A Review on the Plastic Hinge Characteristics of Beam-Column Joints in RC Moment Resisting Frames

Surya SS*, Sajeeb R

Department of Civil Engineering, T.K.M College of Engineering, Kollam-691005

*Corresponding author: surya959865@gmail.com

doi: https://doi.org/10.21467/proceedings.112.7

ABSTRACT

The behavior of beam-column joints plays a crucial role in the performance of Reinforced Concrete (RC) moment-resisting frames in earthquake-prone areas. In beam-column joints with high strength concrete and shear reinforcement in joints, the plastic hinge is formed at the beam-column joint interface, which is an undesirable failure mode. Predicting the behavior of plastic hinges subjected to large inelastic deformations caused by extreme loads such as earthquake plays an important role in assessing maximum stable deformation capacities of framed concrete structures. The present paper reviews the plastic hinge characteristics of beam-column joints of RC moment-resisting frames. A careful study and understanding of joint behavior are essential to arrive at a proper judgment of the design of joints. Various types of joints and the influence of bond strength characteristics, forces acting on joints, reinforcement detailing, and the concept and formation of plastic hinges in the joints are thoroughly reviewed.

Keywords: Beam-Column Joints, Rotation Capacity, Plastic Hinges.

1 Introduction

Beam-column connections are critical regions for the reinforced concrete framed structures in seismic prone areas. Proper anchorage of reinforcement is essential to enhance the performance. Detailed studies of joints for buildings in seismic regions have been undertaken only in the past three to four decades. It is worth mentioning that the relevant research outcomes on beam-column joints from different countries have led to conflicts in certain aspects of design. In the analysis of reinforced concrete moment resisting frames, the joints are generally assumed as rigid. In Indian practice, the joints are usually neglected for specific design with attention being restricted to the provision of sufficient anchorage for beam longitudinal reinforcement. During a strong earthquake, an RC column develops plastic deformations in regions often defined as plastic hinge regions. The formation of a plastic hinge in an RC column in these regions depends on the characteristics of the earthquakes as well as on the column details.

2 Beam-Column 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 joints should have adequate strength and stiffness to resist the internal forces induced by the framing structures.

2.1 Indian Standard Classification

In a moment-resisting frame three types of joints can be identified: interior joint, exterior joint, and corner joint as shown in figure 1&2. When four beam frames into the vertical faces of a column, the joint is called an interior joint. When one beam frame into a vertical face of the column and two other beams frame from perpendicular

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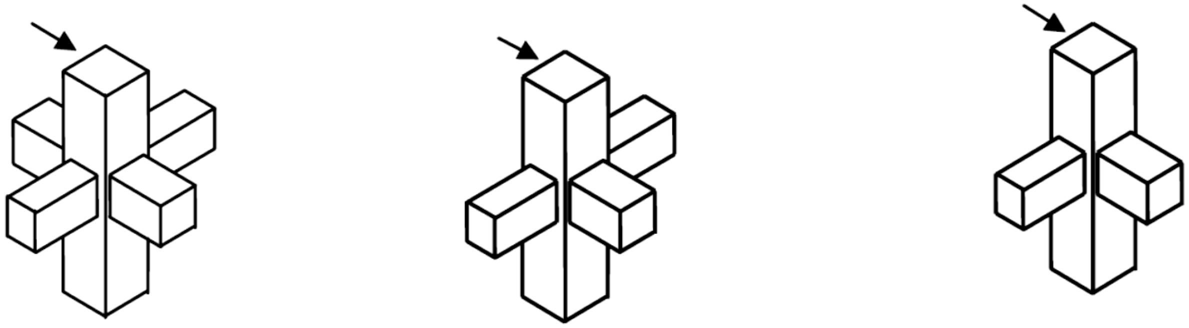
Published by AIJR Publisher in "Proceedings of International Web Conference in Civil Engineering for a Sustainable Planet" (ICCESP 2021) March 5th–6th, 2021. Organized by Habilete Learning Solutions, Kollam, Kerala, India in collaboration with American Society of Civil Engineers (ASCE); TKM College of Engineering; and Baselios Mathews II College of Engineering, Kollam, Kerala, India.

Proceedings DOI: 10.21467/proceedings.112; Series: AIJR Proceedings; ISSN: 2582-3922; ISBN: 978-81-947843-3-3

directions into the joint, then the joint is called an exterior joint. When a beam each frames into two adjacent vertical faces of a column, then the joint is called a corner joint.



