CHAPTER – 2
LITERATURE REVIEW

2.1 GENERAL

This chapter deals with the previous research works related to the behavior of beam column joint under earthquake loading. Experimental study on the different types of fibres and their effect on the behavior and strength of the beam column joint. Also it deals with finite element modeling of concrete structures, particularly in ANSYS finite element package as reported by various authors has been presented in respective sequence. The following is the order of the presentation of the literature reviewed.

 ✓ Behavior of beam-column joints in bare frame under earthquake loading
 ✓ Seismic behavior of High Performance Concrete (HPC)
 ✓ Seismic behavior of Steel Fibre Reinforced Concrete
 ✓ Seismic behavior of Polypropylene Fibre Reinforced Concrete
 ✓ Seismic behavior of Hybrid Fibres (Steel and Polypropylene fibre) Reinforced Concrete
 ✓ Finite element modeling of fibre reinforced concrete by ANSYS
 ✓ Summary of literature review
2.2 BEHAVIOUR OF EXTERIOR BEAM-COLUMN JOINTS UNDER EARTHQUAKE LOADING.

Lee et al. (1977) investigated the behavior of six beam-column joints designed according to ACI-ASCE committee 352. The test variables were the quantity of transverse reinforcement, magnitude of axial load on the column and severity of loading. They have concluded that the cracks were formed on each specimen in their joint and beam portion and they were more numerous and severe in specimen without axial load. Their results also indicated that there was slightly higher initial stiffness in the specimen with column axial load and lower stiffness in specimen without column axial load. The shear resisting capacity was also increased by an increase in the transverse reinforcement.

Uzmeri (1977) carried out experimental study on the behavior of eight reinforced concrete beam-column joints subjected to slow load reversals simulating seismic loading. Variables were the quantity and size of joint reinforcement and stress strain characteristics of joint steel. It is reported that the assumption of rigid beam-column joints could give invalid results. It suggested that the use of joint reinforcement with flat yield plateau might be undesirable for confinement. It is recommended that joint stirrups should be extended above and below the beam steel at same spacing as in the joint for a distance of at least half the core dimension to prevent premature failure in the column joint stirrups above or below the beam.

Abrams (1987) conducted tests on eight small-scale joints, four medium-scale joints and six large-scale joints. Specimens were subjected to reversals of lateral force to study scale correlations for nonlinear hysteresis properties. It was concluded that stiffness deterioration was the highest for small-scale specimens as a result of weaker bond between model reinforcement and mortar. One-quarter scale specimens showed force deflection response similar to those of large-scale specimens. It was recommended that minimum usable scale for testing of 1/4 scale model.
Kumar et al. (1991) carried out experimental works on exterior beam-column joints. They tested twenty three specimens simulating typical exterior beam-column joints subjected to axial compression and uniaxial bending. The effects of column axial load, grades of concrete in beam and column, transverse reinforcement of beam and column on the performance of joints were studied. The steel-column shoe with a groove at the Centre to hold a steel ball was fixed at each end of the column to provide a ball joint for simulating the ends are held in position. A hydraulic jack with proving ring was used to apply the load at the beam end. The lower end of the column was placed through a ball joint on a 50-T hydraulic jack. The upper end of the column was supported under the steel girder. It was reported that the efficiency of joints increases with the increase in axial load on column for the same grade of concrete in beam and column and richer grade of concrete in column. However the trend was reverse when the concrete grade of beam was richer than that of the column.

Gencoglu.etal (1993) is reported the strengthening of the deficient RC Exterior beam-column joint using CFRP under the cyclic loads that simulate seismic excitation. To strength the deficient external beam-column joints, CFRP fabrics attached on the exterior surface of concrete was extremely effective on the ductility, absorbed total, dissipated and recovered energy in addition to ultimate displacement and load carrying capacity. The experimental test result indicates that the strengthening method shifted the localization hinge of specimen to the beam and mode of failure of beam-column joints could be directly affected.

Hwang and Lee (1999) proposed a method to determine the shear strengths of exterior beam-column joints for seismic resistance. The method termed as the softened strut-and-tie model, is based on the strut-and-tie concept and derived to satisfy equilibrium, compatibility and the constitutive laws of cracked reinforced concrete. They checked the accuracy of the proposed
procedure by comparing calculated shear strengths with experimental data reported in previous literature.

Thirugnanam et al. (2001) reported about the ductile behavior of SIFCON structural members. Tests were carried out on single span beam and multi-bay multi-storey R.C frame with SIFCON beam-column joints to study the structural response of the frame under cyclic loading. They mixed 8% of volume of fibre with the concrete in the joint region. They reported that the use of SIFCON in the hinging zones of the R.C structure increases the first crack load by 40%, ductility by 100% and energy absorption capacity by 50%.

Kumar et al. (2002) carried out experimental study to clarify the effect of joint detailing on the seismic performance of lightly reinforced concrete frames. The parameters studied were the effect of joint rotation, column axial load, cross reinforcement in the joint and percentage of longitudinal reinforcement in the beam. About eight T-shaped beam to column joint subassemblies designed and detailed as per IS:13920-1993 were tested under cyclic loading. They found that use of cross reinforcement in the joint reduced damage in the joint but also reduced the ductility and energy dissipation capacity. The test results indicated that presence of axial load in column and allowing free joint rotation not only increased the strength and ductility but also reduced the damage in the joint region. Hence it was concluded that ductility and energy dissipation capacity increased with a decrease in the percentage of longitudinal reinforcement.

