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# A Literature Review on Beam Column Joints with Different Loading Condition and Methods of Strengthening

Satish S. Kotwal[1], Vidyanand S. Kadam[2], Mayur M.More[3], Ananda S Patil[4], Nitish A Mohite[5]
*1, 2, 3, 4, 5 Assistance Professor, Bharati Vidyapeeth's College of Engineering, Kolhapur,*

***Abstract: The beam–column joint is measured as the most important zone in a reinforced concrete moment resisting frame. It is subjected to large forces during earthquake and its behaviour has a major influence on the response of the entire structure. As a result, a great attention has to be paid for good detailing of such joint. The absence of transverse reinforcement in the joint, insufficient development length for the beam reinforcement and the inadequately spliced reinforcement for the column just above the joint can be considered as the most important causes for the failure of the beam–column joint under any unexpected transverse loading on the building. The recent earthquakes revealed the importance of the design of reinforced concrete (RC) structures with ductile behaviour. Ductility can be described as the ability of reinforced concrete cross sections, elements and structures to absorb the large energy released during earthquakes without losing their strength under large amplitude and reversible deformations.***

## I. LITERATURE REVIEW

### *A. Said M. Allam , Hazem M.F. Elbakry , Israa S.E. Arab(2018)*

The joints between beams and columns are crucial zones in a reinforced concrete moment resisting frame. The behaviour of such joints greatly influences the strength and ductility of the overall frame. In this research, analysis of three-dimensional numerical models of exterior reinforced concrete beam-column joints under monotonic loading was performed using the finite element ABAQUS package.

Concrete and reinforcing steel material nonlinearities, as well as bond characteristics between reinforcing bars and surrounding concrete were considered in the analysis. A parametric study involving thirty joint models was conducted to examine the influence of concrete strength, column axial load, joint stirrups and shape of the beam top reinforcement on the beam tip load and displacement capacities.

The concrete dimensions and reinforcement of the studied models were chosen to ensure the occurrence of joint failure. The use of straight bars for beam top reinforcement resulted in generally lower ultimate loads than those obtained with L- and U-shaped bars. Similar joint behavior was demonstrated for the cases of using Land U-shaped beam top reinforcement.

### *B. Jawed Qureshi, Dr. Yashida Nadir, Shaise K John(2020)*

Presented are test results from eight full-scale pultruded FRP beam-to-column joint subassemblies. Moment-rotation behaviour, failure modes, joint classification and load enhancement due to semi rigid end conditions are discussed. Testing is divided in two series: first had FRP beam-to-steel column joints and second FRP beam-to-FRP column joints. The joints are either flange and web cleated or flange cleated only.

The connection method is bolting or 'hybrid' combining both bolting and bonding. Test parameters include effects of adhesive bonding, column flexibility, cleat material and joint configuration. Bolted and bonded joints not only increased moment resistance but stiffness as well. Using steel cleats instead of FRP resulted in a 50% increase in the moment resistance. Four failure modes, shear-out failure, adhesive debonding with shear-out failure, tensile tearing of the column flanges from the web and de lamination cracking of cleats were observed. Use of adhesive increased both moment capacity and rotational stiffness, but it reduced the maximum rotation capacity. Bolted and bonded joints failed in a brittle manner due to adhesive failing in tension and shear, and the failure transferring to the bolted region. There was 60% increase in moment capacity for FRP beam-to-steel column joints and 20% for FRP beam-to-FRP column joints. While industry practice of using adhesive alongside bolting should be continued, any improvement in either moment or rotational stiffness should be used cautiously.