(a) Interior Joint (b) Exterior Joint (c) Corner Joint

Figure 1. Types of Joints in a Moment Resisting Frame (Uma and Jain, 2006)

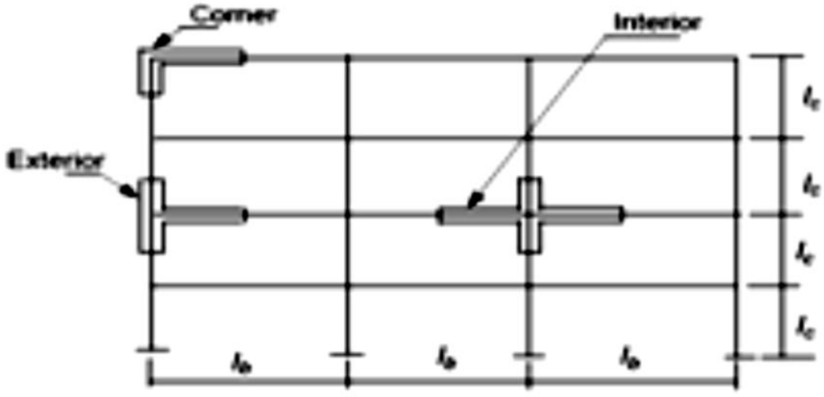


Figure 2. Typical frame with beam-column joints (Uma and Jain, 2006)

2.2 International Classification

ACI-ASCE Committee classifies the beam-column joint in two categories based on loading conditions and anticipated deformations:

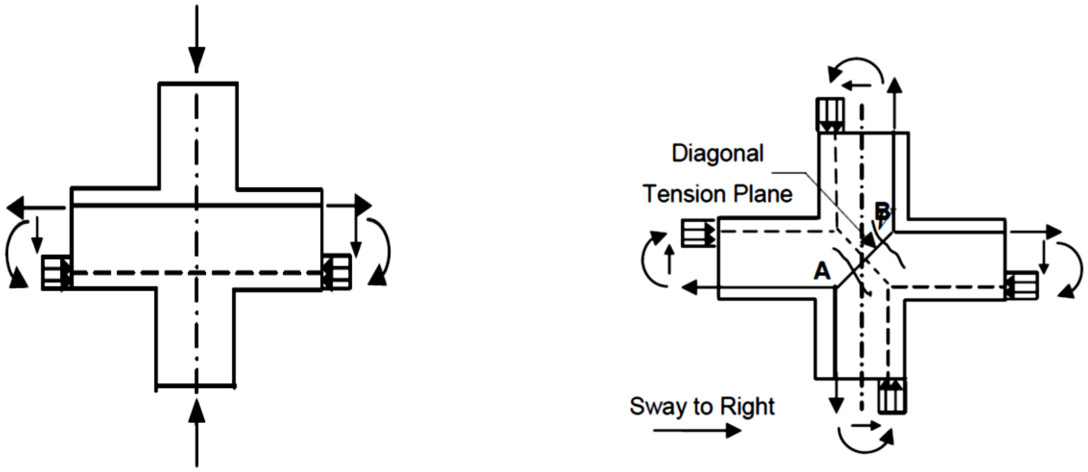
(a) Type 1 joint-These are designed based on strength without considering special ductility requirements.

(b) Type 2 joint:-These are designed to have sustained strength under deformation reversals into inelastic range.

Any joint in a structural frame designed to resist gravity and normal wind loads fall into the Type 1 category. Joints in framed structures designed to resist lateral loads due to earthquake, blast, and cyclonic winds fall into the Type 2 category (ACI-ASCE Committee 352, 1985).

2.3 Forces on joint

The pattern of forces acting on a joint depends upon the configuration of the joint and the type of loads acting on it. The effects of loads on the three joints are discussed with regarding stresses and the associated crack patterns developed in them (Uma and Jain, 2006). The forces on an interior joint subjected to gravity loading can be depicted as shown in figure 3(a) and due to lateral or seismic loading is shown in figure 3(b). Cracks develop perpendicular to the tension diagonal *A-B* in the joint and at the faces of the joint where the beams frame into the joint.



(a) Gravity loading (b) Seismic loading

Figure 3. Forces in interior joint (Uma and Jain, 2006)

2.4 Failure pattern of joint

Flexural cracking in the beam portion during early load stages is followed by the propagation of a diagonal crack in the connection zone. Further loading leads to the failure, either by plastic hinge formation in the beam at the face of the column or by extensive cracking in the connection zone, depending upon the relative influence of reinforcement percentage, detailing, and column load (Scott al, 1996). This behavior of exterior joints up to failure can be divided into two stages: (a) up to diagonal cracking in connection zone and (b) after diagonal cracking up to the failure. The bending moment transferred from the beam to the column is carried by the column in equal amounts, above and below the joint until the diagonal crack forms (Somerville and Taylor, 1972). At the point of joint cracking, the main reinforcement of the beam portion is in tension over its full length at high column loads as indicated in figure 4.

