A Review on The Effect of Reinforcement on Reinforced Concrete Beam-Column Joint Behavior

B. A. Solahuddin[1,*]

[1]Faculty of Civil Engineering Technology, Universiti Malaysia Pahang, Lebuhraya Tun Razak, 26300 Gambang, Kuantan, Pahang Darul Makmur, Malaysia

*Corresponding author's E-Mail: solahuddin.08@yahoo.com

ABSTRACT: The beam-column joint is a key zone where the elements connect in three directions in a reinforced concrete structure. Constructing a reinforced beam-column junction has practical obstacles. The purpose of this review is to highlight the typical behaviour of reinforced concrete beam-column joint (RCBCJ) on the exterior, interior and top level. Previously published research investigated beam-column joint under gravity and seismic load as well as the effect of a variety of parameters on the mechanical behaviour of beam-column joints. The effect of reinforcement configuration, eccentricity, joint aspect ratio (h_b/h_c), concrete compressive strength and compressive column axial load are investigated in the current studies. A beam-column joint is introduced in accordance with ACI 318-02 (2002) [1] and Egyptian code (2007) [2]. Based on the experimental results, reinforcement inclusion benefits the behaviour of RCBCJ by increasing its strength, mechanical properties and structural performance.

Keywords: *Beam; Column; Reinforcement*

1. INTRODUCTION

The behaviour of beam-column joint has a considerable effect on the response of reinforced concrete moment-resisting frames subjected to cyclic stress, including stiffness deterioration, strength degradation, and energy dissipation. El-shafiey et al. (2015) [3] previously focused on the shear strength of the beam-column connection and accompanying important parameters such as the presence of joint stirrup and the longitudinal steel design of the beam. The design of beam-column connection is a critical component in designing an earthquake-resistant reinforced concrete moment-resisting frame.

Difficulty in repairing and retrofitting RCBCJ building structure is due to a seismic attack and structural crack. In addition, beam-column connections are subjected to significant reversed cyclic loading during a large earthquake. Therefore, numerous studies have been conducted on the behaviour of beam-column joint because the design of beam-column joint is critical for earthquake-resistant design. These studies conducted on a beam-column joint can be categorized into three broad categories: shear strength of beam-column joint, effects of reinforcement on beam-column joint behaviour and eccentric beam-column joint.

2. BEHAVIOUR OF REINFORCED CONCRETE BEAM-COLUMN JOINT

Kusuhara and Shiohara (2008) [4] loaded ten half-scale RCBCJ sub-assemblages to failure using statically cyclic loading to acquire fundamental data such as stress in yielding bars and joint deformation. All specimens had 300 mm x 300 mm cross-sections for the beams and columns. Three sets of D6 hoops were inserted into the beam-column joints of all specimens. The quantity of joint shear reinforcement was 0.3%, which meets the AIJ Guidelines minimal requirement (1999) [5]. Next, it was discovered that the specimen with transverse beams improved its narrative shear capacity when the joint was severely damaged. The bond of the beam bar conveying through the joint remained lower than the bond strength. Insufficient anchorage length of beam bars in exterior joints resulted in decreased shear capacity from 100 kN to 70 kN and less joint damage.

Megget et al. (2004) [6] conducted cyclic loading tests on four exterior reinforced concrete beam-column sub assemblages. Maximum beam elongation was between 2.7% and 3.8% of the beam depth. The tested beams reinforced with Grade 500E, almost 35% larger than those obtained for the identically sized beams reinforced with Grade 430 at the same level of ductility. There appeared to be a minimal performance difference between joints with continuous U-bar anchorage and those with the more common 90-degree hook and tail anchorage. Moreover, the U-bar detail had a significant advantage in that it simplified the reinforcing joint zone. The additional transverse bars within 90-degree bend allowed a shorter development length and this seemed to operate well, as there was no occurrence of beam bar sliding.

Chalioris et al. (2008) [7] examined the efficiency of crossed inclined bars (X-bars) as shear reinforcement in external reinforced concrete beam-column connection subjected to cyclic deformation. The results indicated that specimens reinforced solely with X-bars had a high load capacity in most loading cycles and accelerated hysteretic energy dissipation virtually throughout the loading sequence. The specimens with crossed inclined bars and stirrups exhibited more significant hysteretic response, superior performance capabilities and cracking was predominantly localized at the beam-joint interface.

Kularni and Patil (2013) [8] discussed their research on the effect of column crossing inclined bar on the shear strength of the cyclically loaded exterior

RCBCJ. They focused on the compressive strength of concrete, aspect ratio of joint, anchorage of longitudinal reinforcement of the beam and the number of stirrups within the joint. Column crossed inclined bar was demonstrated to be a feasible method for enhancing the shear capacity of cyclically loaded beam-column joint. The inclusion of an inclined bar introduced a new shear transferring mechanism. The bigger the joint aspect ratio (h_b/h_c), the less the joint shear capacity contributed by the crossed inclined bar. Subsequently, external beam-column junction reinforced with crossed inclined reinforcement demonstrated a high percentage of strength. In comparison, the load resistant capacity was enhanced compared to other joint configurations.

