STUDY OF BEAM COLUMN JOINT WITH DIFFERENT REINFORCEMENT DETAILING STATE OF THE ART REVIEW

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ABSTRACT- For any reinforced concrete framed structure, the beam column joint has always been a vulnerable location for failure. The inspiration for choosing this topic is the evidences displayed by the failure of these joints in multiple RC structures. Intensive research is being carried out to strengthen such a vital location in the structure, with modification incorporated in the joint region. The present study is to understand the effect of different type of detailing at joint region. This paper reviews the state of the art research works related to the structural behaviour of connections between various elements under seismic loading. The paper presents several past research works for better understanding and to gain confidence about the behaviour of beam column joint with different reinforcement detailing.

Keywords— Beam column joint, reinforcement detailing, seismic loading, load displacement curve.

1. INTRODUCTION:

Recent study on beam column joint lead to the revelation that, this particular junction of structural members is one of the most vulnerable, in terms of failure tendency. For a long time now, studies have been conducted to enhance the strength of this particular failure location. Many of these studies showed that a difference incorporated in the detailing of the joint reinforcement enhances the property of the joint. These differences can be in the form of addition of reinforcement, reduction of reinforcement or even as modification of existing reinforcement.

This paper presents a summary of all of the research work that has been carried out in the topic of beam column joint. It also includes studies conducted on different types of concrete and also review on codal provisions.

2. LITERATURE REVIEW:

Bindhu K R (2009)[1] studied the behaviour of columns and exterior joints under seismic type loading. Cross inclined bars were provided as a replacement of ties in the joint region for the joints having transverse reinforcement detailed as per IS 13920 : 1993. The specimens having special confining reinforcement as per IS 13920:1993 showed improved ductility and energy absorption capacity than the specimens detailed as per IS 456:2000 and SP34.The performance of the specimens with non-conventional confinement reinforcement had exhibited higher ultimate strength with minimum cracks.

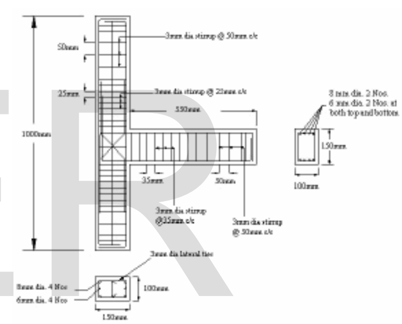
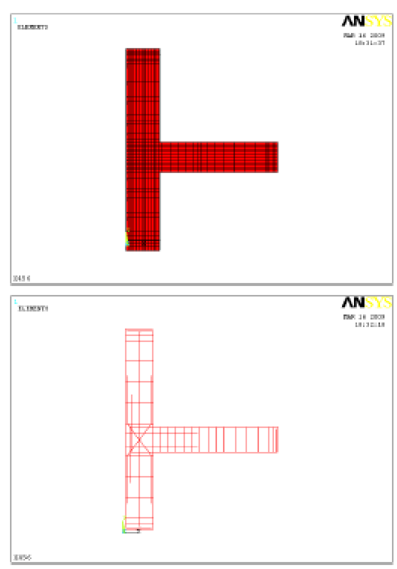


Figure 4.6 Reinforcement Details of the Beam-Column Joint Specimen as per IS 13920 with Diagonal Confining Bars (Type 2)



(b) as per IS 456 and Cross Inclined Bars
Figure 5.5 (Continued)

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Kaviarasu(2012)[2] analysed the behaviour of beam column joint under the influence of headed bars. Emulative precast connections were developed. The Ultimate load carrying capacity, displacement, ductility, energy dissipation capacity, strain in reinforcements was considered. In the precast specimens the strain in the column main reinforcement were negligible and the strain in longitudinal reinforcement of the beam was higher for all the specimens tested which indicates beam mode of failure.

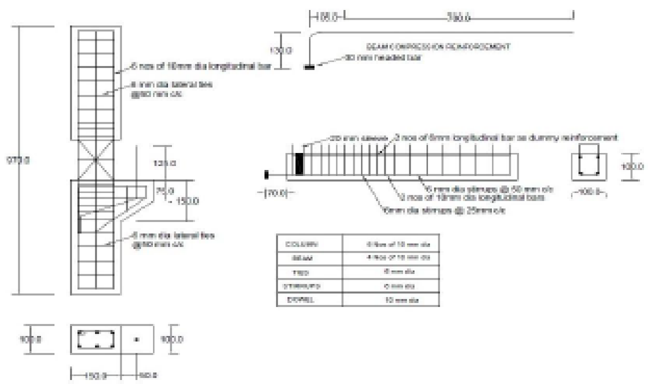

Fig 4.2. Precast Specimen 1

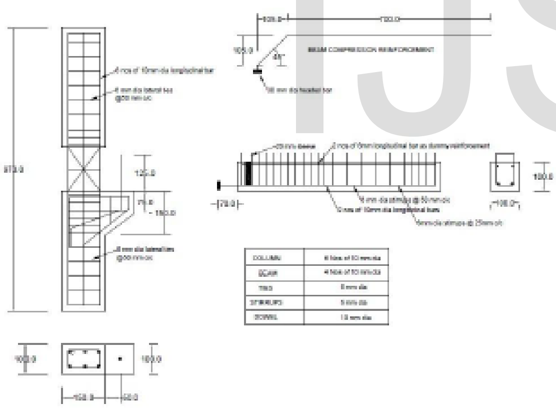

Fig 4.3. Precast specimen 2

Vandhana R K, Bindu K R (2014)[3] studied the RCC interior beam column joint under reversed cyclic loading. Beam column joints are designed based on strong column weak beam behavior. The joint shear strength and stiffness are greatly influenced by the factors like concrete compressive strength,slab transverse reinforcement. The statistical modeling is used to represent ther jointy behaviour to decide the shear strength and energy absorption capacity.