*C. Hussein M. Elsanadedy, Yousef A. Al-Salloum, Mohammed A. Alrubaidi, Tarek H. Almusallam, Nadeem A. Siddiqui, Husain Abbas,(2020)*

This study aims at investigating the efficacy of using an innovative hybrid strengthening technique composed of near-surface mounted (NSM) steel rebars along with fiber reinforced polymer (FRP) sheets to prevent (or diminish) the risk of progressive collapse in precast reinforced concrete (RC) beam-column joints. The study details tests involving one control specimen that is a half-scale single-story precast RC beam-column assembly having two bays. One monolithic test specimen with continuous longitudinal beam rebars was employed for comparison. The third specimen was similar to the control one, but it was retrofitted using FRP sheets combined with NSM steel rebars within the beam-column joint zone. The base of the center column was released, and a dynamic load was applied in the vertical direction on this column for simulating the column-removal scenario of progressive collapse. The proposed strengthening technique was efficient at enhancing the peak load and dissipated energy of the upgraded specimen by about 16.9 and 12.4 times, respectively, of control precast specimen. The provision of end anchorage of bolted steel plates at the end of CFRP sheets of outer joints of strengthened specimen PC-S not only altered the failure mode from interfacial end debonding to IC debonding but also enhanced the peak load resistance by about 10% due to the delay of the CFRP debonding at outer joints.

*D. JianBing Yu, Wei Zhang, ZhanZhan Tang, Xuan Guo, Stanislav Pospisil(2020)*

This paper experimentally investigated the seismic behaviour of 9 full-scale reinforced concrete (RC) joints—8 precast RC joints and 1 cast-in-place RC joint—under cyclic loading. The precast concrete (PC) joints were divided into 3 types: cast-in-place, precast beam cast-in-place column, and fully precast with assembly. With the presence additional reinforcement at the joint core and debonding of reinforcement in some joints, the PC joints differed with other types of joints. The experimental results, such as hysteretic behavior, energy dissipation capacity and stiffness degradation, were analyzed, which showed that the PC joints with steel strands anchored into the joint core zone could meet the seismic code requirements. Additionally, a finite element analysis of the new type of PC joint was performed numerically, and the predicted seismic performance was in very good agreement with the experimental results. Finally, a skeleton model of the PC joint was established through parameter analysis. A parametric numerical analysis of the new type of PC frame beam column joints showed that the axial compression ratio had a great influence on the bearing capacity of the specimen. Increasing the concrete compressive strength and the additional reinforcement diameter in the joint core zone can increase the stiffness of the joint to a certain extent

*E. Xinyu Shen, Bo Li, Yung-Tsang Chen, Walid Tizani(2020)*

Horizontal stirrups are normally required in reinforced concrete (RC) beam-column joints (BCJs) for resisting shear forces in seismic design. For RC moment-resisting frames subjected to a high lateral load, a large number of stirrups are needed in joint cores. This may cause reinforcement congestion, leading to construction difficulty and insufficient concrete compaction, which can result in poor seismic performance. In this study, a novel reinforcement detail in the form of unbonded diagonal bars mechanically anchored at beam ends is proposed for RC interior BCJs. The detail alleviates the reinforcement congestion through partially replacing horizontal stirrups, and improves the seismic performance of BCJs by plastic hinge relocation and input shear force reduction mechanisms. Four 2/3-scale RC interior BCJ specimens were prepared and tested under quasi-static cyclic load, including one specimen designed with the current code and three specimens adopting the proposed reinforcement detail. Test results show that the proposed reinforcement detail is able to relocate the plastic hinges away from beam-joint interfaces as well as improve the loading capacity, energy dissipation capacity, stiffness, and bonding condition of beam reinforcements within the cores of BCJs. The combined use of stirrups and the proposed reinforcement detail significantly enhances the cracking resistance and reduces joint distortion, while additional amount of stirrups results in a marginal improvement. Replacing horizontal stirrups with the proposed reinforcement detail in BCJs can alleviate the reinforcement congestion inside the joint core. However, conventional stirrups are still necessary to confine the joint cores and resist shear forces in BCJs with the proposed reinforcement detail.