Pampanin et al. (2002) carried out experiments to investigate the inherent seismic vulnerability of reinforced concrete beam-column connections designed for gravity load only. Experimental tests on six 2/3 scaled beam-column joints, with structural deficiencies, designed only for gravity load, were performed under simulated seismic loads. It was reported the significant vulnerability of the joint panel zone region and the critical role of the slippage phenomena due to the use of smooth bars and of inadequate anchorage. It was observed to have a
particular “concrete wedge” brittle failure mechanism, due to the interaction of shear cracking and stress concentration at the hook anchorage location, in the exterior beam-column joint specimens.

Murthy et al. (2003) reported the experimental evaluation of effectiveness of different details of longitudinal beam bar anchorage and transverse joint reinforcement in exterior beam-column joints of moment resistant frames. Twelve specimens were tested with four different arrangements for anchorage of beam longitudinal bars namely Type P, Type Q, Type R and Type S and three different arrangements of reinforcement in joint regions namely Type 1, Type 2 and Type 3. The test results indicated that among all, the specimens with joint reinforcement Type 2 were the most effective and that if provided additional strength to the specimens beyond cracking and reduce the strength deterioration. The Type R specimens (with full anchorage of longitudinal beam bars) provide the best performance consisting the strength and ductility of specimens. It was concluded that of all the joint reinforcement detailing schemes investigated, the ACI standard hook with hairclip-type transverse reinforcement was a preferred combination because of its ease of construction and overall effectiveness.

Liang and Montesano’s (2004) presented results from tests of four reinforced concrete RC column-steel (RCS) beam subassemblies under large displacement reversals and dynamic analyses of RCS systems under various ground motions. The test specimens were designed following a strong column-weak beam philosophy and a deformation-based capacity design method for the connections. Results from this research shows that RCS frame systems perform satisfactorily under seismic excitations. It was reported that test specimens have good strength and stiffness retention capacity with excellent energy dissipation up to displacement levels of approximately 5.0% drift.

Au et al. (2005) reported about a new detailing especially developed for low to medium seismicity, which involves the use of additional diagonal bars in
the joint. They conducted cyclic load test on six half scale interior beam-column subassemblies with different joint details. From the results they reported that the joints containing the newly proposed details, with or without axial load in the column, exhibit better behavior at the lower range of ductility factors in terms of higher load carrying capacity, greater stiffness and less strength degradation.

Rajesh Prasad et al. (2005) reported about the dynamic response of gravity-designed reinforced concrete connections. Six tests were conducted on full scale specimens, which were subjected to reverse cyclic displacements applied at different speeds varying from slow quasi-static loading to high-speed dynamic loading as fast as 20 Hz. It was concluded from their experiments that maximum joint shear failure occurred due to lack of transverse hoops inside the joint cores. The damage patterns and failures of the specimens showed a better correlation with the residual storey shear stiffness than with the loss of storey shear strength during the repeated cycles.

Asha and Sundararajan (2006) have presented the behavior of external beam column joints with detailing as per IS 13920:1993 under seismic conditions. The primary variable was the type of confinement in the joint region extended from the column. Four types of confinement namely, square hoops, square spiral, circular hoop and circular spiral were used. For strain controlled testing, screw jack was used to apply displacement load at beam end. Column ends were fixed to pivot assembly. The loading programming consisted of a simple history of reverse symmetric displacement of increasing amplitudes. The test specimens were evaluated in terms of load-displacement relation, ductility, stiffness, load ratio and cracking pattern. It was reported that exterior beam-column joint with square spiral in the joint region was the most effective of all the specimens tested.

Uma and Meher Prasad (2006) studied the behavior of beam-column joint. They presented a review of the postulated theories associated with the
behavior of joints. It was suggested that in seismic design, the damages in the form of plastic hinges are accepted to be formed in beams rather than in columns. It was reported that the factor impacting the bond transfer within the joint appears to be well related to the level of axial load and the amount of transverse reinforcements in the joints. The functional requirement of a joint, which is the zone of intersection of beams and columns, is to enable the adjoining members to develop and sustain their ultimate capacity. The demand on this finite size element is always severe especially under seismic loading. The joints should have adequate strength and stiffness to resist the internal forces induced by the framing members. The high internal forces developed at plastic hinges cause critical bond conditions in the longitudinal reinforcing bars passing through the joint and also impose high shear demand in the joint core.

Alexandors and Tsonos (2007) conducted experiments to study the cyclic load behavior of reinforced concrete beam-column joint of modern structures. They examined the seismic performance of four one-half exterior beam-column joints. The four sub assemblages were designed and constructed in turn, according to Eurocode 2 (E1) and Eurocode 8 (E2), according to ACI 318R.02 (A1) and according to Greek Earthquake Resistant Code. The sub assemblages were subjected to cyclic lateral load histories so as to provide the equivalent of severe earthquake damage. It was reported that A1 and E2 beam column joint performed satisfactorily during the cyclic loading sequence to failure allowing the formation of plastic hinges in their adjacent beams. The joint E1 and G1 performed poorly under reverse cyclic loading. They indicated that the current design procedures could sometimes result in severe damage to the joint, despite the use of a weak girder-strong column design philosophy.

