A Review of Analysis of RC Beam Column Joint Strengthened with Steel Reinforced Polymer System Under Cyclic Loading

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Abstract - *Now a day the vulnerability of reinforced concrete (RC) framed buildings towards seismic activities under earthquake is very high because of the improper performance of beam-column joints (BCJs). This can be avoided by strengthening RC beam-column joints using Steel Reinforced Polymer (SRP) systems or Steel Reinforced Grout (SRG). Numerous studies were concluded that, the SRP strengthened specimens can overcome diagonal cracks and shear failure at the joint during earthquake. Studies were such that SRP strengthened specimens have increased strength and enhanced ductility & energy dissipation. And also shows that, the characteristics of SRPs are similar to that of CFRPs except in terms of cost as SRPs are available at reasonable cost. This paper presents the review of studies conducted about the behavior of SRP and CFRP strengthened beam column joints under cyclic loading.*

Key Words: Beam column joint, joint shear, carbon fibre reinforced polymer, steel reinforced polymer, cyclic loading

1.INTRODUCTION

Now a day, earthquakes caused many concerns about the flexibility and withstanding power of the existing RC moment-resisting frame structures. A beam-column joint is the most crucial zone in the RC framed structures. Since the beam-column joints (BCJs) undergoes diagonal cracks and shear failure when subjected to higher forces and moments under earthquake, it plays a significant role in the response of a structure. Inappropriate design and detailing of the joint shear (JS) reinforcement thereby undergoing sudden brittle failure known as joint shear. This results in reduction of the service life of a structure & severe damage to infrastructure. Generally, in earthquake resisting frame the column should be stronger than beam.

Damage must be avoided by using different techniques during construction stages because repairing of damaged joints is very difficult after it appears. This led to the requirement of strengthening the beam-column joints. Common techniques for repairing or strengthening of shear-deficient RC BCJs include reinforced or prestressed concrete jacketing, concrete masonry unit jacketing, steel jacketing or addition of external steel plates. Latest techniques involve Carbon Fiber-Reinforced (CFRP) system, Glass Fiber-Reinforced (GFRP) system etc. A new composite made of steel tapes which is known as SRP was recently invented in addition to CFRP & GFRP.

SRP system consists of steel tape which is composed of high tensile strength steel (HTSS) cords made by twisting steel wires within a micro-fine brass or galvanized coating for the protection against both fire and corrosion; it can be in-situ applied via wet lay-up by using epoxy resin or inorganic matrix, thus obtaining strengthening systems known as SRP (Steel Reinforced Polymer) or SRG (Steel Reinforced Grout), respectively. The wrap wire works to tighten the during tensile loading and these twisted wires of SRP system shows a mechanical interlock between the cords & polymeric resin matrix, resulting in better bond and load transfer to the resin system. SRPs have the capacity to increase the strength and enhance the ductility & energy dissipation. Also, diagonal orientation of externally bonded SRPs at the joint seemed to be very effective in overcoming the diagonal cracks and shear failure at joint during earthquake.

2. REVIEW ON ANALYSIS OF STRENGTHENED BEAM COLUMN JOINTS

2.1 Beam Column Joint Strengthened with Steel Bars

The experimental and analytical investigations are carried out on high-strength concrete beam-column joints with high-yield-strength bars in beams and columns. Parametric studies via finite-element analysis were performed to examine the influence of various parameters on the strength, bond condition, and energy dissipation capacity of the specimens. The joint shear behaviour and bond strength of the specimens are further investigated and the validity of the design requirements of ACI 318 and NZS 3101 for high-strength steel reinforcements is examined. All specimens used in this study displayed ductile failure mode and it is concluded that the use of high-strength concrete and applied axial compression loading can improve specimen bond conditions. Axial compression loading increased the energy dissipation significantly and use of HSS reinforcements resulted in a smaller energy dissipation capacity. Using longitudinal beam reinforcements of a higher grade caused a slight decrease in bond strength in the joint region (Alaee & Li, 2017). [2]

To understand the behavior of exterior beam-column joint sub-assemblages with transverse reinforcements detailed as per IS 456 and IS 13920, the specimens were tested under two different axial loads to evaluate the effect of axial load at joints. The earthquake analysis and design are carried out by incorporating all the modifications as per the latest revisions of IS 1893 and IS 13920. The experimental study revealed that the usage of rectangular spiral reinforcement significantly improves the seismic capacity of external beam-column connections. The test results indicated that the latest revisions for joint design assure the beam failure to take place before the joint failure. Enhancements in the performance of beam-column joints detailed as per IS 13920 in the reversal of loading were also observed (Bindhu et al., 2009). [3]

Investigation on over congestion at the beam- column joints because of excessive amounts of rebar in beams and columns in the rigid-framed railway bridges were conducted. In this research, an attempt is made to reduce not only shear rebars, but also longitudinal rebars in beam-column joints of rigid-framed railway bridges to avert over congestion by using steel fibers. The effects of steel fibers on the structural performance of beam-column joints in reducing the amount of steel rebars are also investigated. The comparable or better performance is expected for the specimens with reduced steel rebars and added steel fibers than that of the control specimens. The experimental results of the specimens were compared in terms of crack patterns, load-displacement relationships, ductility, energy dissipation capacity & stiffness degradation and it has been revealed that after reducing the amount of steel rebars the performance of specimens with steel fibers was comparable with that of the specimens without reduction of steel rebars (Niwa et al., 2012). [7]

