A STUDY ON IMPROVED PERFORMANCES OF EXTERIOR BEAM-COLUMN JOINT USING VARIOUS STRENGTHENING MEASURES : A REVIEW

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ABSTRACT

The ever increasing failure of structures, loss of life and staggering economic losses due to earthquake have raised the concern against earthquake safety to alarming level. Devastating failures in past have witnessed the behavior of beam-column joints governing the global response of structures. Congestion of reinforcement and construction difficulties has escalated the attention required for strengthening RC beam-column joints. In this study, an attempt have been made to carry out experimental investigations on effect of various strengthening techniques such as steel fiber reinforcement, carbon fiber reinforcement polymer (CFRP) strengthening, steel haunch strengthening and confining joint reinforcement technique. The effectiveness of each measure was evaluated experimentally. These specimens were tested under horizontal loading and their behavior was discussed with emphasis on strength, displacement ductility, stiffness and failure mechanism. Special attention was given to crack-width study.

The non linear finite element analysis response of beam-column joint was studied for basic model using ANSYS software along with initial and progressive cracks up to failure. The analytical and experimental results were compared and presented in this work to make scientific conclusions.

INTRODUCTION

During the design of any structure safety against earthquake is the most important criteria to be considered. Frequently occurring earthquakes in last few decades have highlighted the susceptibility of structures to earthquake failures. Reinforced Concrete (RC) framed structures, being the most common configuration type have suffered the most. This type of construction generally serves its purpose well under normal loads. However, the performance of such structures under seismic loads has exposed the vulnerability of this construction type. Reinforced concrete framed structures generally develop inelastic deformations when they are subjected to strong earthquakes. Earthquake induced energy is dissipated through the formation of plastic hinges, preferably in the beams rather than in columns. The design approaches should be in such a way to give emphasis to the columns and the beam-column joints since the failure of these regions can affect the integrity and stability of a significant portion of the structure. As beam-column joints are one of the most inaccessible regions in any structure therefore it is difficult to repair them once they are damaged. The emphasis of this study is to understand and compare different measures for strengthening beam-column joints.

LITERATURE REVIEW

In the present study literature review literature review is divided into two parts, out of which first part include review of various international codes and the second part deals with work done in fields of strengthening beam-column joints.

Before moving to the literatures, it is always good to see the stand of the various countries codes. Fortunately due to awareness and researches toward the earthquake hazards, we have many codes dealing with the beam column joints. But few are dealing in details as mention below. IS 13920:1993, ACI 352-2002, ACI 318.2011, NZS 3101:2006 and EN 1998:2003.

2.2. Review from past research done

Uma and Meher Prasad **(2006)** studied the behaviour of beam-column joint. They presented a review of the postulated theories associated with the behaviour of joints. They suggested that in seismic design, the damages in the form of plastic hinges are accepted to be formed in beams rather than in columns. They 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. They suggested that 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.[6]

Asha and Sundararajan **(2006)** have presented the behaviour 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. They have used four types of confinement namely; square hoops, square spiral, circular hoop and circular spiral 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. They reported that exterior beam-column joint with square spiral in the joint region was the most effective of all the specimens tested.[11]

Sudhir K. Jain, R.K. Ingle and Goutam Mondal **(2006)** proposed new provisions for inclusion in IS 13920: 1993.They suggested that the provisions in IS 13920:1993 are inadequate to prevent shear and bond failure of beam-column joints in severe seismic shaking. Therefore, these provisions need to be upgraded substantially with inclusion of explicit provisions on shear design and anchorage requirements. They proposed provisions for shear design of beam-column joint and anchorage requirements of tension beam bars in the joint area and also suggested provisions for the confinement of wide beam and column connections.[12]

Genesio et al.**(2010)** researched in the area of seismic retrofitting of poorly detailed RC beam-column joints and structures using haunch type element connected with post installed anchors were studied. It was observed that fully fastened haunch retrofit solution (FFHRS) have improved the seismic performance of the structure. It was also investigated that the effectiveness of the FFHRS is directly related to the efficiency of anchor group used to fasten the haunch elements. Conclusions were made that in cases where the anchor group performed well, a ductile failure in the beam could be induced and where the anchor group suffered concrete cone failure, joint shear failure occurred.[13]

Pankaj Agarwal, Ankit Gupta, and Rachanna G. Angadi (**2013**) presented the experimental work for evaluation of Exterior RC Beam Column Joint strengthened with FRP under cyclic load. Four RC T-joints with different detailing; two unconfined (according to IS: 456-2000) and the other two confined (according to IS: 13920-1993) were tested. Cyclic load has been applied using Quasi-static testing technique .In this study, comparison of strength and ductility of undamaged and retrofitted specimen has been done. Also the behavior of confined specimen is compared with the unconfined one. Confined specimen experienced lesser number of cracks as compared to the unconfined model but the behavior of all the four models was almost same, with initial flexural cracks in the beam and then shear cracks in the joints and then failure and spalling of joint and nearby region.[14]

Neeru Bansal, Naveen Kwatra and Varinder S Kanwar **(2013)** conducted an experimental program to evaluate the structure behavior of opening corners having U type detailing. The parameters of investigation were: strength measured in terms of joint efficiency, ductility, and crack control. They suggested that a substantial increase in post-cracking tensile strength, ductility and crack control can be achieved by adding steel fibers to the concrete. U type detailing system was tested by them with crimped-type flat steel fibers having aspect ratio of 30 and 50 at different percentage volume fractions of 0.5%, 1.0%, 1.5% and 1.75%. The investigations indicate that in the specimen, there is a 30%-35% gain in efficiency with increase in volume fraction up to a certain limit beyond which there is a drop in mix workability and joint efficiency.[15]