*F. P. Saranya, Praveen Nagarajan, A.P. Shashikala(2020)*

Geopolymer concrete (GPC) is a cementless concrete in which polymerization gives strength to concrete. In this present study, geopolymer concrete was developed from Ground Granulated Blast furnace Slag (GGBS) and dolomite. The behaviour of GGBS-dolomite geopolymer concrete was found to be brittle in nature. Experimental investigations were conducted to evaluate the effect of the addition of steel fibres to GGBS-Dolomite geopolymer concrete. Improved engineering properties were observed for steel fibre reinforced geopolymer concrete.

The performance of beam-column joints was monitored with the addition of 0.25, 0.5 and 0.75% steel fibres by volume of concrete under monotonic loading. Parameters such as ultimate load, energy absorption capacity, and ductility index and crack behaviour of steel fibre reinforced geopolymer concrete were compared with geopolymer concrete (without steel fibres). Higher ductile behaviour, energy absorption and toughness were observed along with the addition of steel fibres. Geopolymer concrete was developed from industrial by products such as GGBS and dolomite. Maximum compressive strength was obtained when GGBS and dolomite become 70:30. Compressive strength was found to increase with the addition of steel fibres. Maximum compressive strength was obtained with the addition of 0.75% steel fibres, further addition of steel fibres reduces compressive strength due to balling effects.

*G. Muhammad Shoaib Khan, Abdul Basit, Naveed Ahmad(2020)*

This paper presents a simplified beam-column joint modeling technique for the inelastic analysis of reinforced concrete moment-resisting frames. The joint model consists of a zero-length link element that is provided with moment-rotation lumped plasticity hinge, provided at the intersection of beam/column elements, to simulate the nonlinear shear behavior of the joint panel. The backbone of the moment-rotation constitutive law was defined using the empirical shear stress-shear strain relationship proposed by Kim and LaFave. The hysteretic response of the joint was simulated using the multi-linear hysteretic rule proposed by Sivaselvan and Reinhorn. The modeling technique was applied to two portal frames tested under quasi-static cyclic loads for predicting the cyclic force-displacement hysteretic response. The prediction was found in good agreement with the experimental response; the numerical models were efficient in simulating the shear behavior of the joints, loading/ unloading stiffness and pinching behavior of the frames' lateral force-displacement hysteretic response. The modeling technique was extended to two-story frames for nonlinear response history analysis for both design base and maximum considered earthquakes. Inter-story drift demands were obtained and critically compared to highlight the efficacy of the accurate modelling of beam-column joint using lumped plasticity shear simulation hinges. The proposed joint shear hinge element is capable of simulating the shear behavior of the joint core area. The model is promising in predicting the cyclic response of RC frames with and without shear reinforcement in the joint. The local damage mechanism predicted using the modeling technique was in good agreement with the experimentally observed damage mechanism.

*H. S. Venkatarajan , A. Athijayamani(2020)*

For last few decades, a momentous amount of interest has been exposed on the possible usages of natural cellulose fibers to replace synthetic fibers like glass, aramid and carbon, in polymer matrix composites. Even though natural fibers are not as strong as synthetic fibers, these are abundantly available, low density, low cost, renewable, and biodegradable. Due to the high price of composites reinforced with synthetic fibers and environmental concerns, the manufacturing industries demand better materials with high strength-to-weight ratio for production of parts and components at the same time with an improvement in quality. With the help of proper review on the performance of natural cellulose fiber reinforced polymer composites, engineers and researchers involved on the development of environmentally friendly materials can develop new materials satisfying ecological requirements with improved property levels. There is an emergent interest among the researchers in the growth of renewable resources (natural cellulose fillers) related polymer composite. Natural cellulose fillers such as fibers and particles and are lightweight, environmentally friendly, renewable, abundantly available and biodegradable. Natural cellulose fibers like sisal, banana, jute, hemp, pineapple leaf and coir are the most commonly used fibers to reinforce polymers. The parts and components made from natural fiber reinforce polymer composites have been used in various industrial and commercial applications.