Kaltakchi et al. (2007) studied the effect of column cross section to frame ductility in R.C. frames. A 2 bay, 2 storeys, 1/3rd scale reinforced concrete frame specimens were tested under reversed- cyclic lateral loading with low level axial loading. Analytical studies were carried out by push over analysis.
From the analytical and experimental test results, it was concluded that the frame lateral ductility was related with column cross section.

Jachong and Lafave (2008) prepared an extensive database of the reinforced concrete beam-column connection test specimens exhibiting joint failure when subjected to reverse cyclic lateral loading. They collected the data of about 341 experimental sub assembles in total from all over the world. It was suggested joint shear strength and deformation models indicate that RC joint shear capacity under reverse cyclic lateral loading is mainly dependent on concrete compressive strength, beam reinforcement and joint transverse reinforcement.

Bindhu.etal(2009) conducted test on 4 sets of specimens having different reinforcement pattern at the joint subjected to reversal loadings. Also observed the failure mode of yield and ultimate strength of the joint. As per IS: 13920-1993, the reinforcement detail of the beam-column joint with and without diagonal confining bars and IS: 456-2000, the reinforcement details of the beam-column joint with and without diagonal confining bars are considered for the specimens. The joints of the assemblages were subjected to both axial and reverse cyclic loads. The crack and failure mode of all the specimens were observed. The results indicate that, the specimens with inclined bars as confining reinforcement exhibited higher strength and minimum cracks in the joint. Also, the contribution of concrete to the total load was about 20% whereas that of steel was around 80%.

Rajaram.etal (2010) conducted a test on behavior of interior RC beam-column joints subjected to cyclic loading. A two bay five storey RC moment resisting frame has been analyzed and designed in Staad pro. A proto type 1/5th scale of beam-column joint model was tested under cyclic loading. Analytical model has been carried out by Ansys software. Ductility, Energy absorption and stiffness parameters were studied. The test results show that the behavior of
interior beam column joint model has been similar to that analytically predicted one.

Bindhu.etal (2010) investigated the effect of cross inclined bars at the joint as confining reinforcement on the behavior of exterior beam-column joint subjected to earthquake loading. Four specimens were cast. Group A comprises of 2 joint assemblages with joint detailing as per IS: 13920-1993 with 2 axial load cases and Group B comprises of 2 joint assemblages with cross inclined bars as confining reinforcements as per IS:13920-1993 with 2 axial load cases same as that of Group A. Analytical study was carried out by ANSYS. The experimental results and analytical study indicate the additional cross bracing reinforcements improves the seismic performance.

Bindhu.etal (2010) presented the study of seismic resistance of exterior beam column joint with diagonal collar stirrups. In the study four numbers of 1/3rd scaled exterior beam-column joint specimens were prepared with and without addition of diagonal collar stirrups at joint as per IS: 13920-1993 for seismic design. All the specimens were subjected to similar type of reverse cyclic loading by displacement control mode. Experimental findings shows that the additional beam reinforcements and diagonal collar stirrups at joints exhibits a better performance than the others.

Balthasar Novak.etal (2012) presented the study of behavior of fibre reinforced beam-column sub-assemblages under reversed cyclic loading. Three different types of specimens namely Type –A, B & C of beam-column sub-assemblages were cast and tested for reversed cyclic loading. Type - A was designed for seismic joint detailing, Type-B is designed for target joint failure and Type- C is designed for flexural failure. The behavior of sub-assemblages was evaluated for failure mode, energy dissipation, strength degradation, shear deformation and strain development in reinforcement. At a drift level of ±5%, both the code based ductile specimens (Type A) showed a strength deterioration
of 30% after the third cycle whereas Type B and Type C specimens experienced 10% and 20%, respectively.

El-SayedMashaly.etal (2012) investigated the performance of the simplified Flexibility Based Fibre Model - II(FBFM) verification. The proposed model relies on calculating the inelastic lengths to integrate the overall element response. The results of the proposed model were compared with the outcomes of the conventional FBFM. The proposed model is capable of describing with satisfactory accuracy and computational efficiency of RC frame structures.

Siva Chidambaram.K.R .etal (2012) investigated the behavior of reinforced beam-column joints with reference to anchorage detailing. Two specimens of 1/5th scale exterior beam column joint specimens considered. First specimen was control specimen and the second was an Externally Anchor aged Specimen (EAS). The IS: 13920-1993 codal provision was followed for EAS. Both the specimens were subjected to cyclic loading condition from elastic to inelastic. With the support of external anchorage system the behavior of EAS was found to be better than conventional method of construction. The experimental test results indicate excellent behavior in energy dissipation, ductility and load-deformation.

Patil.etal (2013) studied the analysis of reinforced beam-column joint subjected to monotonic loading for stiffness, maximum stress and load vs displacement. Results indicate that, the behavior of corner beam column joint is different than that of exterior beam column joint. As the stiffness of the structure changes the displacement, minimum and maximum stress changes are non-linear.

Romanbabu.m.etal (2013) presented research of experimental studies on beam-column joint with fibres under cyclic loading to observe the enhancement in the strength, stiffness, ductility and energy dissipation capacity of the joints. The model was scaled to one third scale with plain concrete and fibrous concrete.
All the specimens were tested under cyclic load. The experimental test results of envelope curve, stiffness, energy dissipation and ductility were compared. The performance of fibre concrete is high in term of all the above parameters were better than plain concrete.