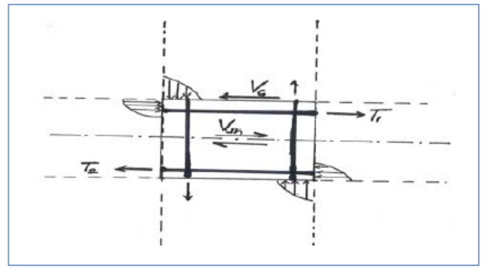

Fig. 3. Horizontal Joint Shear

Shyh-Jiann Hwang, Hung-Jen Lee et. al.(2005)[4] studied to understand the role of hoops on shear strength of reinforced concrete beam column joint. Nine exterior reinforced concrete beam column sub assemblage were tested carry shear as a tension tie and constrain the width of crack. The joint hoops are found to act as a tension tie as well as to constrain the crack width. The elastic joint hoops are effective in restraining the displacement reversals.

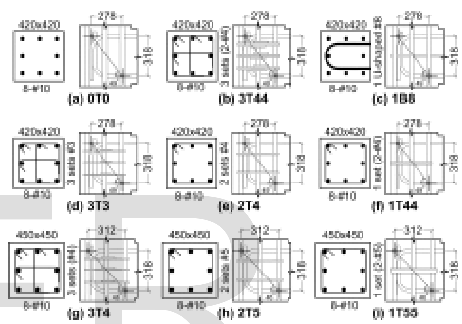

Fig. 5—Beam-column joint details.

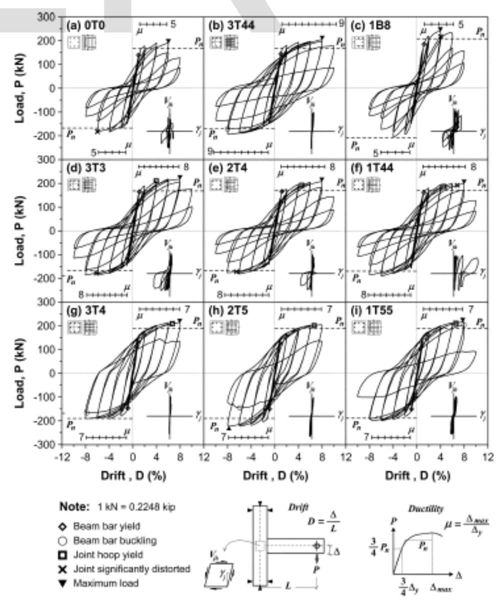

Fig. 6—Load-versus-deflection response of specimens.

Siva Chidambaram.K.R, Thirugnanam.G.S (2012)[5] conducted a comparative study on behaviour of reinforced beam-column joints with reference to anchorage detailing. The control specimen (CS) constructued and detailed as per IS

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13920:1993 codal provisions and externally anchorage specimen (EAS) cast with small projection beyond the column face. The first crack load of the externally anchorage specimen is 45 more than the conventional joints specimen.

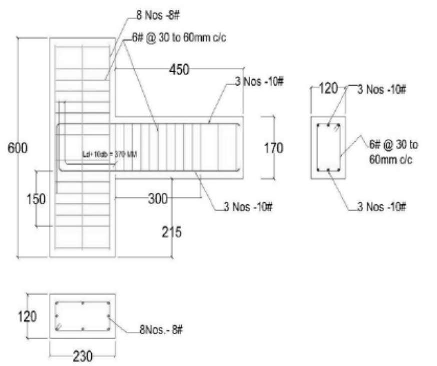

Figure 2. Reinforcement detailing of the conventional Beam Column Joint as per IS 13920: 1993

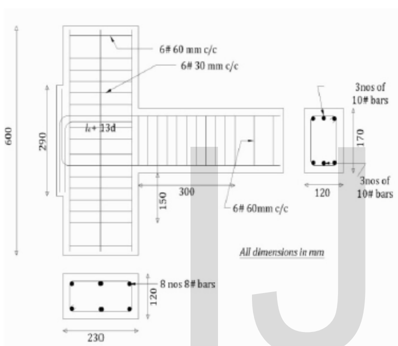

Figure 3. Ductile Detailing of Special Anchorage Beam Column Joint

Stavroula Pantazopoulou and John Bonacci(1992)[6] studied the implications of the frequent questions about beam-column joints. The mechanics of beam-column joints loaded frame structure are investigated in this paper. The role of stirrups and axial load on the behaviour of the joints are illustrated clearly. Through persistent debate and careful scrutiny of experiments over the past several decades, recommendations for reliable design of beam-column joints have evolved.