I. Raju Sharma , Prem Pal Bansal( 2018)

The performance of beam column joint (BCJ) significantly affects the behavior of RC framed structures during the earthquake. The absence of ductile detailing in pre-seismic designed RC beam column joints lead to a greater extent of damage in the non-linear rotation. The retrofitting offers a greater flexibility to strengthen the damaged beam column joint. However, the limitations of retrofitting materials and the extent of initial damage in RC beam column joint affects the retrofitting performance. Therefore, an experimental investigation is carried out to evaluate the efficacy of ultra high performance hybrid fiber reinforced concrete (UHP-HFRC) in retrofitting, and the effect of initial damage on the performance of (UHP-HFRC) retrofitted exterior beam column joint. Park and damage indices model is used to defining the initial damage as complete, severe, moderate and slight. Exterior BCJ, initially damaged are then retrofitted using UHP-HFRC. The test results indicate that the UHP-HFRC retrofitting increases the load carrying capacity, energy dissipation, and ductility of retrofitted BCJ over control specimen.

The load hysteresis behavior of retrofitted beam column joint significantly improved as compared to control specimen. The hybrid fibers in UHP-HFRC impart the confinement and provide the ductile plateau in a post-elastic stage of the retrofitted specimen.

*J. Yasmeen Taleb Obaidat, Ghazi A.F.R. Abu-Farsakh, Ahmed M. Ashteyat(2018)*

This paper presents an experimental work on repair of partially damaged reinforced concrete beam- column joints using carbon fiber-reinforced plastics (CFRP) plates. The investigation carried out is mainly dedicated to study the behavior of repaired RC beam-column joints under cyclic loading with a variety of retrofitting schemes. Eight specimens were prepared and tested to investigate the repairing efficiency for improving strength-capacity, stiffness and behavior of partially damaged RC joints. The control specimen was tested up-to-failure under cyclic loading. Seven specimens were loaded up-to a certain load level which was about 80% of expected failure load (known as preload). Then, they were retested after repairing using various schemes of CFRP-plates. The results were examined through load versus drift ratio; initial-stiffness of curve, ductility index and maximum load. Besides, strains in CFRP-plates were measured and the failure modes of the test specimens; due to crack-pattern and CFRP-debonding, were monitored. The results showed the important issue of repairing and enhancing the joint-performance and hence delaying premature debonding of the various CFRP-configurations. The failure mode of the control specimen was due to the occurrence of diagonal cracks in the joint because of lack of shear reinforcement. Therefore, this specimen failed at a much lower load than the repaired joints.

*K. Khaled Allam, Ayman S. Mosallam, Mohamed A. Salama( 2019)*

Lack of joint confinement for the majority of pre-1970 reinforced concrete (RC) frame construction has resulted in weakening the link between the column and the beam and collapse of the whole structure. The main focus of this research study is based on four interrelated tasks: (i) design and development of innovative repair and retrofit techniques for reinforced concrete (RC) beam-column joints using advanced FRP composite laminates and pre-cured composite connectors; (ii) experimental evaluation of the different techniques using full-scale testing; (iii) comparison in behavior between as-built and different retrofit specimens; and (iv) conclusions and recommendations for future research. Experimental results confirmed the superiority and success of the proposed strengthening protocols, not only in restoring the original strength capacity, but also in enhancing the overall seismic performance of the deficient joints evaluated in this study including strength and ductility. For example, the use of carbon/epoxy wet layup composite laminates resulted in an appreciable increase of both strength and ductility up to 1.34 and 3.04 times, as compared with as-built specimen, respectively.