Joshi. P. K. et al. (2014) investigated the behavior of beam-column joint under cyclic loading. Four specimens were considered and cast according to IS: 1893 (Part –I) and IS: 139920-1993. The investigation is limited to load carrying capacity, load vs deflection characteristics and mode of failure. From the test it was concluded that, as the load was increased in each cycle the deflection was found to increase. The crack has been developed in compression face during forward loading and in the case of reversed loading cycle, the development of crack has been formed in the tension face.

Kailuthin. et al. (2014) reviewed the behavior of reinforced concrete beam column joint. The review mainly focused on strength, ductility, stiffness and anchorage of exterior joint. The general behavior of common types of joints in reinforced concrete moment resisting frames has been discussed. The review concludes that a significant amount of ductility can be developed.

### 2.3 SEISMIC BEHAVIOUR OF HIGH PERFORMANCE CONCRETE

Montesinos and Wight (2000) investigated the seismic behavior of beams after increasing hoops spacing and evaluate the potential of High Performance Fibre-Reinforced Cement Composite (HPFRCC) materials as a replacement of joint transverse reinforcement. They also tested a 3/4-scale exterior beam-column subassembly under large displacement reversals. The result indicated that ‘the specimen with ECC material exhibited a large number of hairline diagonal cracks with little damage at the end of the test (5.0% drift). In terms of shear distortion response, it is clear that the ECC connection exhibited excellent performance during the test, even though no transverse steel reinforcement was used in the connection region.
Suresh Gupta et al. (2002) reported about the usage of HPC (High Performance Concrete) in the construction industry. It was reported that HPC as an optimized solution considering the economics, strength and durability required for special structures. The materials and their properties which were added to concrete to increase its strength where included. The mix design procedure for High Performance Concrete was shown.

Montesinos (2005) conducted experiments on several High Performance Fibre-Reinforced Cement Composite (HPFRCC) materials for the use in earthquake-resistant structures including beam-column connections, low-rise walls, and coupling beams. The results emphasized on the potential of HPFRCC for the use in earthquake resistant structures. The use of HPFRCCs in beam-column connection allowed total elimination of joint transverse reinforcements while leading to outstanding damage tolerance.

Ganesan et al. (2007a) reported the behavior of steel fibre reinforced high performance concrete members under flexure. The experiments were conducted on ten beam specimens to compare the behavior of High Performance Concrete (HPC) and Steel Fibre Reinforced High Performance Concrete (SFRHPC). HPC mix for M₆₀ grade was obtained based on ACI 211 method, 10% replacement of cement by silica fume and 20% replacement of cement by fly ash were considered for preparing HPC. Four volume fractions of steel fibre, namely, 0.25%, 0.5%, 0.75% and 1% were used. It was reported that comparing HPC beams, with SFRHPC beams additionally reinforced with 1% volume fraction of fibres, the first crack load was increased by 25% and ultimate load was found to increase by about 15%. They also stated that the energy absorption capacity and ductility factor improved considerably when fibre content was increased.

Ganesan et al. (2007b) reported the experimental results of ten Steel Fibre Reinforced High Performance Concrete (SFRHPC) exterior beam-column joints under cyclic loading by using M₆₀ grade concrete. Volume fraction of the fibres
used in this study varied from 0 to 1\% with an increment of 0.25\%. Joints were tested under positive cyclic loading and the results were evaluated with respect to strength, ductility and stiffness degradation. Test results indicated that the provision of SFRHPC in beam-column joints enhances the strength, ductility and stiffness, and is one of the possible alternative solutions for reducing the congestion of transverse reinforcement in beam-column joints. An attempt were made to compare the shear strengths of beam-column joints obtained by using the models proposed by Tsonos et al. (1992) Bakir et al. (2003), Jiuru et al. (1992). As these models are meant for the joints in ordinary concrete, comparison was not found to be satisfactory. The model proposed by Jiuru et al. (1992) was modified to account for the presence of high performance concrete. The proposed model was found to compare satisfactorily with the test results.

Ganesan (2008) has carried out a research programme to ascertain the feasibility of using SFRHPC (Steel Fibre Reinforced High Performance Concrete) in the beam-column region by using steel fibre. The volume fraction of fibre ranges from 0 to 1\% with an increment of 0.25\%. The specimens were tested in a Universal Testing Machine. The cyclic load was given with a load increment of 0.5 kN. The experimental results showed that an increase of about 20 \% in first crack load and 37\% in ultimate load for SFRHPC specimens with 1\% steel fibres. The SFRHPC joints exhibit enhanced strength, ductility and stiffness and forms one of the alternative solutions for reducing the congestion of reinforcement in beam column joints. The technique of inclusion of steel fibres in beam-column joint appears to be a useful solution in the case of joints subjected to repeated, cyclic loading or seismic loading.

Performance Concrete with and without seismic detailing and two specimens with HPC at confinement joints, were considered and compared for final conclusions. Experimental test has been carried out for lateral load displacement, hysteresis loop, load ratios, percent of initial stiffness vs displacement curve, total energy dissipation, strain in beam main bars, and crack pattern. The exterior beam-column joint with 10% metakaolin + 30% quarry dust performs better in load carrying capacity, more energy dissipation, less joint distortion and more ductility than the beam column joint with normal concrete. Metakaolin and quarry dust concrete increases the shear strength and ductile behavior compared to conventional concrete.