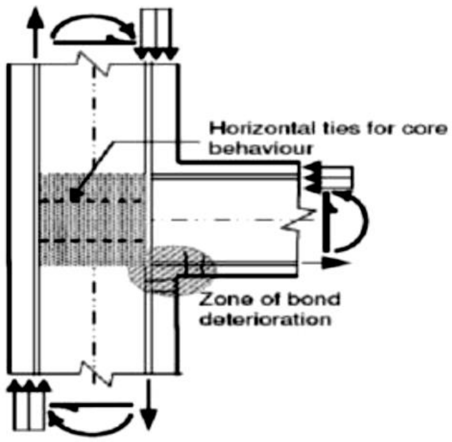


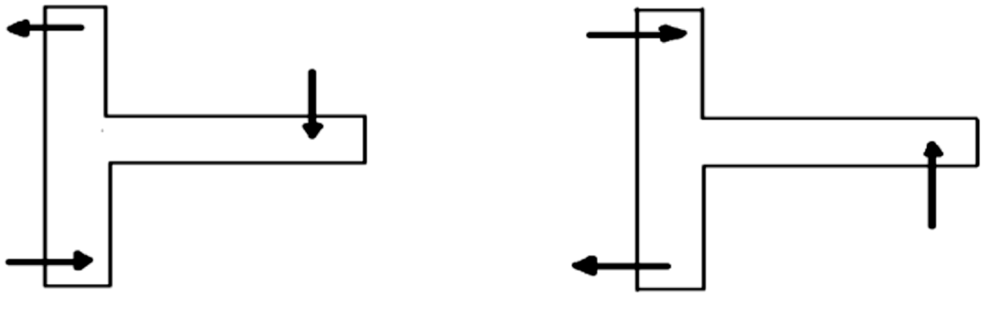
Figure 4. Bond Deterioration (Sarkar and Agarwal, 2007)

2.5 Bond Strength Requirements

The moment resisting frames from the adjoining members cause tension or compression forces in the longitudinal reinforcement passing through the joint. During plastic hinge formation these forces produce large tensile forces that are transferred through the bond. When longitudinal beam bars near the column face are stressed beyond yield stress splitting cracks are initiated along the joint face which is referred to as yield penetration. A longitudinal bar is to be provided with adequate development length at the joint, considering yield penetration into consideration. Therefore, the size of the beams and columns framing into the joint depends on the bond requirement of the bar (Uma and Jain, 2006). The bond performance of the reinforcing bar is influenced by confinement, clear distance between the bars, and nature of the surface of the bar. For effective bond performance confinement of the embedded bar is very essential to transfer the tensile forces. The additional confinement is obtained from column axial compression and with reinforcement that helps in arresting the splitting cracks. Joint horizontal shear reinforcement improves anchorage of beam bars (Ichinose et al, 1991).

2.6 Influence of Loading

One of the factors affecting the beam-column joint behavior is the loading on the joint. Type as well as the amount of load is found to affect the strength, efficiency, rotation capacity, and mechanism of failure. The presence of U and L shaped bars as the top reinforcement for beams is a major factor affecting the ultimate load at the beam tip (Allam et al, 2018). The ultimate load at the beam tip increases with an increase in the number of stirrups. The slip of longitudinal reinforcing bars was addressed to be the main reason for the increase in rotation at the end sections of beams and columns (Joel et al, 2016). The connection between the beam and column must be strong enough as it serves as a part of the vertical load-carrying system. In the conventional cast-in-situ reinforced concrete framed structures the occurrence of reinforcement congestion at beam-column joints to achieve higher yielding strength has remained a continuous problem in the detailing of beam-column joints to endure tough cyclic loading (Yalcinder& Hedayat,2010). The shear capacity of the joints can be enhanced by providing joint ties (Hamil et al, 2000). The presence of beam steel anchorage reduces the joint shear capacity due to the U-bar transferring all the beam's load into the joint region. With the increase of the ratio of bending moment of the column to beam, the plastic hinges are more likely to develop in the beam, and the ductility of the joint improves (Lu et al, 2011).The plastic rotation capacity of the exterior joint decreases with an increase in axial load (Kumar and Shamim, 1999). Typical forces acting on the joint during ground shaking are shown in figure 5.



