly depends on proper detailing of reinforcement in beam-column joints. Under seismic excitation the beam-column joint region is subjected to horizontal and vertical shear forces whose magnitudes are many times higher than those under normal circumstances. Conventional concrete loses its tensile resistance after the formation of cracks. However, fibre concrete can sustain a portion of its resistance following cracking to resist more cycles of loading.

Beam-column joints have a crucial role in the structural integrity of the buildings. For this reason they must be provided with adequate stiffness and strength to sustain the loads transmitted from the beam and columns. The formation of plastic hinges on columns must be prevented since it affects the entire structure. For adequate ductility of beam-column joints, use of closely spaced hoops as transverse reinforcement was recommended in ACI-ASCE Committee 352 – 2002 report. Because of congestion of reinforcement, casting of beam-column joint will pose difficulties and lead to honey combing in the joint region of concrete.

ACI Committee 352 recommends the design aspects of different types of beam column joints, calculations of shear strength and reinforcement details to be provided. However the recommendations are not intended for fibre reinforced concrete. Review of literature indicates that numerous studies were conducted in
past to study the behavior of beam column joints with normal concrete. All the studies are carried over is limited to normal strength concrete and recent studies indicate that improvements in the behavior of beam column joints are possible through the use of fibre reinforced concrete and other supplementary cementitious materials.

1.2 EXAMPLES OF BEAM-COLUMN JOINT FAILURES IN PAST EARTHQUAKES

A lot of examples can be found where beam-column failed with inadequate reinforcement in transverse direction.

1.2.1 Turkey earthquake, 1999

![Figure 1.1 Failure of Exterior Beam - Column Joint](http://architizer.com/blog/turkey-to-seismic-proof-all-of-the-countrys-20-million-homes)

**Source:** (http://architizer.com/blog/turkey-to-seismic-proof-all-of-the-countrys-20-million-homes)

**Figure 1.1 Failure of Exterior Beam - Column Joint**
On 19 August 1999 at 14:16 and 15:18 UTC (5:16 and 6:18 PM local time), two light-to-moderate earthquakes with magnitudes of 4.8 and 5.0 occurred approximately 80 km to the west of the main shock. Previous aftershocks of this size were centered to the east of the main shock, further from the cities of Bursa and Istanbul. Some of the aftershocks may be large enough to cause additional damage. Buildings that have already been damaged by an earlier earthquake are at highest risk from damage due to a future aftershock.

Figure 1.1 (http://architizer.com/blog/turkey-to-seismic-proof-all-of-the-countrys-20-million-homes) demonstrating a good example of this failure mode. Most of these joints showed brittle shear failures, due to non-ductile performance, either due to poor anchorage of the main reinforcing bars or simply inadequate transverse reinforcement in the joints, of reinforced concrete moment-resisting frames.

1.2.2 Gujarat Earthquake -2001

Many structural damages can be seen in major cities like Bhuj and Gandhidnam during Gujarat earthquake in the year 2001. Figure 1.2 shows a two storey commercial building failure in Gujarat. (http://www.st.hirosakiu.ac.jp/~tamao/Gujarat/web/Gujarat_7_1.pdf). The building is designed and the space is used for commercial purpose. In column the anchoring of the reinforcement in beam column cannot be secured in a short direction and some of the beams have been completely pulled out from beam-column joints. In comparison with second floor, the ground floor is not having enough stiffness, strength in short direction and swayed in the opposite direction.
**1.2.3 West Sumatra Earthquake -2007**

A powerful earthquake occurred in west Sumatra on March 6, 2007. It reflected a lot of severe damage in buildings. Figure 1.3 (http://www.newworldencyclopedia.org/entry/Earthquake) shows the failure of beam-column joints. From the site investigations, it is concluded that the frames were constructed without ductile detailing. The reinforcement provided in the column is not sufficient in quantity as well as development length. Also, the column is failed in shear due to unconfined condition in the joint.

**Source:** (http://www.newworldencyclopedia.org/entry/Earthquake)

*Figure 1.3 Failure of Beam Column Joint in west Sumatra earthquake*
In 1970s, all the buildings have been identified due to the absence of adequate seismic design and detailing for ductile behavior. Experimental findings on R.C. frames show the excessive damage failure of exterior beam column joints which lead to the collapse of a building. The poor joint behavior in old buildings can be attributed to the inadequate provision of shear reinforcement in joint, particularly poor bond properties and deficient anchorage detailing in the joints.

1.2.4 West Sumatra Earthquake -2007

On March 6, 2007, a powerful earthquake hit the Indonesian island of Sumatra. It resulted in 70 fatalities, 500 injuries and severe damage or collapse of nearly 15,000 buildings.

Figure 1.4 (http://www.newworldencyclopedia.org/entry/Earthquake) shows the failure of beam-column joints of the concrete moment frames which was constructed without ductile detailing. The reinforcement steel did not extend sufficiently into the joint, nor did it have adequate development length. Furthermore, the joints were not confined and hence were susceptible to shear failure.