G.Appa Rao, V.Navya and R.Eligehausen (2013) studied the effect of haunch element on the performance of RC beam-column joint. It was investigated that at a location of 0.2 times the span of the beam from the centre of column a haunch element oriented at 45 degrees produced the highest reduction of shear stresses in the joint region. It was also observed that haunch elements exhibits better performance in the term of shear strength, ductility and less stiffness degradation.[16]

Mohamed H.Mahmoud **(2014)** et al. carried out an experimental study for the structural performance of RC exterior beam-column joint rehabilitated using carbon-fibre reinforced polymer (CFRP).Seven specimen were strengthened by them. Different strengthening configuration by use of CFRP sheet was proposed. Conclusions drawn by them were that CFRP sheet showed its efficiency in improving characteristics of the deformed beam-column joints if only the proper configuration is chosen. Use of CFRP as a strengthening material led to increased ultimate capacity and decreased ductility. Diagonal overlying sheet for absence of stirrups in joint region and L-shaped Fabric sheet for insufficient bond length were observed to be better configurations to overcome these defects.

Objectives

The existing reinforced concrete beam-column joints which are designed as per code IS 456:2000 do not meet the requirements given in the ductility code IS 13920:1993. Hence the beam-column joints that are not designed as per the ductility code may not perform well when subjected to seismic forces. The effectiveness of the strengthening has to be evaluated experimentally. Keeping these points in the mind, the following objectives are formulated.

1. Investigate different detailing of the joint reinforcement.
2. Study the effect of different parameters that are known to affect the behaviour of these joints such as type of longitudinal and transverse reinforcement, beam longitudinal reinforcement ratio, beam transverse reinforcement ratio, joint reinforcement ratio and detailing, concrete compressive strength.

3. To evaluate the contribution of various measures (CFRP sheets, confining reinforcement, ductile detailing, steel fibres, Steel Haunch,) on behavior of beam-column joint.

4. Validation of experimental result by comparing with analytical models of joints developed using finite element software package ANSYS.

Need for Present Investigations

Primitively Concrete jacketing and steel jacketing were the two conventional methods adopted for strengthening the deficient reinforced concrete beam-column joints. Both of these methods have been obsolete now as concrete jacketing increases the cross sectional area and self-weight of the structure while steel jacketing fails to resist weathering attacks. Both require laborious and operationally intensive approach to be implemented. With the advancement of research work innovative measures like confining reinforcement and ductile detailing were suggested by design codes. Usually followed new technique for strengthening the reinforced concrete structural members is through confinement with a composite enclosure. To prevent the damage due to joint shear failure they come up with idea of joint confining with the rebar.

Confining the Beam-column joints isn't so easy because there are already rebar coming from three directions. With the extra provision as per the present codes confining stirrups leads to the problem of the congestion as shown in Figure 1.15.

Figure 1.15 Congestion at the Beam-Column Joints (ref.: www.concreteconstruction.net)

As introduced earlier keeping in mind the need of strengthening of beam-column joint we must introduce new strengthening techniques like steel fibres, FRP reinforcement and Steel haunch

.Apart from that present research work will serve as a guideline to compare all these measures to strengthen joint and help us to adopt one to enhance the strength and ductility of joints.

8.1. Conclusions

In the present work which was reported in preceding chapters investigations were made regarding contribution of different methods in strengthening of beam column joint. The purpose of this investigation was to evaluate the performance of beam-column joint strengthened by different methods and to compare those methods over a common platform. Based on experimental and analytical investigations following conclusion were drawn.

1. Basic specimen failed due to the development of tensile cracks at the interface between beam and column, the cracks propagated further leading to quick degradation in stiffness.

2. The specimen with confining reinforcement have shown an increase in joint efficiency by 9.35% over basic model and a slight increase in displacement ductility factor with nominal increase in cost.

3. It is found that specimen casted with 1.5% of steel fiber have shown 14.02% increase in joint efficiency and about 20% increase in displacement ductility although high drop in ultimate stiffness of specimen was noticed.

4. It is found that specimen wrapped with CFRP sheet have shown 23.37% increase in joint efficiency as compared to basic model. Although decrease in ductility of specimen is noticed as the lowest displacement ductility factor of 1.414 was calculated by experimental results.

5. Specimens strengthened with steel haunch have shown the highest increase of 60.47% in joint efficiency over basic model. It was also noticed that the haunch strengthened specimen showed high ductility and high ultimate stiffness.
6. By performing crack behavior comparison for various models it was noticed that in all the specimens tensile crack were developed at the interface of beam and column. A vertical cleavage was formed at the junction of all the specimens .SFRC specimen and

Steel Haunch strengthened have undergone large displacement without developing wider cracks as compared to other models depicting high ductility.

7. The experimental result for basic model was well correlated with the FE analysis results and percentage deviation of 10.54% was found between both the results.

8. A detailed cost- benefit analysis has been carried out for various models and it has been found out that efficiency of Haunch strengthened model was maximum in term of cost effectiveness.

8.2. Future Scope

1. Experimental investigations may be carried out for cyclic load and full scale model can be tested which was not possible due to limitation imposed by infrastructural limitations.

2. Finite Element modeling can be done for all other strengthening techniques used in present work and result can be compared with experimental findings.

3. Experimental studies on innovative haunch strengthened joint can be extended and proper guidelines for design of haunch can be investigated.

4. In the present work square shaped loops for confining reinforcement were used. The studies can be extended for different profile of confinement reinforcement.

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