(a) Ground Movement (Left to Right) (b) Ground Movement (Right to left)

Figure 5. Forces on the exterior joint during ground shaking (ACI 318-02, 2002)

2.7 Significance of Reinforcing bars

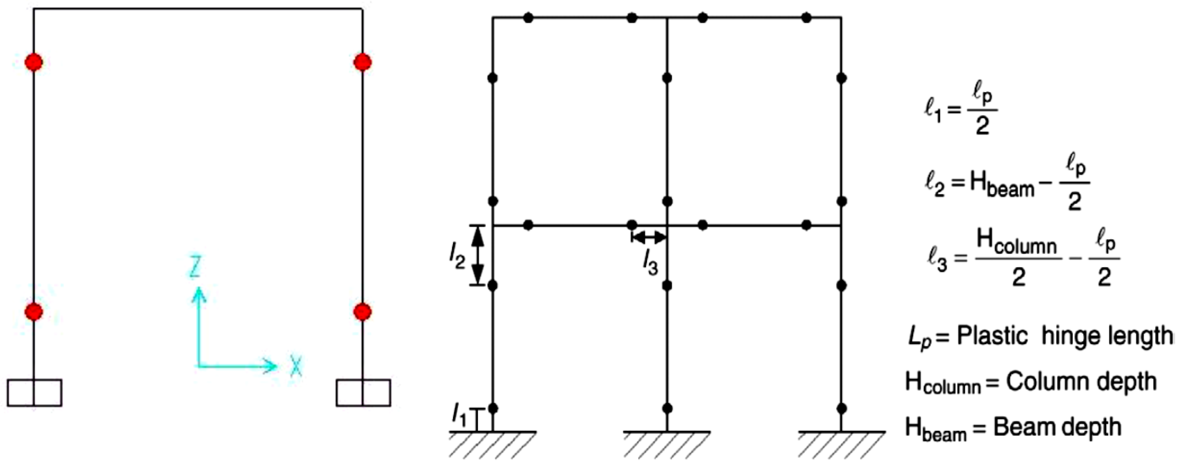
The presence of reinforcement affects the performance of individual members as well as beam-column joints. The lateral drift capacity and energy dissipation capacity improves with the usage of small-headed bars and these joints satisfied the ACI 374 acceptance criteria (Kang et al, 2010). These bars can be effectively anchored in the exterior beam-column joint under inelastic deformation reversals. Potential beam plastic hinge relocation is possible with the use of headed bars. The plastic hinge formation at the face of the column results in the yielding of the reinforcing bars in the beam-column joints results in bond deterioration between the reinforcing bars and the surrounding concrete. Relocating plastic hinges in beams moves the plastic mechanism away from the column face (Chutarat and Aboutaha, 2003). Additional cross diagonal confining bars reduces the formation of cracks in the joint region (Bindhu and Jaya, 2010). Under monotonic loading, the presence of crossbars increases the joint ductility and load-carrying capacity. A large number of closely spaced cracks having lesser crack width develops in beam-column joint with closely spaced transverse reinforcement (Hooda et al, 2013). The addition of steel fibers improves the joint core stiffness which in turn improves the joint behavior for strength and ductility. Joints behave in a ductile manner due to earlier plastic hinging in beams than in the columns (Lu et al, 2011). The load-carrying capacity and the deformation of the beam increases with an increase in the diameter of reinforcing bars (Harish et al,2015). Joints reinforced with additional cross diagonal bars and with steel fibers extending towards the beam and column prevent the crack formation at the interface (Hemalatha et al, 2014). The addition of steel fibers has a major influence on increasing the shear capacity of the joint. For a precast beam-column joint, the joint ductility can be enhanced with doweled bars and cleat angles (Chakravarthy et al, 2018) as connectors. The satisfactory performance of a beam-column joint, particularly under seismic loads, depends strongly on the lateral confinement of the joint. Effective confinement benefits in two ways: (1) core concrete is strengthened and its strain capacity is increased, and (2) column longitudinal bars are prevented from buckling. Confinement of core concrete is achieved by a combination of longitudinal column reinforcement and either transverse members framing into the column or transverse reinforcement or both (ACI-ASCE Committee1985).ACI-ASCE Committee 352 recommends that at least two layers of longitudinal reinforcement should be provided between the top and bottom levels of longitudinal reinforcement of the deepest beam framing into the joint.

3 Concept of Plastic Hinges

The ability of statically indeterminate structures of ductile material to yield at critically stressed sections while maintaining approximately constant moments of resistance at these sections, causes further load increments to be re-distributed onto other stronger parts of the structure so that the structure will bear as much load as it possibly can before failure occurs. This forms the basic concept, whether the theory is applied to reinforced concrete or structural steelwork. Plastic behavior characterized by large plastic rotations without appreciable change in moments of resistance at these points under further loading causes the extra loads to be borne by other critical sections that still remain elastic. Such regions behave like hinges rotating under constant plastic moments and are termed plastic hinges