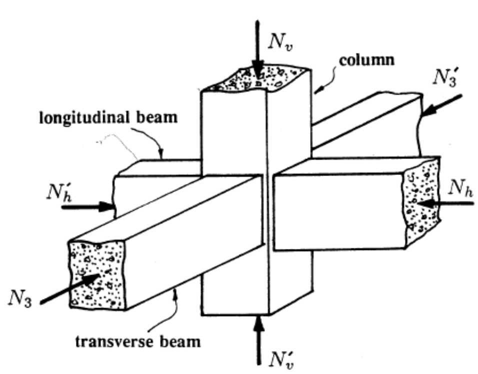

Fig. 2 — Internal axial forces at the connection

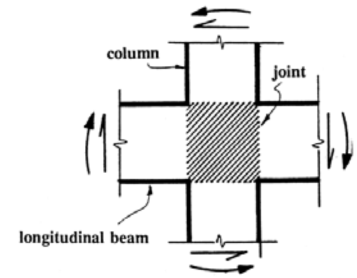

Fig. 1 — Actions at the boundaries of the joint

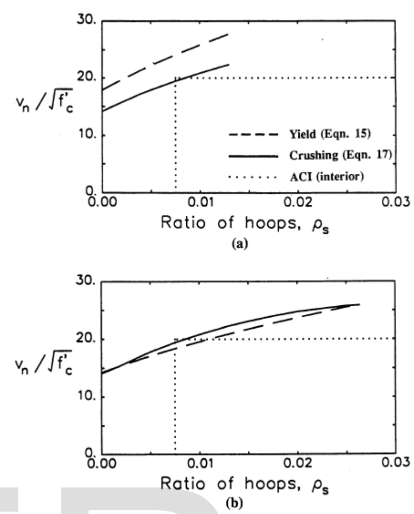

Fig. 7 — Design shear strength: (a) Case A; (b) Case B

Sergio Malcocer et al(2000)[7] studied the behaviour of a precast concrete beam column connection. Beam column joints are tested under unidirectional and bidirectional cyclic loading. In one structure continuity was achieved by placing hoops around the extensions of 90-deg hooks of beam bottom reinforcement that protruded from the beam ends to the joint. In the other specimen, hooks were replaced by U-shaped prestressing strands that were lap-spliced to the bottom beam reinforcement that was in turn terminated flush at the beam end Specimens exhibited a ductile response. Specimen behavior was controlled by joint shear.

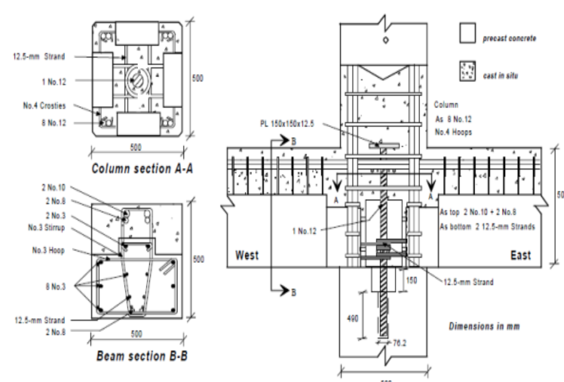

Figure 3. Joint Reinforcement of Specimen J2, EW Direction

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Bing Li(2009)[8] investigated the seismic performance of lightly reinforced concrete exterior beam-column joints. Experimental results of four lightly RC exterior beam column joints with and without beam stubs under cyclic loading with constant column axial force applied at the top of the column. Test results showed that when the hooks anchored down in the column increased the tensile stress in the diagonal concrete strut in the joint core.

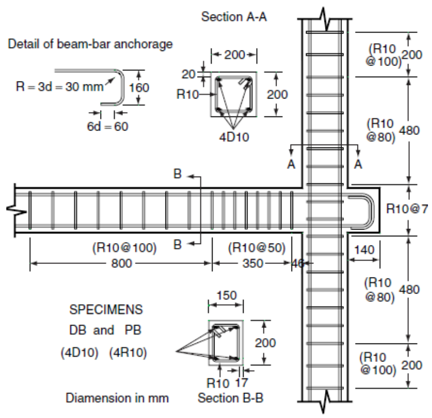

Figure 2. Reinforcement detail of Specimens DB and PB

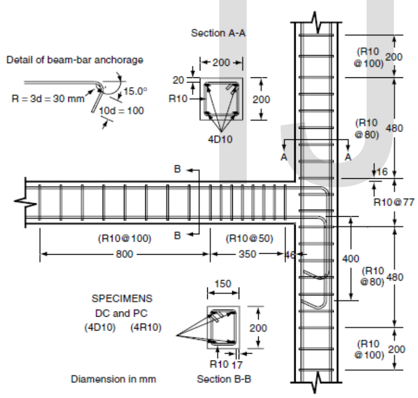

Figure 3. Reinforcement detail of Specimens DC and PC

Mohammad Soleymani Ashtiani et al(2014)[9] studied the implementation of high- strength self-compacting concrete in beam column joints and assessment of its seismic behavior under reversed cyclic loading. Three interior beam- column subassemblies chosen to vary in concrete type and compressive strength are designed as per New Zealand standard NZ3101:2006. The cracking pattern at different load levels and the mode of failure are also recorded and compared among different specimens.