Also, the proposed technique for enhancing shear strength and rebar bond slippage of the joints using high-strength carbon/epoxy FRP composite laminates and a hybrid composite connectors (HCC) achieved significant results. The novel proposed technique improved the shear strength of the joint 2.5 times the control deficient specimen. Experimental results indicated that FRP composite systems proposed in this study succeeded in enhancing the strength, stiffness and ductility of the seismically deficient reinforced concrete beam-column joint. The test setup was capable of capturing the shear deficiency behaviour of the beam-column joint and the enhancement in its behaviour after retrofit.

*L. Yashuang Liu, Hua Ma, Zhenbao Li, Wenjing Wang(2020)*

This study evaluated a new type of joint for connecting reinforced concrete (RC) beams with a concrete-filled steel tube (CFST) column that consists of U-shaped steel end plates and longitudinal reinforcement coupling sleeves. The proposed joint configuration was designed to fully realise the advantages of prefabricated structures, including a short construction period, easy construction control and low environmental impact. Low-cycle reversed loading tests were conducted to evaluate the seismic behaviour of three full-scale joint specimens, namely a cast-in-place joint and two prefabricated RC beam–CFST column joints connected using reinforcement coupling sleeves. The results indicate that the prefabricated joints exhibited plumper load–displacement curves and a good connection behaviour. The prefabricated joints failed in bending, thereby resembling the failure of the cast-in-place RC beam–CFST column joint. The failure region was concentrated in the area outside of the U-shaped end plate. The coupling sleeve connection was reliable, and the plastic hinge at the beam end moved further outward. Compared to the cast-in-place joint, the prefabricated RC beam CFST column joints exhibited a similar bending capacity. The proposed prefabricated RC beam–CFST column joints failed in bending at the beam end, and showed similarity to the joint cast-in-place. The damage was mainly concentrated in the area where was out of the wrapped concrete by the U-shaped steel plate.

*M. Elaheh Ilia, Davood Mostofinejad(2019)*

Beam-column assemblies of many existing reinforced concrete (RC) buildings are typically designed and built before the development of the current seismic codes; that may permanently fail in non-ductile behaviors, including column flexural hinging or joint shear failure mode, during ground motions. The current experimental research, therefore, was conducted to evaluate the efficiency of newly proposed rehabilitation schemes in retrofitting of deficient RC beam-column connections using fiber reinforced polymers (FRPs). To do so, five half scale exterior beam-column joints were constructed and tested under constant axial and reversal-cyclic lateral loadings. The joint specimens were designed with strong beam-weak column theory and insufficient transverse reinforcement in the joint region. Of these, four specimens were strengthened with CFRP sheets and the remaining specimen was used as a control. In the strengthening patterns, to eliminate any surface debonding of FRP, the recently developed externally reinforcement on grooves (EBROG) method was used. Besides, CFRP anchor fans were employed in the beam-column interface to completely anchor the longitudinal FRP sheets and also transfer the forces between the beam and the column. This paper presented the results of an experimental program where the lateral hysteretic behaviour of the deficient RC beam-column joints rehabilitated with CFRP sheets was investigated. The test matrix included five half-scale exterior beam-column joints which were designed to demonstrate the typical existing buildings planned to resist only gravity loads without any permission for seismic loads under a strong beam-weak column condition as well as a shear deficiency in the joint core. The study focused on the efficiency of the proposed rehabilitation schemes in providing a more ductile behaviour for deficient joints.

## II. CONCLUSION

From the literature review, the behaviour of exterior beam-column joints has been widely investigated for monotonic and cyclic loading. The main parameters for joints have been determined the Concrete compressive strength, Anchorage detailing of longitudinal beam bars in the joint region, Geometric aspect ratio of the joint, Reinforcement ratio in beam and column, & shear deformation, Some authors use special joint detail thereby shifting the plastic hinge away from the column face.

Some Author under monotonic & cyclic loaded, considered yield point of steel & crushing of concrete as well plotted graphs for load – deflection curves. And Load –deflection curves were compared both experimental & analytical comparison was done. In some cases Shear capacity of Joint & flexure capacity of beam were also estimated.