3.1 Formation of plastic hinges

The formation of plastic hinges in a structure has considerable importance, therefore the main aim of the researchers was to understand the sequence of formation of plastic hinges (Ravikumara et al, 2015) during ground motions. In a moment-resisting frame, the formation of plastic hinges can be assessed concerning the elastic stiffness value (Hassan et al, 2020). A nonlinear analysis can be used to capture the possible plastic hinge locations with sufficient accuracy with more hinges appearing at the columns. In ductile moment-resisting frames which comprise of beam and columns, plastic hinges are usually formed at the interface of the beam-column joints, especially for short span beams. But in long-span beams where the dominant load is gravity load, the plastic hinge may form outside the beam-column joint interface at a distance inside the beam (Paulay and Priestley, 1992).To avoid the formation of plastic hinges at the joint interface a special detailing of longitudinal steel reinforcement in the beam at critical section around the joint (Fadi and Hacha, 2014) such as the slotted-beam detailing technique has been proposed for ensuring plastic hinge relocation from the face of the column to the beam. In buildings constructed before the enforcement of joint shear reinforcement, the joints were mostly deficient, resulting in the formation of the plastic hinge in the core of the joint (Baluch et al. (2012), which led to brittle failure. Plastic hinges will form in the redundant RC structure when one of its critical sections reaches the ultimate capacity (Abdelwahed et al, 2019). The number of plastic hinges and its location is shown in figure 6 (a) and (b)



(a) (b)

Figure 6. Location of plastic hinges

(a) in beams (Ravikumara et al, 2015) (b) in columns and beams (Inel and Ozmen, 2006)

3.2 Significance of Hinge Rotation Capacity.

The rotation capacity is defined as the rotation of a critical section of a beam from the yield stage to the ultimate stage (Prabhakara et al, 2020). A change in loading conditions enhances the rotation capacity of plastic hinges in beam-column joints. Plastic hinge rotation capacity depends on both the type of loading and the reinforcement index. Reinforcement index (ω) is given by ω=ϱ*fy/f′c, where ϱ is the reinforcement percentage given by$100 * As/(b * d)$**,** fy is the yield strength of tension reinforcement and f′c is the compressive strength of concrete (Kheyroddin et al, 2007). Plastic hinge rotation capacity can be determined as the integral of the curvature after steel yielding in the plastic zone given by (Carmo et al, 2010):

$$\theta pl = \int_0^{lp} \frac{1}{(r} - \frac{1}{ry)} * dl = \int_0^{lp} \frac{(\varepsilon s - \varepsilon sy)}{(d-x)} * dl \tag{1}$$

(Where $1/r$ is the total curvature, $1/ry$ is the yielding curvature, $\mathcal{E}s$ total strain & $\mathcal{E}sy$, yielding strain of steel reinforcement, x is the neutral axis depth and θpl is the plastic rotation capacity). The forced-based plastic hinge integration methods can be used for determining the plastic rotations of the beam-column connections (Scott et al, 2006). For a displacement-based formulation, the plastic hinge rotation is computed from the boundary values of the displacement field. However, in a displacement formulation as every single member consists of several displacement fields it is more difficult to compute plastic rotation with this formulation. The relative rotations developed by the slippage of the reinforcement in the beam inside the joint region and the relative rotations produced by the combined effect of local slips caused due to opening of cracks in the beam adjacent to column along the length *lp* (Length of the plastic hinge) (Alva et al ,2013). Plastic hinges will form in the beam-column joints of moment-resisting frames as a result of the rotational difference between auxillary nodes (Huras et al, 2018).

3.3 Significance of Energy Dissipation Characteristics

Plastic energy is dissipated through the rotational deformations of the beam, column plastic hinges, and it includes the contribution from the axial deformation of the column plastic hinges (Merter et al, 2017). The total plastic energy in the whole frame is obtained from the sum of the plastic energy dissipated in beam and column plastic hinges as shown by equation (2).

$$\Sigma Ep, frame(t) = Epi - beam(M - \theta) + Epi - column(M - \theta) + \Sigma|Nc * \delta pc| \qquad (2)$$

The total plastic energy dissipated (ΣEp, frame *(t)*) in a frame has two separate parts. The term Epi-beam $(M - \theta)$ represents the contribution of beam members to the total plastic energy dissipation and Epi-column $(M - \theta) + \Sigma \mid NC * \delta$pc $\mid$ represents the contribution of column members to the total plastic energy contribution in a framed structure due to its nonlinear behavior. The low energy dissipation capacity of beam-column joints improves the ductility requirement of the low-rise RC moment frame structures (Jiang et al, 2018). Additional diagonal reinforcing bars have improved energy dissipation capacity than the beam-column joints detailed with conventional reinforcements (Bindhu and Jaya,2010). For a dapped-end (Liu et al,2019), beam to column joint under reverse loading the plastic hinges relocates at a certain distance away from the column edge due to the improved structural integrity of the joint. A sample plastic hinge mechanism of the RC multi-story frame structure which is affected by a strong ground motion and plastic energy distribution is shown in figure7. The Contribution of rotational deformations of beam and column plastic hinges and the contribution of axial deformations of column plastic hinges to the total plastic energy dissipation (Meter et al, 2017) is shown in figure 8.

