CHAPTER 1

INTRODUCTION

1.1 GENERAL

Generally reinforced concrete structures in high seismic prone zones are analyzed as moment resisting frames and the beam-column joints are assumed as rigid. Joints are the weakest links in structural systems. In Indian practice, the joint detailing is usually neglected for specific design with attention restricted to provision of sufficient anchorage for longitudinal beam reinforcement. As per ACI-352 code, lot of valuable work has been done in this area very recently. However, improvement is much needed in our understating of joint behavior and existing detailing practices. The joints are severely damaged as they are very vulnerable to earthquakes. As repairing these damaged joints are difficult, the damage to the structure must be avoided. Thus, beam-column joints must be designed and same to be detailed to resist earthquake effects. This study makes the awareness of beam-column joints design and detailing to the designers.

1.2 MOTIVATION OF THE STUDY

Proper anchorage of reinforcement is vital to enhance the performance of beam-column joints for the earthquake load resisting structure. Congestion of reinforcement and construction difficulties are frequently reported while using conventional reinforcement detail in beam-column joints of reinforced concrete structures and also American Concrete
Institute (ACI)-352 recommends additional research on use of T-headed bar (mechanical anchorage) in the design of beam-column connections in concrete structure. An effort has been made to study and evaluate the performance of RC beam-column joints.

Reinforced concrete (RC) buildings designed before the mid-1970s may have serious structural deficiencies and are considered substandard according to current seismic design criteria. Specifically, the failure of the beam-column joints has been the reason of building collapse in many recent earthquakes worldwide. Earthquake load causes the structural analysis one of the most challenging problem in engineering. Special design with detailed measures are required to resist the earthquake force. The main points of vulnerability are beam-column joints, anchorage failure of main reinforcing bars in beams and columns, shear failures in columns. This study makes the designers aware of the theoretical background on the design and detailing of beam-column joints highlighting importance. Based on this, some of the past disastrous failures reported in the earthquakes so far are indicated in Section 1.3.

1.3 GENERAL DISCUSSION ON THE PAST DISASTROUS FAILURES STRUCTURES CAUSED BY EARTHQUAKES

When the reinforced concrete structure frame is subjected to earthquake, loading joints are severely damaged and repairing the damaged joints is difficult so damage must be avoided. Some of the past disastrous failures structures due to earthquakes so far are indicated below.

Turkey Earthquake: 1999, August 17

In the Izmit, Turkey, earthquake (Sezen et al 2000), several reinforced concrete (RC) moment resisting frame buildings structure experience damage at beam-column joints as shown in Figure 1.1; it is
apparent that no transverse hoops are present in the joint.

Figure 1.1 Severe damage to RC framed structure beam-column joints
(in the Izmit, Turkey, Earthquake of August 17, 1999, Sezen et al 2000)

In one case, the collapse of a RC building structure was attributed
Figure 1.2 Collapse of RC building due to failure of beam-column joints
(In the Izmit, Turkey, earthquake of August 17, 1999, Sezen et al 2009)

Figure 1.3 Failures in beam-column joints
(In the Izmit, Turkey, earthquake of August 17, 1999, Sezen et al 2009)
Greece Earthquake: 1999, September 17

In the Athens, Greece, earthquake of September 7, 1999 (EERI 1999b), the beam-column joints of RC framed structure had no joint confinement reinforcement hoop bars, as shown in Figure 1.5.
Taiwan Earthquake: 1999, September 27

The failure of beam-column joint was the cause for the partial collapse of a 15-story building as shown in Figure 1.6 in the 1999 Chi-Chi, Taiwan, earthquake (Uang et al 1999, EERI 1999c); poor transverse reinforcement in the beam-column joint region was the major reason for the collapse. In another instance, inadequate beam-column joint confinement caused a 22-storey building tilted as shown in Figure 1.7, and the building had to be demolished (Uang et al1999); buckling of the longitudinal column bars is evident.

Figure 1.6  Damage to partially collapsed 15-story building: beam-column joint failure
(In the Chi-Chi, Taiwan, earthquake of September 21, 1999, Uang et al 1999, EERI 1999c)
Figure 1.7 Damage to 22-story building beam-column joints
(In the Chi-Chi, Taiwan, Earthquake of September 21, 1999, Uang et al 1999)

Figure 1.8 School collapse due to failure at exterior beam-column joints
(Taiwan Earthquake, September 1999)
Venezuela Earthquake: 1967, July 29

The reinforced concrete framed structures failure is the main cause of inadequate joint confinement and anchorage of beam longitudinal reinforcement to the column as shown in Figures 1.8-1.9.

![Figure 1.9 Exterior beam-column joint failure of RC structure](image)

**Figure 1.9 Exterior beam-column joint failure of RC structure** (Residence petunia no.2, Caracas, Venezuela earthquake, South America, July 29, 1967 Magnitude: 7.5, NISEE)

Indonesia Earthquake, 2009

Severe damage on the reinforced concrete framed structures beam–column joints failure are caused due to poor detailing and inadequate joint confinement as shown in Figure 1.10.
In this case, hoops were not used in the joint and this lead to the failure. Similar damages of beam-column joint were investigated in Sichuan Earthquake, China, 2008 (Figure 1.11), and in
L'Aquila Earthquake, Italy, 2009 (Figure 1.12).

![Image of failure of beam-column joint](image)

**Figure 1.12 Failure of beam-column joint**  
(L'Aquila Earthquake, Italy, 2009)

Mexico, Earthquake 1999 June 15

![Image of inadequate detailing of joint](image)

**Figure 1.13 Inadequate detailing of joint**  
(In the Tehuacan, Mexico, earthquake of June 15, 1999. EERI 1999)
Tohoku-chiho Taiheiyo-oki Earthquake in Sendai, Japan 2011

Figure 1.14 Joint shear failure of beam-column joints

The damage is reported (Shiohara et al 2011) for a nine-story RC residential building in Sendai as shown in Figure 1.14 (N-building) designed and constructed in 1969 by old design codes. The shear failure of beam-column joints were observed to the joints which conforms to the current seismic design codes.

1.4 SUMMARY

The exterior joints of reinforced concrete buildings are vulnerable to failure. Interior joints with beams framing on all four sides are less vulnerable due to the confinement provided by the beams. Failure of a joint can result in redistribution of gravity loads to neighboring joints (and columns) and progressive collapse of the building. Many of the RC framed structure beam-column joints collapses due to lack of adequate anchorage and transverse reinforcement which can be vulnerable to shear failure; unconfined beam-column joints core can also experience axial failure beam-column joints. Generally in older concrete frame buildings, there is no proper joint reinforcement detailing and this leads to failure of the joint failure.