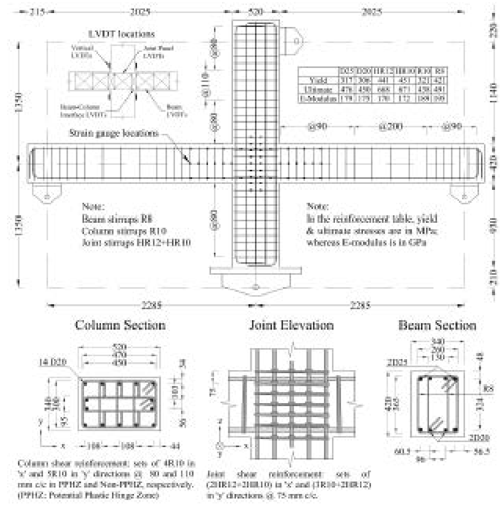

Figure 2.1.1. Details of the beam-column subassemblies and instrumentations (dimensions are in 'mm')

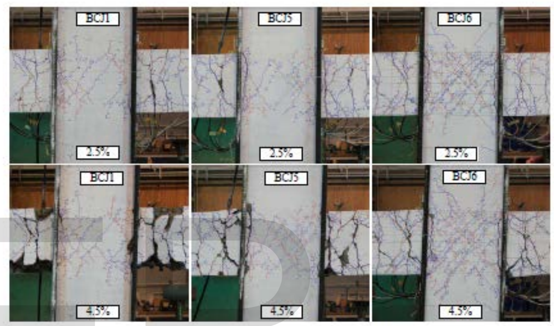

Figure 2.2.2. Pictures of BCJs at drift ratios 2.5% and 4.5%

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Sakai and Sheik (1989)[10] studied the variations in confinement in reinforced concrete columns. Main focus on characteristics of materials, characteristics of cross-section, behavior of columns and other mechanical characteristics and design constraint such as structural detailing. A comprehensive review on confinement of reinforced concrete columns has been presented. Based on the review of the previous research , it appears that a re-examination of the ACI code provisions for confinement will be needed.

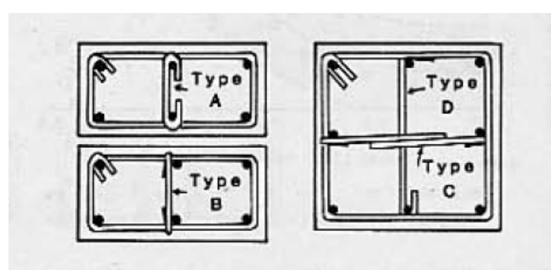

Fig. 8—Types of crossties

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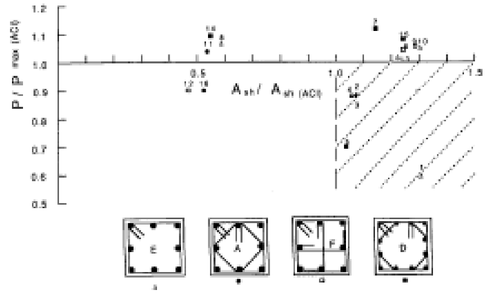

Fig. 11—Relationships between the test parameters and the ACI Code

Mo and Wang(2000)[11] analysed the seismic behavior of RC columns with various Tie configurations. To expedite the fabrication of reinforcement cages of columns , a new configurations of transverse reinforcement with alternate ties for column is proposed. The new configurations of transverse reinforcement with alternate ties provides comparable or improved seismic performance than typical configurations normally used in the construction. Finally, it is further established that current ACI requirements for compression lap splices is adequate when the proposed configuration of transverse reinforcement with alternate ties is used.

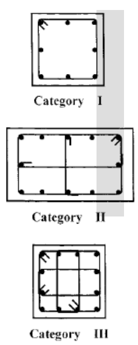

FIG. 1. Categories of Reinforcement Configurations

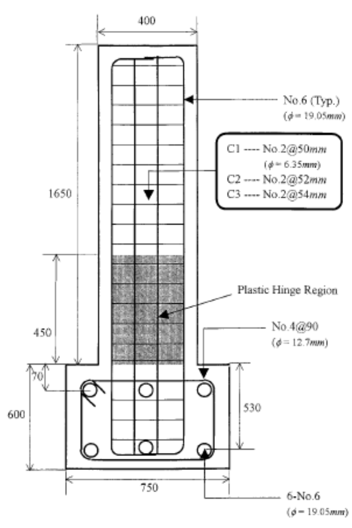

FIG. 3. Reinforcement of Specimen

Shyh-Jiann Hwang(2004)[12] studied the seismic design and detailing of exterior reinforcement concrete Beam- column joints. To investigate the effect of joint hoops on the shear strength of exterior reinforced concrete beam column connections subjected to earthquake loading. The deterioration of beam-column joint under displacement reversals could be effectively restrained by the elastic joint hoops. Lesser amount of hoop reinforcement with wider vertical spacing up to 300 mm could be used without significantly affecting the performance of joints.