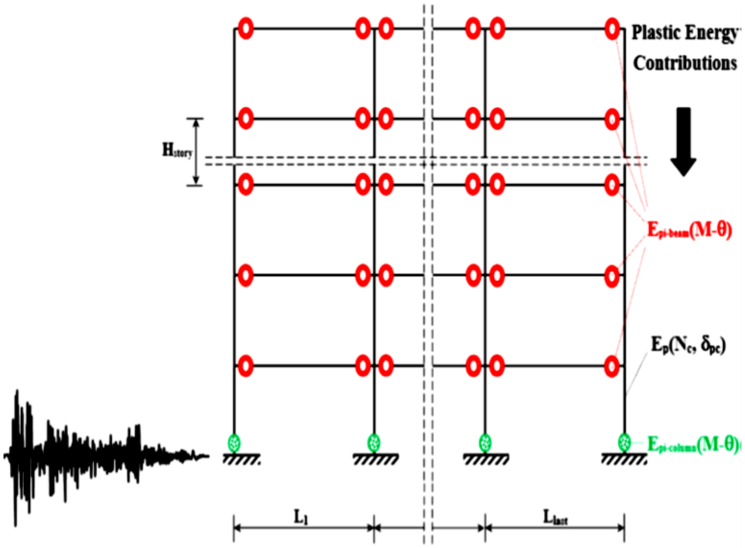


Figure 7. Sample plastic hinge mechanism

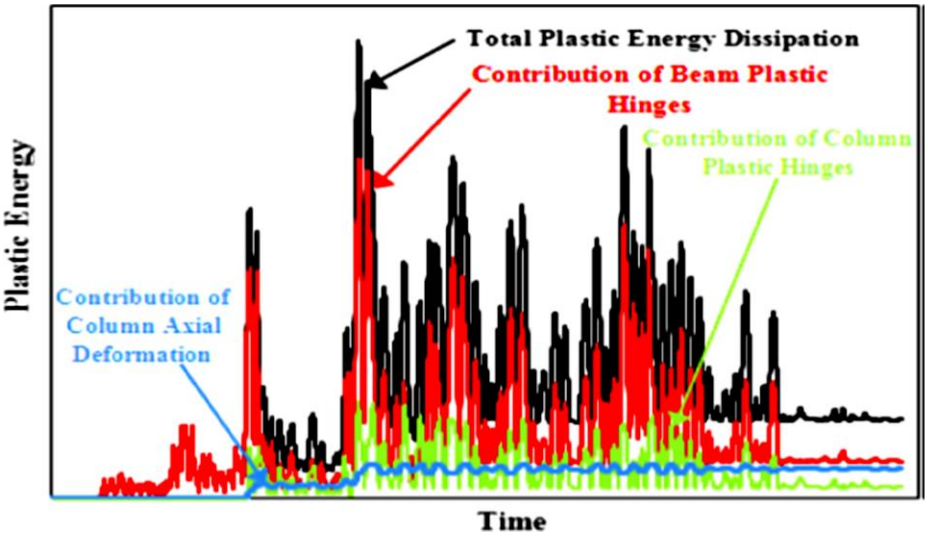


Figure 8. Plastic energy contribution graph and plastic energy dissipation (Merter et al, 2017)

4 Conclusion

The design of beam-column joints has been given less attention in the Indian design practice. The behavior of beam-column joints plays a crucial role in the seismic performace of moment-resisting frames. The general behavior of common types of beam-column joints in reinforced concrete moment-resisting frames and the mechanisms involved in a joint performance concerning bond and shear transfer have been reviewed. The following conclusions may be drawn from the review carried out:

(i) Failure of the beam-column joint generally happens either by the formation of the plastic hinge in the beam at the face of the column or by extensive cracking in the connection zone. The failure pattern is dependent on reinforcement percentage, detailing, and column load.

(ii) A longitudinal bar is required to be provided with adequate development length at the joint to prevent yield penetration. The size of the beam and column at the joint depends on the bond requirements of the bar.

(iii) The shear capacity of the joints can be enhanced by providing joint ties.

(iv) The plastic hinge formation at the face of the column results in yielding of the reinforcing bars which in turn results in bond deterioration between the reinforcing bars and the surrounding concrete

(v) The addition of steel fibers improves the joint core stiffness, which in turn improves the joint behavior concerning strength and ductility.