Kaung and Wong (2011) [9] investigated the efficiency of horizontal stirrup in the joint core of exterior RCBCJ with non-seismic design under reversed cyclic loading. It was discovered that horizontal stirrup installed in non-seismic beam-column joint significantly increased the junction seismic behaviour and shear strength. The horizontal stirrup ratio should not exceed 0.4% in non-seismically constructed exterior beam-column joint subjected to low to moderate seismicity in order to increase shear capacity. In the worst-case scenario examined in this study, a joint failed in shear when the beam strength reached 68% of its design flexural capacity, meaning that the joint failed when the beam was only loaded to service load. However, the joint with transverse reinforcement significantly improved seismic behaviour and failed when the beam strength exceeded 83% of its ultimate flexural capacity.

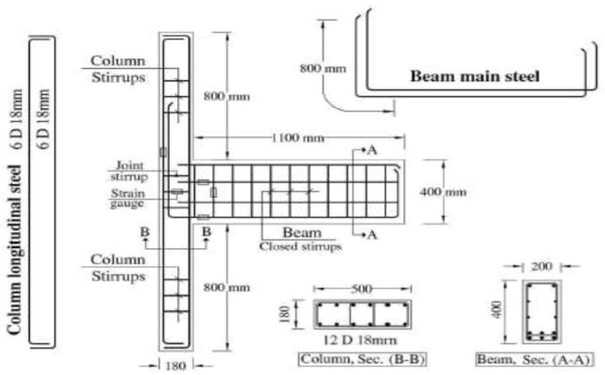

Figure 1: Reinforcement details (El-shafiey et al., 2015) [3]

El-shafiey et al. (2015) [3] investigated four reinforced concrete beam-column junction specimens subjected to torsional moment acting on the beam. They conducted research on the effect of joint stirrup designed following Egyptian standards (2007) [2]. They demonstrated the importance of longitudinal side reinforcing steel configuration. The presence of joint stirrup and the developed length of beam steel shifted failure away from the joint panel. Hwang et al. (2014) [10] conducted an experimental investigation to determine the seismic performance of beam-column connection reinforced with Grade 600 MPa (87.0 ksi) bar. Current design codes restricted the column depth to the beam reinforcing bar diameter ratio (h_c/d_b) to avoid excessive bond slip. The seismic performance performed well with the inclusion of RCBCJ by increasing the strength from 40 MPa to 60 MPa.

3. CONCLUSION

First, the compressive strength of concrete has a greater effect on the joint shear strength than the column axial force ratio or the joint shear reinforcement ratio. Next, the compressive column axial load less than 20% of nominal capacity has no effects on the shear strength of unreinforced external joint. Then, according to AIJ Guidelines (1999) [4], the minimum amount of joint shear reinforcement is 0.3%. After that, hysteretic energy dissipation is enhanced by the usage of X-bar as joint shear reinforcement. Finally, a joint without stirrup fails in shear when the beam strength reaches only 68% of the design flexural capacity, but a joint with transverse reinforcement has significantly superior seismic behaviour and fails when the beam strength exceeds 83% of its final flexural capacity.

REFERENCES

[1] ACI 352R-2, Recommendations for design of beam-column connections in monolithic reinforced concrete structures, June 18, 2002.

[2] Egyptian Code for Design and Construction of Reinforced Concrete Structures, (ECP 203-2007) 2007.

[3] T. El-shafiey, A. Atta, H. Afefy and M. Ellithy (2015) "Experimental Study of RC Exterior Beam column Joint Subjected to Torsional Moment" International Conference on Advances in Structural and Geotechnical Engineering ICASGE'15.

[4] Kusuhara, F., and Shiohara, H., (2008), Tests of R/C Beam-Column Joint with Variant Boundary Conditions and Irregular Details on Anchorage of Beam Bars‖, the 14th world conference of earthquake engineering.

[5] AIJ Guideline (1999).

[6] Megget, L. M., Barton, M. B., and Fenwick, R. C., (2004), ―Seismic design and behavior of external RCBCJs using 500E grade steel reinforcing, the 13th world conference of earthquake engineering, Paper No. 3472.

[7] Chalioris, C. E., Favvata, M. J., and Karayannis, C. G., (2008), Reinforced concrete beam–column joints with crossed inclined bars under cyclic deformations, Earthquake Engineering and Structural Dynamics, Vol. 37, pp. 881–897.

[8] Kularni, S. M., and Patil, Y. D., (2013), A Novel Reinforcement Pattern for Exterior RCBCJ, Procedia Engineering, Vol. 51, pp. 184 – 193.

[9] Kaung, J. S., and Wong, H. F., (2011), Effectiveness of Horizontal Stirrups in Joint Core for Exterior Beam-Column Joints with Nonseismic Design‖, Procedia Engineering, Vol. 14, pp. 3301–3307.

[10] H.J. Hwang, H. Park, W. Choi, L. Chung, and J. Kim (2014). Cyclic Loading Test for Beam-Column Connections with 600 MPa (87 ksi) Beam Flexural Reinforcing Bars. ACI Structural Journal, Vol. 111, No. 4, PP.913-923.