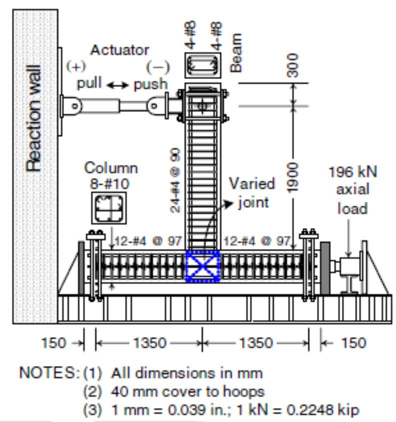

Fig. 2 Specimen configuration and test setup

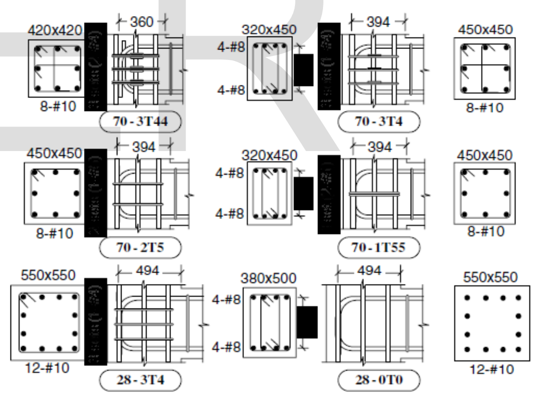

Fig. 3 Beam-column joint details

A.K.Kalilulthin(2014)[13] produced a review on behavior of reinforced concrete Beam- column joint. Deals with the requirement criteria for the desirable performance of joints such as i)The strength of the joint should not be less than the maximum demand ii)The capacity of the column should not be jeopardized by possible strength degradation iii)The joint should also be considered as an integral part of the column. iv)The joint reinforcement necessary to ensure satisfactory performance should not cause undue construction difficulties.

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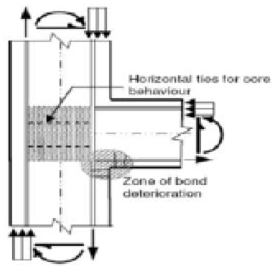


Fig 8: Bond deterioration
(Source: Pradip Sarkar, Rajesh Agrawalet.al., 2007)

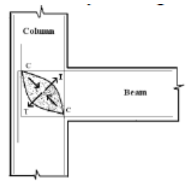


Fig 9: Diagonal compression and tension fields in RC exterior beam-column joints
(Source: PradipSarkar, Rajesh Agrawal and DevdasMenon, 2007)

S. R. Uma & Sudhir K. Jain(2006)[14] formulated a codal review on the seismic design of beam-column joints in RC moment resisting frames. It presents critical review of recommendations on well-established codes, regarding design and detailing aspects of beam column joints. The behavior and expected performance of flexural members of reinforced concrete moment resisting frames can be realized only when the joints are strong enough to sustain the severe forces set up under lateral loads.

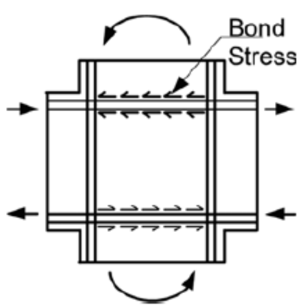
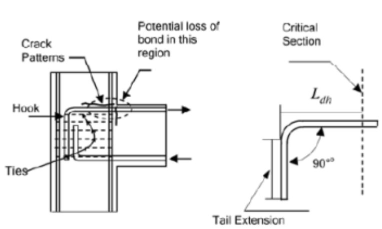


Fig. 2 Bond condition in an interior joint



(a) Anchorage details

Code	Critical section from face of the column	Tail extension
ACI	Column face	$12d_b$
NZS	$min.\ of \begin{cases} h_c/2 \\ 8d_b \end{cases}$	$12d_b$
EN	$5d_b$	$10d_b$

(b) Hook details

Fig. 4 Details of exterior joint

Dr.S.R.Uma and Prof. A. Meher Prasad[15] investigated the seismic behavior of Beam Column Joints in Reinforced Concrete moment resisting frames. One of the basic requirements of design is that the columns above and below the joints should have sufficient flexural strength when the adjoining beams develop flexural over strength at their plastic hinges. he mechanisms involved in joint performance with respect to bond and shear transfer are critically reviewed and discussed in detail. A significant amount of ductility can be developed in a structure with well designed beam-column joints wherein the structural members could perform satisfactorily as per the capacity design principles.