Source : (http://www.newworldencyclopedia.org/entry/Earthquake)

Figure 1.4 Failure of Beam Column Joint in West Sumatra Earthquake
The vulnerabilities of pre-1970s RC buildings have been identified to be due to the absence of adequate seismic design provisions, capacity design considerations and detailing for ductile behavior. Experimental works on sub assemblages and R.C frames have shown that the excessive damage or failure of beam-column joints, in particular exterior (or corner) joints, can lead to the global collapse of a building. The poor joint behavior of older construction can be attributed to the inadequate shear reinforcement in joint region, the poor bond properties of plain round bars reinforcement (commonly used prior to 1970s) and the deficient anchorage details into the joint region.

1.2.5 China Earthquake 2008

A 7.9 magnitude Wenchuan earthquake (named after its epicenter in Wenchuan Country) Jolted Sichuan Province of China on 12 May 2008. Many buildings in Sichuan had inadequate construction quality including insufficient reinforcement, poor detailing and poor quality concrete. Some of the poor detailing includes lack of reinforcement in transverse ties and embedment length for reinforcement anchorage in the beam column joint. Closely spaced transverse reinforcement in the form of closer ties with 135° hooks provides concrete confinement, buckling restraint of longitudinal reinforcement and additional shear capacity, which improve the nonlinear performance.

1.2.6 Observations on past earth quakes

Observations are failure of structures due to seismic effects. The poor detailed in the joint region was observed main reason for failure. This includes lack of reinforcement, lack of ties laterally embedment length and performance of concrete in the joint region.

1.3 RESEARCH OBJECTIVES

The knowledge of design of reinforced concrete structure is very essential in carrying of anticipated loads acting on the structures during the life span
especially lateral forces like earthquake. To achieve this performance level, special provision of steel reinforcement details are required in the critical zone of beam-column joint of reinforced concrete bare framed structures. To ensure the ductility characteristics of concrete, considerable amount of lateral reinforcement is necessary in the beam-column joint region and thereby allowing the formation of plastic hinge in the beams near the column faces.

By considering the practical approach of “Weak beam - Strong column” is very much desired because of reinforcement installation and workability of concrete in beam column joint regions. The overlapping of reinforcement in beam column joints forms complex nature, the placing and compaction of concrete is very difficult. Under these circumstances research is necessary to investigate the alternative solution to achieve the ductility characteristic of concrete at very low cost.

From the review of literature survey, the use of fibres in concrete is having a good potential in this direction. Steel fibre and Polypropylene fibre show some promise in this direction. By adding these types of fibres in concrete as secondary reinforcement in the beam column joints, certain characteristic of concrete like ductility, stiffness, energy absorption capacity can be improved at a very low cost.

Previous experimental researches were conducted on conventional concrete specimens with Fibre Reinforced Concrete. The present study deals with High Performance Reinforcement Concrete detailing and incorporated with metakaolin and fibres of Steel and Polypropylene in the bare frame. The reinforcement detailing is followed as per IS: 456-2000 and IS: 13920-1993 code provisions. The addition of Steel and PolyPropylene fibres along with concrete in frame against cyclic loading has increases the ductility and energy absorbing capacity. These fibres may contribute to the reduction of damage against failure due to earthquake, thereby contributing the reliable and durable structures.
1.4 ORGANISATION OF THE THESIS

This thesis comprises of nine chapters.

**Chapter one** gives a brief introduction to the investigation carried out and explains the research significance of the present investigation.

**Chapter two** presents an overview of studies in the field of seismic behavior of beam-column joints with and without inclusion of various fibre in reinforced concrete. Also, the finite element modeling of beam-column joint by ANSYS has been critically discussed.

**Chapter three** describes the properties of various materials used in this work, the specimen details, along with test setup of experimental works and methodology used.

**Chapter four** describes the basic tests on High Performance Concrete and the relationship between the statics modulus of elasticity, modulus of rupture and compressive strength are established by experimental investigations to compare the results with codes of various countries and their validity have been discussed.

**Chapter five** summarizes the experimental behavior of various parameters like lateral deflection, strength, stiffness, ductility, and energy dissipation capacity of Reinforced Concrete Bare Frame (RCBF).

**Chapter six** summarizes the experimental behavior of various parameters like lateral deflection, strength, stiffness, ductility, and energy dissipation capacity of Steel Fibre Reinforced Concrete Bare Frame (SFRCBF).

**Chapter seven** summarizes the experimental behavior of various parameters like lateral deflection, strength, stiffness, ductility, and energy
dissipation capacity of Polypropylene Fibre Reinforced Concrete Bare Frame (PPFRCBF).

Chapter eight discussions and comparison of the experimental results with ANSYS model.

Chapter nine based on the results of this research investigation, Summarizes the conclusions and recommendations are given for further research.

1.5 SUMMARY

This Chapter overviewed about beam column joint with examples of beam column joint failures in past earthquake. Research objectives are highlighted. Organization of thesis is presented with details.