(vi) Joints reinforced with additional cross diagonal bars and with steel fibers extending towards the beam and column prevents crack formation at the interface

(vii) Special joint detailing resulted in the shifting of plastic hinges away from the column face.

(viii) 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 design principles

All parameters affecting the behavior of beam-column joints should be considered while designing the joint to ensure a proper seismic performace of moment-resisting frames in earthquake-prone areas.

How to Cite this Article:

Surya, S. S., & Sajeeb, R. (2021). A Review on the Plastic Hinge Characteristics of Beam-Column Joints in RC Moment Resisting Frames. *AIJR Proceedings*, 52-61.

References

Abdelwhaed, B. (2019). *Numerical Analysis of Progressive Collapse for Reinforced Concrete Frames.* Applied and Computational Mechanics, 1385-98.

ACI 318-02. (2002)*Building Code Requirements for Structural Concrete (ACI 318M-02) and Commentary (ACI 318M-02)*, American Concrete Institute, ACI Committee 318, Farmington Hills, MI, 2002.

ACI-ASCE Committee 352. (1985) *Recommendations for Design of Beam-Column Joints in Monolithic Reinforced Concrete Structures*, ACI, J., pp.266-283.

Ali, Kheryoddin. & Hosein, Naderpour. (2007). *Plastic Hinge Rotation Capacity of Reinforced Concrete Beams*. International Journal of Civil Engineering, Vol.5 No.1.

Alva, G.M.S., Ana, LHCE.& Mounir Khalil, E.D.(2007). *An Experimental Study on Cyclic Behaviour of Reinforced Concrete Connections*. Canadian Journal of Civil Engineering, 34565-75.

Baluch, M.H., Rahman, MAKE., Ahmed. D .&llki, A.: *Finite Element Simulation of Low Concrete Strength Beam-Column Joints Strengthened with CFRP*, 15th World Conference on Earthquake Engineering (2012).

Bindhu, K.R. &Jaya, K.P.(2010). *Strength and Behaviour of Exterior Beam-Column Joints with Diagonal Cross Bracing Bars*. Asian Journal of Civil Engineering (Building and Housing),Vo1.11 No.3,pp .397-410.

Chutarat, N. &Aboutaha, R.(2003). *Cyclic Response of Exterior Reinforced Concrete Beam-Column Joints Reinforced with Headed Bars-Experimental investigation*. ACI Structural Journal, 100(2):259-264.

Fadi, O.&El-Hacha, R.: *Plastic Hinge Relocation using the RC Beam-Column Connection.* Proceedings of 10th U.S National Conference in Earthquake Engineering, Earthquake Research Institute, AK,(2014).

Hakan Yalciner., &Amir, A. Hedayat. (2010). *Repairing and Strengthening of an Existing Reinforced Concrete Building: A North Cyprus Perspective*. American J. of Engineering and Applied Sciences 3 (1): 109-116, 2010 ISSN 1941-7020

Hamil, S.J.:*Reinforced Concrete Beam-Column Connection Behavior*. Ph.D. Thesis, University of Durham, UK(2000).

Hareesh, R., Nambiyanna, B. & Prabhakara, R.(2015). *Analytical Investigation of External Beam-Column Joint Using ANSYS By Varying The Diameter of The Longitudinal Reinforcement in Beam*.International Journal of Engineering Research and Applications, ISSN:2248-9622, Vol-5,Issue-8,(Part-1), pp.01-05.

Hemalatha, G. & Johnson,K.(2017). *Analysis and Experimental Study on Strength and Behavior of Exterior Beam-Column Joints with Diagonal Cross Bracing Bars and Steel Fibers for Improving The Join Ductility*.International Journal of Civil Engineering and Technology(IJCIET), Vol-8, Issue-1, pp.170-188.

Ichinose, T.(1991). *Interaction Between Bond at Beam Bars and Shear Reinforcement in RC Interior Joints*.Design of Beam-Column Joints for Seismic Resistance, SP-123, American Concrete Institute, Farmington Hills, Mich, pp.379-400.

Jiang, K., Feng.F., Hwang, H.G. & Yi W.J.(2018*). Earthquake Response of Low Rise RC Moment Frame Structures According to Energy Dissipation Ratio of Beam-Column Joints*, Journal of Structural Integrity and Maintenance, 3(1), 33-43.

Kalyana Chakravarthy, P., Janani, R.& llango, T.(2018). *Analyzing the Strength Aspects of Precast Reinforced Beam-Column Connections*. International Journal of Mechanical Engineering and Technology, Vol-9, Issue-13, pp.118-133.

Kumar, V. & Shamim, M.(1999). *Influence of Beam Reinforcement on Exterior Beam-Column Joints*. Journal of Structural Engineering, SERC, Vol-26, No-2, pp.123-127.