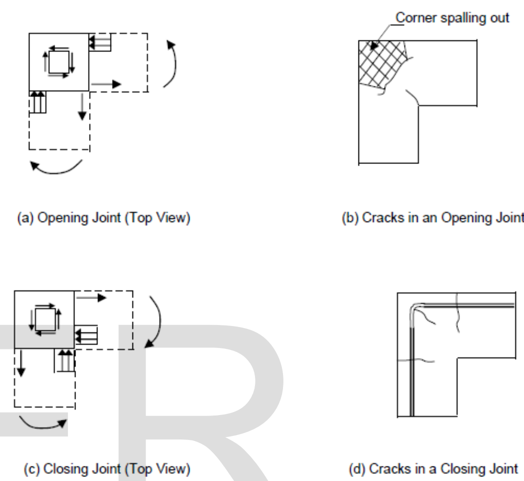


Fig. 4. Corner joints [2]

K.R. Bindhu, P.M. Sukumar and K.P. Jaya(2009)[16] compared the behaviour of exterior beam-column joint sub assemblages with transverse reinforcements detailed as per IS 456 and IS 13920. A six-storeyed RC building in the zone III is analyzed, and one of the exterior beam-column joints at an intermediate storey is designed. All the specimens failed due to the development of tensile cracks at the interface between beam and column. The joint region was free from cracks except for some hairline cracks, and therefore the joints had adequate shear-resisting capacity.

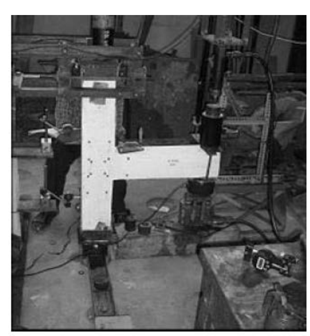


Fig. 6 Test setup in the laboratory

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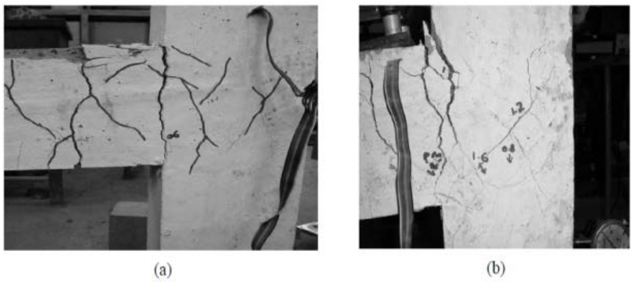

Fig. 8 Crack patterns in the specimens in the first series for (a) Specimen A1-456 and (b) Specimen A1-13920

Hung-Jen Lee and Si-Ying Yu(2009)[17] studied the cyclic response of exterior beam column joints with or without eccentricity to evaluate the use of mechanical anchorages in place of hooked bar anchorages. The primary test variables were the anchorage methods of longitudinal beam bars and the eccentricity between the beam and column center lines. The first pair of joint specimens used standard 90-degree hooks for the beam bar anchorage. The next two pairs of joint specimens used screw deformed bars with mechanical anchorage devices in place of hooked bars in the joints.The use of a single mechanical anchorage device in place of the 90-degree hook terminating in the joint resulted in an equivalent or better performance under large inelastic displacement reversals.

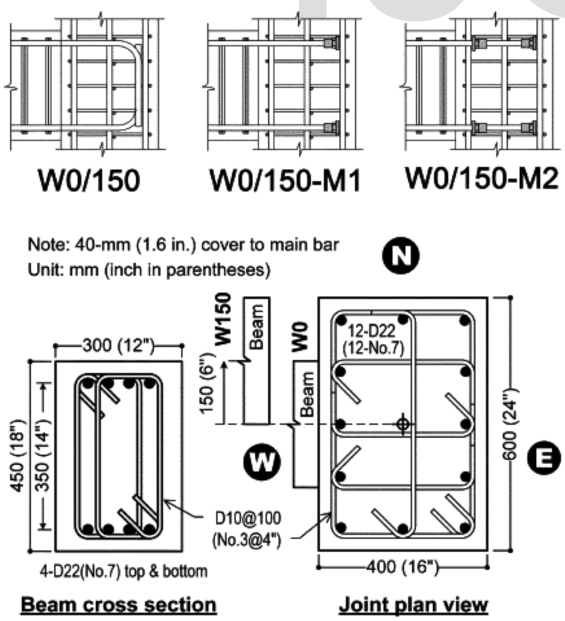

Fig. 3—Specimen designation and reinforcing details.

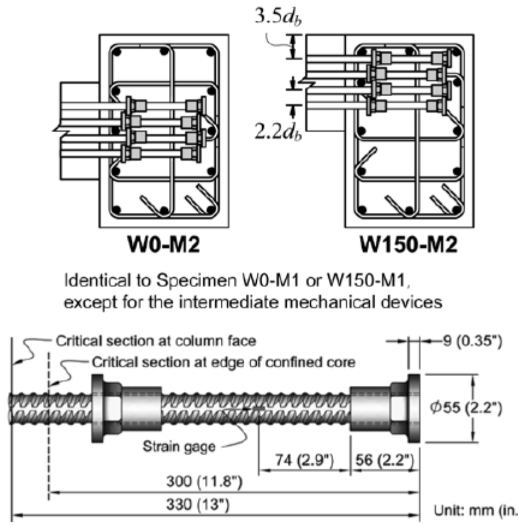

Fig. 4—Details of mechanical devices for test specimens (plan view).

Xilin Lu, Tonny H. Urukap, Sen Li and Fangshu Lin(2012)[18] introduced a new design philosophy involving the use of additional diagonal bars within the joint particularly suitable for low to medium seismic effects in earthquake zones. Ten full-scale specimens were tested and the detailing has been shown to be effective in improving the seismic resistance of joints. The results of the experiment showed that adding additional bars is a promising approach in reinforced concrete structures where earthquakes are eminent. In terms of overall cracking observation during the test, the specimens with additional bars compared with the ones without them showed fewer cracks in the column.