2.4 SEISMIC BEHAVIOUR OF STEEL FIBRE REINFORCED CONCRETE

ACI Committee 544 (1993) had published a guide for specifying, proportioning, mixing, placing and finishing steel fibre reinforced concrete. This guide describes the current technology in specifying, mixing, placing and finishing of Steel Fibre Reinforced Concrete (SFRC). The emphasis in this guide is on the differences between conventional concrete and SFRC and on how to deal with them. Guidance is provided for mixing techniques to achieve uniform mixtures, placement techniques to assure adequate compaction and finishing technology to assume satisfactory surface texture. Tabulation for sample mix proportions was also included.

ACI Committee 216 (1999) had published a guide specifying the measurement and properties of fibre reinforced concrete.

Gefken and Ramey (1989) have carried out experimental work to determine whether the increase in joint hoop spacing in conventional seismic joints could be achieved using steel fibre concrete in place of conventional concrete in the joint region. Ten beam-column specimens were tested. The specimens were cast by using normal concrete and by using steel fibre reinforced
concrete with fibre volume fraction of 2% in the joint region. A cyclic load was applied at the beam tip by using universal testing machine. It was determined that steel fibre concrete specimens with joint hoop spacing of up to 1.7 times the spacing recommended by ACI–ASCE committee 352 for a conventional seismic joint had the same or better ductility, ultimate strength, energy dissipation capacity and joint stiffness. It was concluded that by using steel fibre concrete, a type 1 joint (non-seismic) could replace a plain type 2 joint (seismic)

Tang (1992) published results of Steel Fibre Reinforced Concrete (SFRC) joint tests. In their laboratory five exterior joints and 7 interior joints were constructed and tested under reverse cyclic loading. Two types of steel fibres were used in their test. The first was of rectangular cross-section with dimensions of 0.4 mm × 0.4 mm - 0.5 mm × 0.5 mm by shearing a thin low-carbon steel plate. The length of these fibres was 25-30 mm and aspect ratio was 54-62. Another was cut wire fibre manufactured by cutting round high strength steel wire which had the diameter of 0.7-0.8 mm with 50-55 mm length and aspect ratio of66-75, the results showed that using steel fibres can significantly increase the joint shear strength and also the shear stress corresponding to the first crack. It was also found that in exterior joint tests the problem of bar slip in the SFRC joint was significantly less than that in the Reinforced Concrete (RC) joint; the slip reduced from 0.8 mm (RC) to 0.46 mm (SFRC). In interior joints tested, the steel fibres provided a better bond capacity and improved the bar anchorage capacity.

Andre et al. (1995) have reported the use of steel fibre reinforced concrete to increase ductility in a beam to column joints during earthquake excitation. Four full scale exterior beam column joints were tested, part of a prototype building designed according to the National Building Code of Canada, under cyclic loading. Two different types of mixes were casting the specimens. The first mix was normal concrete mix without fibre. The second mix was fibre mix consisting of 1.6% of steel fibre in the joint region. The experimental results
indicated that Fibre Reinforced Concrete is an alternative to conventional confining reinforcement to increase ductility. Steel fibre bridging across cracks in the concrete mix increase the joint shear strength and can reduce requirements for closely spaced ties. The performance of a joint is closely related to the volume content and aspect ratio of the fibres. They presented that the specimen with fibre concrete had dissipated 10% more energy than the seismically detailed specimen.

Ganesan and Indira (2000) have reported the experimental results of exterior beam-column joints that employ Steel Fibre Reinforced Concrete (SFRC) and natural rubber latex under cyclic loading. Ten numbers of beam column joint were cast by using two different volumetric ratios of transverse reinforcement in the core of the joint and four different values of volume fraction of \( V_f \) steel fibres namely 0.5 \%, 1.0\%, 1.5\% and 2\% and two different values of dry rubber content of \( l_f \) 0.5\% and 1\%. Test results have indicated that latex modified SFRC with \( V_f = 1\% \) and \( l_f = 0.5 \% \) have maximum joint strength, ductility and energy absorption capacity of the joint. The specimens were tested in a universal testing machine of 300 T capacities. The specimen was mounted in a vertical position and a hydraulic jack was used to apply the load at the free end of the column.

Gebman (2001) made six 1/2-scale beam-column joints; two of those were conventional joint specimens and four steel fibres reinforced joints. The steel fibres used were of 30mm length and an aspect ratio of 60. For reducing the amount of lateral hoops in the joint, 2\% steel fibres (by volume) was added in the joint region to increase the joint hoop spacing from 10.2 cm (for two conventional joints) to 15.2 cm (for two fibre joints) and 20.3 cm (for the other two fibre joints). Residual load-bearing capacity, damage tolerance, and energy dissipation capacity were considered in this research for comparing the joint behavior. The test results showed that the performance of specimens with steel fibres were better than other specimens. Steel fibre specimens had a significant
improvement in load bearing capacity as well as the damage tolerance because of the smaller width of cracking. However, it was observed that the steel fibre joints had more cracks than the conventional joints. The energy dissipation capacity of the steel fibre specimens dramatically increased and the increase was approximately 100% (for hoop spacing of 20.3 cm) and 300% (for hoop spacing at 15.2 cm) compared with the conventional joints.