Lukasz, Huras., Piotr, Bonkowski., Marek, Nalepka., Seweryn, Kokot. &Zbigniew, Zembaty,(2018*). Numerical Analysis of Monitoring of Plastic Hinge Formation in frames Under Seismic Excitations*. Journal of Measurements in Engineering, Vo1.6 Issue.4, ISSN:2424-4635.

Mahmoud, Al-Hassan. &Mohamad, Abdelrahim.(2020*). Plastic Hinge Assessment of RC Moment Resisting Frames*. International Journal of Advanced Engineering, Sciences and Applications, Vol.1, Issue-3, Pages 37-41, ISSN:2703-7266.

Mehmet, Inel. &Hayri Baytan, Ozmen. (2006). Effects *of Plastic Hinge Properties in Nonlinear Analysis of Reinforced Concrete Buildings*. Engineering Structures, 28(2006)1494-1502.

Michael, H, Scott.& Gregory, L, Fenves,(2006). *Plastic Hinge Integration Methods for Force-Based Beam-Column Elements*.Journal of Structural Engineering, 1342:244-252.

Naveen, Hooda., Jyoti, Narwal., Bhupinder, Singh., Vivek, Verma.&Parveen, Singh.(2013). *An Experimental Investigation on Structural Behavior of Beam-Column Joint*.International Journal of Innovative Technology and Exploring Engineering (IJITEE), Vo1.3, Issue-3, ISSN: 2278-3075.

Onur, Merter.& Taner, Ucar. (2017). *An Analytical Research on Determination of Bean and Column Contribution to Plastic Energy Dissipation of RC Frames*.Arab Journal of Science and Engineering, 42:3761-377.

Paulay, T., Priestley, M.J.N.: Seismic Design of Reinforced Concrete and Masonry Buildings, Wiley, New York(1992).

Pradip, Sarkar., Rajesh, Agarwal.&Devadas, Menon. (2007). *Design of RC Beam-Column Joints Under Seismic Loading-A Review*. Journal of

Structural Engineering, Vol-33, N0-6, pp.449-457.

Prbhakara, R., Nambiyanna, B., Nakul, R. &Bharathi, Ganesh. (2020). *Analysis of Rotation Capacity of RC Beams Over Formation of Plastic Hinges*. Advances in Structures, Systems, and Materials, pp .259-266.

Qiong Liu, Shanghong Chen, Wein Lin &Fanjin Zeng (2019). *Experimental Study on Novel Energy- Dissipating Prefabricated Beam-Column Joints*. Advances in Civil Engineering, Article ID: 8151087,17 pages.

Ravikumara, H.S., Supriya, Kulkarni, R.& Babu, Narayan, K.S.(2015). *A Study on Plastic Hinge Formation in RC Frame by Nonlinear Static Analysis*. International Journal of Research in Engineering and Technology,eISSN:23191163.

Ricardo ,Joel, Teixeira ,Costa., Paulo ,Providencia, A .& Dias, M.P.G .(2016). *Anchorage Models for Reinforced Concrete Beam-Column Joints Under Quasi-Static Loading*.ACI Structural Journal, 113(3):503-51.

RNF ,do, Carmo,J., Valenca, D.&Dias-da-Costa.(2013). *Plastic Rotation and Tension Stiffening Effect Analysis in Beams Using Photogrammetry*. IBRACON Magazine of Structures and Materials Vol-6, No-3, pp. 475-498, ISSN:1983-4195.

Said M, Allam., Hazem, M.F Elbakry., & Israa, S.E Arab. (2018). *Exterior Reinforced Concrete Beam-Column Joint Subjected To Monotonic Loading*. *Alexandria Engineering Journal*,57, 4133-4144.

Scott, R.H.(1996). *Intrinsic Mechanism In Reinforced Beam-Column Connection Behavior*. ACI.Structural Journal, pp.336-346.

Somerville, G.&Taylor, H.P.J.(1972). *The Influence of Reinforced Detailing on the Strength of Concrete Structures*. The Structural Engineer, pp.7-19.

Thomas, H, Kang, K., Sang-Su, Ha.&Dong-Uk, Choi. (2012). *Bar Pullout Tests and Seismic Tests of Small-Headed Bars in Beam-Column Joints*. ACI Structural Engineering, Vol-107, No-1, Title No.107-S04,

Uma,S.R.& 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, pp.579-597.

Xilin, Lu., Tony, H, Urukap., Sen, Li.& Fangshu, Lin(2012). *Seismic Behavior of Interior RC Beam-Column Joints with Additional Bars Under Cyclic Loading*. Earthquake and Structures, Vol.3, Issue 1, pISSN: 2092-7614, eISSN: 2092-7622.