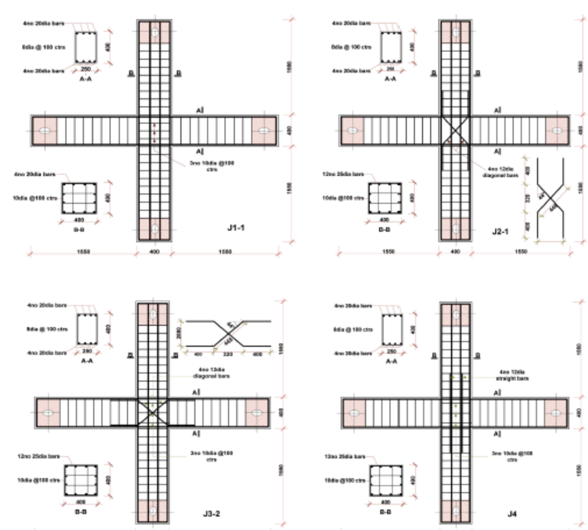

Fig. 1 Sample design and detailing of test specimens. J1-1 (Group I), J2-1 (Group II), J3-2 (Group III) and J4 (Group IV)

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Thomas H.-K. Kang, Myoungsu Shin, Nilanjan Mitra, and John F. Bonacci(2009)[19] provide a detailed review for the test data; and, finally, propose design guidelines to supplement ACI 352R-02 and 318-08 on the subject of headed bars anchored in beam-column joints. The tested specimens are categorized into three different groups in terms of failure modes established by the writers as follows: Category I: member flexural hinging followed by modest joint deterioration Category II: member flexural hinging followed by joint failure Category III: joint failure prior to member flexural hinging. A detailed review of previous research on the use of headed bars in reinforced concrete beam column joints subjected to quasi-static reversed cyclic loading is presented.

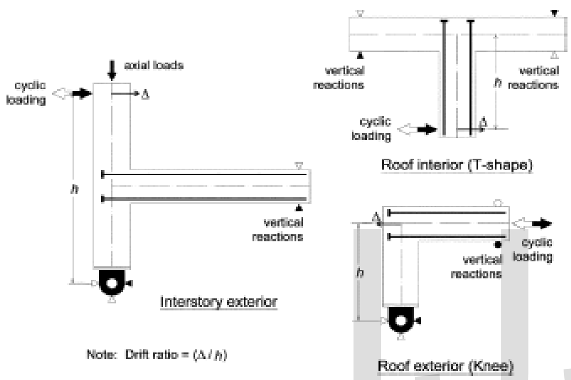

Fig. 2—Schematic diagrams of investigated beam-column joint subassemblies with headed bars.

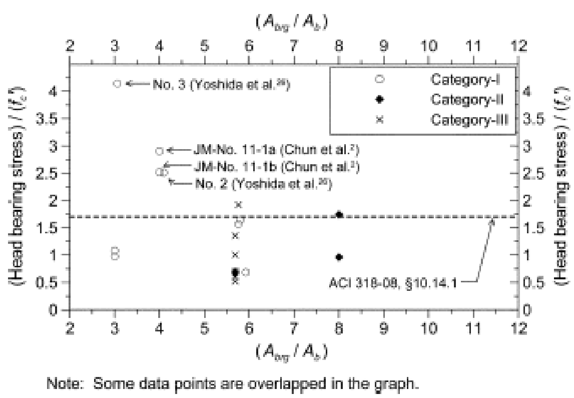

Fig. 9—Head bearing stress versus net bearing area for all categories.

Nilanjan Mitra(2007)[20] developed a series of analysis and design tools to support the performance-based design of reinforced-concrete beam-column joints. Data from previous experimental investigations of joints, spanning a wide range of geometric, material and design parameters, were assembled. The probabilistic modeling strategy provides a first-hand estimate of the factors responsible for failure initiation within the joint region and also identifies the relative importance of the factors in determination of the failure initiation mechanism in the joint region.

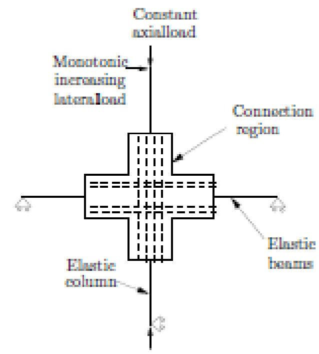

Figure 3.17: Simulated joint specimen with loading and boundary conditions

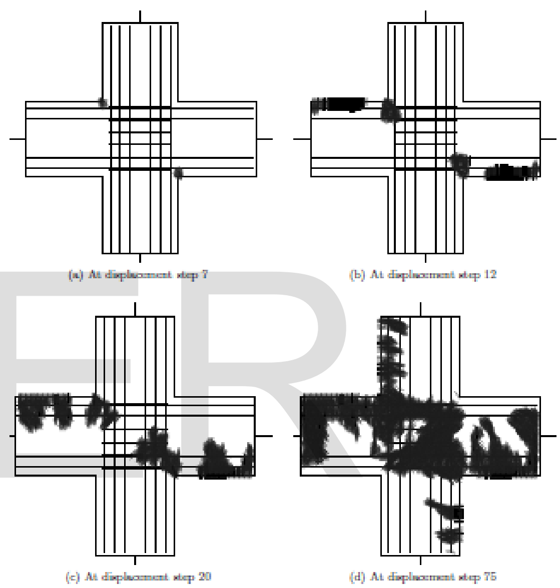

Figure 3.25: Cracked gauss points at different displacements demands

3. CONCLUSION:

The review of the literature shows that the beam column joint requires special attention with respect to its detailing detail. The major source of failure is the lack of capability of the joint to withstand the shear force experienced at the juncture.