Bayasi and Gebman (2002) have reviewed the available literature and further reported an experimental study regarding the effect of using steel fibres in seismic beam-column connections. They noted that the addition of steel fibres to seismic joints without changing joint design to improve resistance to earthquake loading. It was reported that due to the confining effect of steel fibres, lateral joint reinforcement can be reduced when using steel fibres in joints. Based on the available test data, it was stated that for the steel fibre reinforcement index \( V_f (l/d) \) ranging between 1.0 to 1.6, the lateral reinforcement reduction ranged between 0.3 and 1.1 % equivalent to 50 to 200 % increase of hoop spacing. They have fabricated \( \frac{1}{2} \) - scale beam-column joints. Reinforcement ratios of the \( \frac{1}{2} \) - scale joint are practically equivalent to the ratios of original joint.

Gencoglu and Eren (2002) have reported the experimental results of steel fibre reinforced concrete on the behavior of the exterior beam-column joints subjected to reverse cyclic loading. Two different ready-mixed concrete mixes of compressive strength 26 MPa and 33 MPa were taken for the study. Hooked steel fibre of volume fraction 1% was mixed with the concrete. They carried out tests on full-scale exterior beam-column joint assemblies subjected to displacement controlled reverse cyclic loading. The results indicated that the ductility and strength capacity could be increased by using Steel Fibre Reinforced Concrete and decreasing the stirrups in the joint and confinement regions of the beam and column.
Mustafa. et al. (2002) investigated the effect of steel fibre reinforced concrete on the behavior of the exterior beam-column joints subjected to reverse cyclic loading. Specimen #1 and #2 were reinforced with closely spaced stirrups in joints. Specimen #3 and #4 are reinforced with steel fibre reinforced concrete. All the four specimens are scaled to one fourth models are tested under reversed cyclic loading. The experimental test results show that the usage of steel fibre reinforced concrete in beam-column joints can be an alternate solution for minimizing the density of transverse reinforcement.

Mirsayah and Banthia (2002) conducted experiments to study the shear behavior of fibre reinforced concrete using direct shear tests. Two steel fibres, one with flattened ends and circular cross section and the other with crimped geometry and a crescent cross section, were investigated at fibre volume fractions varying between 0 and 2%. Direct comparison was made with flexural toughness. It was reported that for the flattened end fibre, an almost linear increase in the shear strength was noted with increase in the fibre volume fraction. The fibre with crimped geometry, shear strength approached a plateau value beyond which no increases in shear strength occurred with an increase in fibre volume fraction. It was observed that plain concrete failed at a low equivalent shear strain of 0.4% and fibre reinforced concrete supported as high as 10% strain in shear.

Liu and Cong (2006) reported about the seismic behavior and failure modes of beam-column joint subassemblies reinforced with steel fibres. Six 2-D exterior beam-column joint subassemblies were tested under simulated seismic loading. The performances of steel fibre reinforced concrete with the conventional joint were compared. It was reported that the steel fiber reinforced concrete within beam-column joints can significantly enhance the shear resistance capacity of joints. Furthermore, it was reported that using steel fibre reinforcement was an effective method to reduce the lateral reinforcement in the beam plastic hinge region. Some preliminary suggestions were made for a simple
but rational analytical procedure to evaluate the joint shear strength when either fibres and/or stirrups were adopted.

Wang and Lee (2007) reported about the Reinforced Concrete (RC) structure strengthened with Ultra-high steel Fibre reinforced Concrete (UFC). They conducted cyclic load test on interior RC beam-column joint sub-assemblages strengthened by means of joint replacement with UFC to observe their seismic performance. Conducted experiments were conducted on mechanical properties of UFC such as compressive, flexural; rebar bonding, slant shear strengths and durability. Test results indicated that the UFC displays excellent performance in terms of mechanical and durable behavior. It was found that UFC-replaced joint frame behaves very well in seismic resistance and its performance was even much better than the frame strengthened with RC jacketing as normally seen in the traditional retrofit schemes.

Siva Chidambaram .K.R .etal (2012) investigated the behavior of reinforced beam-column joints with reference to anchorage detailing. Two specimens of 1/5th scale exterior beam column joint specimens considered. First specimen is control specimen and the second is an ExternallyAnchor aged Specimen (EAS). The IS: 13920-1993 codal provision is followed for EAS. Both the specimens where subjected to cyclic loading condition from elastic to inelastic. With the support of external anchorage system the behavior of EAS was found to be better than conventional method of construction. The experimental test results indicate excellent behavior in energy dissipation, ductility and load-deformation parameters to current design recommendations.

### 2.5 SEISMIC BEHAVIOUR OF POLYRPOPYLENE FIBRE REINFORCED CONCRETE

Gustavo.J Parra-Montesinos. et al (2005) is studied the ultra-molecular weight polyethylene fibers in a 1.5% volume of fraction, which represented the minimum value for which a tensile strain hardening behavior was obtained from
direct tension tests. Two specimens of large-scale subassemblies, consisting of beams into a column from two opposite sides, to evaluate the adequacy of connection design in zones of high seismicity. The results of two specimens of High Performance Fibre Reinforced Concrete (HPFRC) are subjected to peak stress of 7.3 and 9.3 MPa which corresponds to $1.2 \sqrt{f_c}$ and $1.4 \sqrt{f_c}$. Experimental test results indicate the performance of beam-column connection goes under large shear reversals with excellent damage tolerance. The sustained drift capacity of the beam is 5% with the rotation of 0.04 rad. The effect of bonding between longitudinal reinforcement and HPFRC material is found to be excellent.