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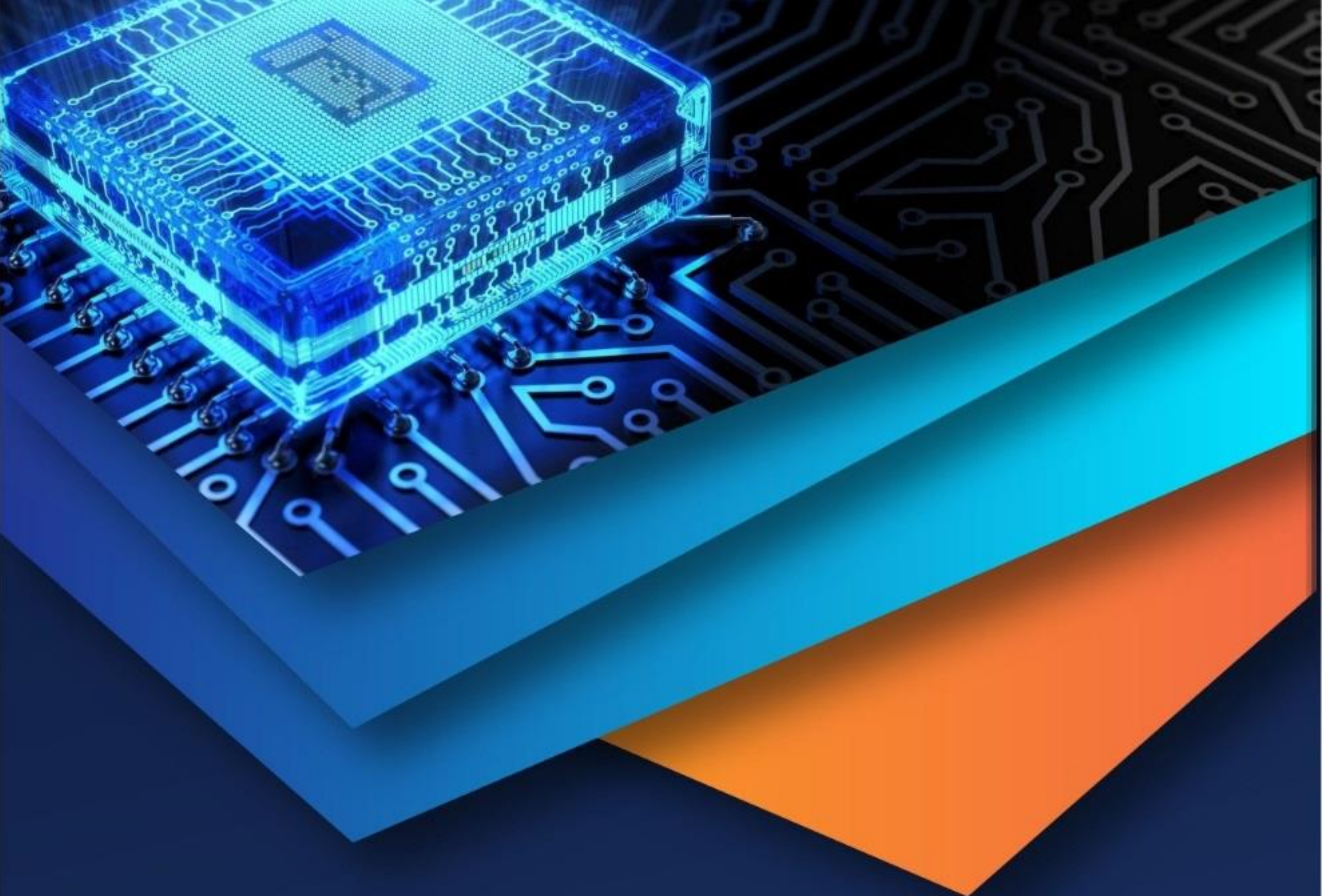


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