Towards the goal of improving such a vulnerable character of the joint, many authors suggested new techniques and methods. They tested these techniques with that of the conventional construction of the beam column joint. All of the testing revealed that the new methodologies adopted by the authors have displayed far better performance in comparison to the conventional beam column joint.

These researches performed have given an insight on various methods to improve such a risky zone of failure. Each of these papers also suggest areas and scope for further study and have given suggestions on how to conduct them as well.

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IV REFERENCE:

[1] Bindhu K R (2009), Behaviour of columns and exterior joints under seismic type loading, *PhD thesis at Anna Univeristy*

[2] Kaviarasu(2012), Influence of joint detailing imprivementin the behaviour of precast beam column joint, *ME thesis at Anna University*

[3] Vandhana R K, Bindu K R (2014), RCC interior beam column joint under reverse cyclic loading,*World Conference on Earthquake Engineering, 2000.*

[4] Shyh-Jiann Hwang, Hung-Jen Lee et. Al.(2005) , Role of hoops on shear strength of reinforced concrete beam-column joints, *Advances in Structural Engineering* Vol. 15 No. 10 2012

[5] SivaChidambaram.K.R, Thirugnanam.G.S (2012), Comparative Study on Behaviour of Reinforced Beam-Column Joints with Reference to Anchorage Detailing, *1122 / JOURNAL OF STRUCTURAL ENGINEERING / OCTOBER 2000*

[6] Stavroula Pantazopoulou and John Bonacci(1992), Consideration of questions about beam column joints, *ACI STRUCTURAL JOUNAL,2000*

[7] Sergio Malcocer(2000) , Behaviour of a precast concrete beam-column connection, *World Conference on Eartquake Engineering, 2000*

[8] Bing Li(2009) , Experimental and Numerical Investigations on the Seismic Behaviour of Lightly Reinforced Concrete Beam-Column Joints, *Advances in Structural Engineering Vol. 15 No. 10 2012*

[9] Mohammad Soleymani Ashtiani et al(2014) , Seismic Performance of High-Strength Self-Compacting Concrete in Reinforced Concrete Beam-Column Joints, *World Conference on Earthquake Engineering, 2012*

[10] Sakai and Sheik (1989) , State-of-the-art report on concrete confinement defining the status of the problem and future direction of work, *ACI STRUCTURAL JOURNAL 1989*

[11] Mo and Wang(2000) , Experiments on RC columns with various tie configurations by reversed cyclic loading, *1122 / JOURNAL OF STRUCTURAL ENGINEERING / OCTOBER 2000*

[12] Shyh-Jiann Hwang(2004) , Seismic Design and detailing of exterior beam column joints, *13th World Conference on Earthquake Engineering*

[13] A.K.Kaliluthin, et. al.(2014) , A Review on Behavior of Reinforced Concrete Beam Column Joint, *International Journal of Innovative Research in Science, Engineering and Technology, Vol. 3, Issue 4, April 2014*

[14] S. R. Uma & Sudhir K. Jain(2006), Seismic design of beam-column joints in RC moment resisting frames - Review of codes, *Structural Engineering and Mechanics, Vol. 23, No. 5 (2006) 579-597*

[15] Dr.S.R.Uma and Prof. A. Meher Prasad , Seismic Behavior of Beam Column Joints in Reinforced Concrete moment resisting frames, *IITK-GSDMA Project on Building Codes*

[16] K.R. Bindhu, P.M. Sukumar and K.P. Jaya(2009), Performance of exterior beam column joint under seismic type loading, *ISET Journal of Earthquake Technology, Paper No. 503, Vol. 46, No. 2, June 2009*

[17] Hung-Jen Lee and Si-Ying Yu(2009), Cyclic Response of Exterior Beam-Column Joints with different Anchorage Methods, *ACI STRUCTURAL JOURNAL*

[18] Xilin Lu, Tonny H. Urukap, Sen Li and Fangshu Lin(2012), Seismic behavior of interior RC beam-column joints with additional bars under cyclic loading, *Earthquakes and Structures, Vol. 3, No. 1 (2012) 37-57*

[19] Thomas H.-K. Kang, Myoungsu Shin, Nilanjan Mitra, and John F. Bonacci(2009) , Seismic Design of Reinforced Concrete Beam-Column Joints with Headed Bars, *ACI STRUCTURAL JOURNAL*

[20] Nilanjan Mitra(2007), An analytical study of reinforced concrete beam-column joint behavior under seismic loading, *PhD thesis at University of Washington*

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