2.2 Beam Column Joint Strengthened with Carbon Reinforced Polymer System (CFRPs)

The efficiency and effectiveness of carbon fiber-reinforced polymer (CFRP) sheets in increasing the shear strength and ductility of seismically deficient beam-column joints were studied. By comparing hysteretic loops, load-displacement envelopes, joint shear distortion, ductility, and stiffness degradation it is found that CFRP sheets are very effective in improving shear resistance and deformation capacity of the exterior and interior beam- column joints and delaying their stiffness degradation during earthquake. For strengthening the beam column joint small thickness of CFRP sheet cause of mechanical debonding, so it can be reduced by improving the thickness of CFRP sheet or implementation of additional layer of CFRP sheets (Aditya Kumar Tiwary, Ashish Kumar Tiwary, 2010). [1]

A technique of involving the embedded carbon fiber–reinforced polymer (CFRP) or steel bars into epoxy-filled holes drilled within the joint core was used and presented a mechanics-based design model for RC BCJs strengthened with embedded bars. Also examined the effect of number and type of embedded bars. The experimental results were used to verify the accuracy of the proposed analytical formulation. The strengthened specimens exhibited less brittle failure when damage occurred in the beam region at the early stages of loading, suggesting the outset of a beam hinge mechanism. Also, they have exhibited the enhancements in joint shear strength, ductility, dissipated energy, and stiffness of6%–21%, 6%–93%, 10%–54% & 2%–35% respectively, compared with the control specimen (Rahman et al., 2018). [8]

2.3 Beam Column Joint Strengthened with Steel Reinforced Polymer System (SRPs)

The experimental works were conducted on SRP to establish its advantages and drawbacks. SRP exhibited better tensile and bond behaviour and when applied for bending reinforcement or for confinement thereby provided equivalent or higher improvement of structural performance in terms of load bearing and displacement capacity. Even if long‐term durability, shear strengthening of RC beams and applications to masonry deserves more investigations. The research performed so far has already demonstrated that SRP is an effective and cost-efficient solution for the rehabilitation of structures (De Santis et al., 2016). [4]

A simple approach is devoted to study the bond behavior of masonry structures strengthened with SRP/SRG systems. The approach, based on experimental evidences and theoretical considerations mainly consists of deriving approximate bond stress-slip laws for the strengthening/support interface layer, able to reproduce the local bond stresses transferring mechanism. Finite Element (FE) analyses are then developed with reference to the experimental tests available in the current literature by adopting the bond stress-slip laws obtained through the proposed approach. The deduced results show the reliability of the proposed approach in simulating the bond behavior of masonry elements strengthened with SRP/SRG (Grande et al., 2013). [5]

An experimental investigation done into the application of steel-reinforced polymer (SRP) composites for strengthening shear-deficient exterior beam-column joints in reinforced concrete frames subjected to seismic loads. Specimens with SRP sheets provided at the joint region in different arrangements were tested under a quasi-static cyclic load applied at beam tip to simulate high levels of inelastic deformations similar to those experienced during a severe earthquake. Specimens strengthened with SRP sheets exhibited higher levels of strength, ductility and energy dissipation and experienced more desirable modes of failure in comparison with a shear-deficient joint specimen. Anchorage of externally bonded SRP reinforcement is indispensable and can be adequately provided by orthogonal SRP wraps. The study concluded that the diagonal SRP sheets at the joint are rather more effective than horizontal and vertical sheets as it helps to overcome the diagonal cracks and shear failure at joint under cyclic loads (Izi et al., 2008). [6]

2.4 Seismic Actions on Beam Column Joints

To highlight the seismic actions on various types of joints and the critical parameters that affect joint performance with special reference to bond and shear transfer. Also presented a review of the postulated theories associated with the behavior of joints. According to this study, the assumption of joint being rigid fails to consider the effects of high shear forces developed within the joint. The study aimed at making aware of the theoretical background on the design of beam column joints highlighting important parameters affecting seismic behavior of joints. The factors impacting the bond transfer within the joint appears to be well related to the level of axial load and the quantity of transverse reinforcements in the joints. The parameters that affects shear demand and shear strength of the joint are explained. The design of shear reinforcement within the joint and its detailing aspects are also discussed. 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 (Uma, 2015). [9]

3. CONCLUSIONS

SRP system consists of steel tape which is composed of high tensile strength steel (HTSS) cords made by twisting steel wires within a micro-fine brass or galvanized coating for the protection against both fire and corrosion; it can be in-situ applied via wet lay-up by using epoxy resin or inorganic matrix, thus obtaining strengthening systems known as SRP (Steel Reinforced Polymer) or SRG (Steel Reinforced Grout), respectively. The wrap wire works to tighten the during tensile loading and these twisted wires of SRP system shows a mechanical interlock between the cords & polymeric resin matrix, resulting in better bond and load transfer to the resin system. The load carrying capacity of the specimens strengthened with CFRP systems is more or less the same achieved by the beam column joint strengthened by SRPs. But it's been found that SRPs are more economical compared to CFRPs and HYSD bars. Seismic actions on beam-column joint found to be resulted in diagonal cracks and shear failure at joint. This can be avoided as far as possible by strengthening the specimens with diagonal configuration of SRPs such that it helps to overcome the diagonal cracks and shear failure at joint during earthquakes. In comparison with beam column joint strengthened with steel bars and CFRPs, the SRP strengthened specimens undergone small displacement at high peak loads. Hence SRP strengthened specimens have efficiently increased the strength, enhanced both ductility & energy dissipation.

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