Rongxian.etal (2011) conducted research on seismic behavior of exterior joints with specially –shaped column reinforced by Polypropylene fibre. Four specimens are cast, three specimens with specially shaped column reinforced by polypropylene fibre and fourth specimen with plain concrete. The experimental outcome strongly recommends the incorporation of Polypropylene fibre in beam-column joint. Additions of Polypropylene shows increases the cracking load and improve the ability to deformation, reduces the width of crack propagation in the core area, stiffness and degradation and improves the pattern of failure.

2.6 SEISMIC BEHAVIOUR OF HYBRID FIBRE (STEEL AND POLYRPROPYLENE FIBRE) REINFORCED CONCRETE

Perumal.etal (2010) carried out an experimental study on the behavior High Performance Concrete in exterior beam-column joint under reversed cyclic loading. Five specimens were considered. First specimen was designed as per IS: 456-2000 for M60 Plain concrete. Second specimen was designed as per IS: 13920-1993. Remaining three specimens where similar to the first one but various combinations of cocktail fibre concrete in the joint region were used. The test results indicate that the addition of polypropylene fibre to the steel fibre
is optimum for a percentage of 0.2, which have more energy absorbing capacity, less joint rotation, more curvature ductility factor and less reinforcement strain.

Yaminpatel.etal (2013) investigated the effects of hybrid fibre combination of 0.5% of steel and polypropylene fibre at beam column joint for M20 concrete. The specimens were designed according to IS: 456-2000. The strength, energy dissipation capacity and shear strength are the some of the parameters for this investigation. Two sets of specimen A and B (each sets contain three specimens) were tested under displacement controlled conditions. In corporation of fibres in the specimen shows high ductility, undergoes large displacement without developing wider crack and congestion of reinforcement in beam-column junction can be avoided. Specimen B shows excellent strength, energy dissipation capacity and damage tolerance.

Ramadevi.K.etal (2013) investigated the seismic behavior of hybrid fibre reinforced concrete bare frames to evaluate the cyclic behavior. Various tests were conducted in concrete. The percentage of fibers considered is 0.75%, 1.5% and 2.0%. The cyclic load was applied to the bare frame to evaluate the seismic behavior. Also the ultimate strength, deflection, ductility factor and energy dissipation of Hybrid Fibre Reinforced Concrete with varying percentage of fibres are studied. The experimental result shows that as the percentage of fibre content increase the test results are increases. The number of cycles increases with increases of fibre percentage.

Geethajali.etal (2014) investigated the study on the behavior of Hybrid Fibre Reinforced Concrete in exterior beam-column joint under cyclic loading. The combination of steel and polypropylene fibre at a volume of fraction of 0.5% was considered for three specimens, and plain concrete, 0.5% of steel fibre and 0.5% of polypropylene fibre specimen of each. The load was applied at a constant interval of 5kN in the forward cycle. Linear Variable Differential Transformers (LVDT) are used to measure the deflection. The experimental test
result of plain concrete was compared with individual incorporation of fibres concrete and hybrid combination of fibre concrete. The hybrid fibre reinforced concrete increases the cracking load of beam column joint in comparison to steel fibre specimen. Also the load carrying capacity increases by 38% for hybrid fibre concrete compared to steel fibre concrete specimen.

2.7 FINITE ELEMENT MODELLING OF FIBRE REINFORCED CONCRETE

Zhang et al. (1994) have presented a reinforced concrete model for nonlinear finite element analysis. They developed smeared/layered reinforced concrete model for three dimensional finite element analyses. That model performed the nonlinear behaviors of both concrete and reinforcement steel on the supposition of compatible deformation of the two materials. The effects of concrete cracking, tension stiffening and dowel action were also considered in the new model. It was assumed that the rebar’s were constructed in three orthogonal directions. That makes mesh generation very convenient. It was assumed that the reinforcement steel was smeared in the concrete or layered in the element, where the number and location of the layers can be adjusted.

Shannag et al. (2007) have reported the experimental results as well as FEM analysis results of cyclic response of fibre reinforced concrete joints. It was used two different concrete mixes viz normal concrete of compressive strength 27 MPa and high performance concrete of compressive strength 75 MPa. It was used 0, 2% and 4% of brass coated steel fibre and hooked steel fibre. It was prepared one third scale reinforced concrete interior beam column joint and observed that the best energy dissipation was exhibited by the specimens strengthened using hooked steel fibres. It was also stated that this dissipated energy increased significantly with increase in fibre content. It was used nonlinear static (pushover) procedure to model the behavior of interior beam-column joints under lateral cyclic loading. The experimental results were found
to be in good agreement with the results of the applied modeling technique and assumptions made. It was reported that the static pushover analysis appears to be a viable tool for predicting the load-deflection and moment curvature responses of beam-column joints.

Bindu and Jaya (2008) reported the performance of exterior beam column joints with cross inclined bars under seismic type loading. Four exterior beam-column joints of one-third scale, designed for earthquake loads as per IS 1893:2002 and detailed as per IS 13920:1993 were cast. The difference between group 1 and group 2 specimen was that the group 2 specimens were tied with diagonal cross inclined reinforcement in the joint region at the two faces. It was reported from their tests that the cross–inclined bars as confining reinforcement improve the seismic performance. It was compared their test results with the analytical model developed by using finite element software package ANSYS. Only half of the system was modeled through thickness so that the symmetry condition was used. Solid 65 elements were used to model the concrete and link 8 elements were used to model the reinforcement. The models were analyzed with monotonic loadings in the upward direction and the performances were compared. The load-displacement relations of finite element model were compared with experimental curve.

Al-Ta’an and Al-Saffar (2008) have used the finite element method to study the nonlinear behavior of beam-column fibrous reinforced concrete joints under short–term monotonic loading. Concrete was represented by eight nodedisoperimetric elements and the reinforcement was represented by axial two noded bar elements embedded in the concrete elements. Strain hardening approach has been employed to model the compressive behavior of the fibrous concrete. In tension a continuous function is used to model fibrous concrete in the pre-peak and post – peak states. Material nonlinearities due to cracking of concrete, crushing of concrete in compression, debonding and pull– out of fibres and yielding of reinforcement have been taken into account. A smeared fixed
crack approach of the cracked concrete in tension is assumed. An incremental – iterative scheme based on Newton – Raphson’s method is employed for the nonlinear solution algorithm and a displacement criterion is adopted for checking the convergence of the solution. It was developed equations for compressive stress-strain relationship and tensile stress-strain relationship for fibrous concrete.

Thirugnanam et al. (2010) presented the experimental study on the behavior of Interior RC Beam Column Joints subjected to cyclic Loading. It was cast 1/5th scale interior R.C beam-column joint designed for seismic load according to IS 1893 (PartI): 2002 and IS 13920: 1993. It was compared their experimental results with FEM model analysis in ANSYS. It was reported that the structural behavior of interior beam column joint model has been similar to that of the analytically predicted one.

Hamid Sinaei.etal(2011) is investigated the effectiveness of composite fibre reinforced polymer layers for exterior beam-column connections through a finite element model. Five specimens are considered including one control specimen and four retrofitted specimen with altered arrangements of Composite Fiber Reinforced Polymer (CFRP). All the specimens were analyzed for the seismic performance of the joints in terms of lateral strength and ductility. Different configuration ratios of CFRP are placed in top, bottom and lateral sides of the beam. The test results are discussed with reference to CFRP position, strength and ductility. Non-linear analysis of Reinforced Concrete connections with FRP overlays shows improvement in L shape overlays under the beam. U shape overlays under FRP on both lateral sides of the beams are very good in strength and ductility enhancement in RC joints. Ductility value decreases in top and bottom of the beam.

Pirti.A.Patel.etal(2012) presented the performance characteristics of non-ductile reinforced concrete beam-column connection using polyester fibres under
cyclic loading with triangular cross section. The test is conducted on non-ductile reinforced concrete beam-column specimen to evaluate the load-deflection behavior, energy dissipation, and stiffness and damping capacity. The incorporation of polyester fibres in plain concrete shows high value of ultimate strength capacity, minimum cracks indicate the high ductility value and energy dissipation.

Syed Sohailuddin S.S. etal(2013) conducted test on finite element modeling of reinforced concrete beam column joint using ANSYS. In his present study, four models were done. First model is with IS: 13920-1993 detailing. Second model with IS: 13920-1993 with cross bracing bars at the joint. Third specimen is with cross bars in beam region of 6mm instead of cross bars in the joint. Fourth specimen with cross bars of 8mm instead of 6mm in beam region. All the specimens were subjected to similar reverse cyclic loading in structures. The test results are compared with previous research and they conclude that the performance of the joint is better than in providing with cross bars of 8mm in beam region.

Patil.S.S.etal(2013) studied the RCC beam-column connection subjected to monotonic loading for corner and exterior beam-column joint for finding the maximum stress, minimum stress, displacement. Variation in stiffness of the beam-column joint is analyzed by Ansys software. From the test results it concludes that, as the load increases the displacement, minimum and maximum stress value increases. When stiffness increases the value of minimum and maximum stress value changes non-linearly.

SuhasiniM.Kulkarni and Yogesh D Patil (2014) evaluated the Advanced Reinforcement Pattern (ARP) in exterior beam-column joint. Two types of specimens were considered. First one is based on Advanced Reinforcement Pattern and second specimen is as per IS: 13920 with H and L type joint. Stiffness, Displacement and Shear strength parameters were studied.
Experimental findings show that the stiffness and displacement values were high in ARP model compared to IS seismic model. Also the shear stress developed in ARP is less than Seismic model joint.

2.8 SUMMARY OF LITERATURE REVIEW

The literature review describes about partial replacement of cementitious materials in plain concrete improves the strength of concrete and shows better workability in pouring of concrete especially in congested reinforcement zones. Also addition of fibres in plain concrete, improves the properties of concrete like ability to deformation, reduces the width of crack propagation in the core area, and increases the stiffness, failure of pattern, stress-strain behavior. Since the literature about the combination of fibres and cementitious materials in frames is limited, an attempt was proposed to make a study on the effect of using metakolin with steel fibre and polypropylene fibre in reinforced concrete frames to evaluate the properties of strength, stiffness, ductility and energy absorption capacity.