Published by :
http://www.ijert.org

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 9 Issue 11, November-2020

Effect of Beam Transverse Position on the Behavior of Reinforced Concrete Beam Column Joints Under Quasi-Static Loading

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***Abstract*:- The study of the beam-column joints is essential for developing a structure with better characteristics. An experimental investigation carried out on the reinforced concrete exterior beam-column joint subjected to Quasi-Static loading is reported in this paper. The objective of this study aimed to attaining a better understanding of the effect of beam transverse position on the behavior of reinforced concrete beam column joints, three real scale beam-column joints were casted, with different eccentric-beam column connections with the same reinforcement. Parameters such as ultimate load, energy dissipation capacity, stiffness degradation, and crack behavior of concrete were examined and the results showed that the concentric beam position is the best position for beam in joint, also is better in the displacement, energy dissipation capacity, stiffness degradation and strength decay.**

1. INTRODUCTION

Reinforced concrete moment resisting frames, which typically consist of a framework of beams and columns, are among the most commonly used lateral load resisting systems. For the first half of the twentieth century, the design of the area where beams and columns join was overlooked. Several earthquakes demonstrated that the beam-column joint in such a system is the weakest link under lateral load. Since the late 1960's, a substantial amount of research has been conducted on the performance of beam-column joints and design codes started to incorporate related design and detailing guidelines [1].

The integrity of beam-column joints in reinforced concrete (RC) frames, especially in a crucial zone, is essential for the satisfactory performance of the whole structure. Therefore, the behavior of external connections between beams and columns is a significant parameter affecting the performance of such R.C frames. An important influence in this regard is the concrete compressive strength, joint reinforcement and relative stiffness of beam and column in each connection [2], which is itself determined by considerations of geometry and reinforcement percentage.

Eccentric joint means the beam and column centerline does not coincide with each other [3]. Most of researchers have studied the eccentric in joints consist of wide beams. Based on study made on various design codes, Li and Kulkarni [4] indicated that the BS8110, British Standards 1997 strictly restricts the use of wide beam-column connections to resist earthquake loads. Such geometric restrictions are often based on historical design practices. However, in the United States, beam width is restricted of (b_c +1.5h_b), where h_b is the beam depth and b_c is the column width. Whereas in New Zealand, the beam width restriction is the lesser of (b_c + 0.5h_c) and 2bc, where h_c is the column depth.

Several experimental and theoretical studies have been conducted to investigate the overall conduct of beam-column joints. A.K.Kaliluthin, et al [5], focused on the general behavior with specific structural properties of common types of joints in reinforced concrete moment resisting frames to be aware of the fundamental theory of the joint for better efficiency. A beam-column joint is a very critical zone in reinforced concrete framed structure where the elements intersect in all three direction .The behavior of joints was found to be dependent on a number of factors related with their geometry; amount and detailing of reinforcement, concrete strength and loading pattern.

Subramani et al. [6] carried out an analytical study using ANSYS for traditional T-shaped concrete frame building joints with strong beam-weak columns. They found that both axial forces and beam to column linear stiffness ratio had impacts on joint capacity and ductility behaviour of the specimens.

The earliest test conducted by Abrams [7] indicated that compressive strength of concrete was sensitive to the rate of loading. Since then, numerous experimental studies have been carried out to investigate the dynamic mechanical properties of concrete over a wide range of strain rates.

The energy absorption and carrying capacity of plain concrete subjected to both static and dynamic loading were investigated by Atchley and Furr [8] using cylinders. The conclusion was that the compressive strength and energy absorbed increased with an increase in the rate of loading, with evidence of becoming a constant value at the higher rates of loading. Based on previous experimental results, Bischoff and Perry [9] and Malvar and Ross [10] summarized the effect of loading rate on the properties of concrete compressive and tensile strength, respectively,

To contribute a better understanding of the behavior of external beam column joints under reversed cyclic loading, in this paper three specimens of beam-column joints with 100mm (0.25 tc) (tc: column length), 75mm (0.18 tc) and zero eccentricity

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distance between C.G of beam and C.G of column were constructed and analyzed. The main parameter is to study effect of beam position on the behavior of reinforced concrete beam column joints under quasi-static loading.

2. MATERIALS CHARACTERIZATION:

2.1 Concrete

The concrete mix with medium workability was designed for M30 grade. Portland Pozzolana Cement of 42N grade with 401 kg/m3 and water cement ratio is 0.475, natural sand used as fine aggregate with 698 kg/m3 and a dolomite coarse aggregates (AGG1& AGG2) with size of ¾ inch (19 mm), 1 inch (26.5mm) coarse aggregates with 594 kg/m3 for AGG1 and 552 kg/m3 for AGG2 are used, After 28 days of cubes curing average test results were 37.8 Mpa.

2.2 Steel

For longitudinal reinforcement of all joints (beams and columns) specimens, conventional deformed steel bars of 16 mm diameter of high tensile steel with yield strength 542.12 Mpa, and ultimate strength 626.67 Mpa were used, while beams stirrups were 10 mm diameter of high tensile steel with yield strength 483.83 Mpa, and ultimate strength 572.96 Mpa were used, and for columns stirrups smooth bars of 8 mm diameter of mild steel with yield strength 358.1 Mpa, and ultimate strength 487.4 Mpa were used.

3. TEST PROGRAM

3.1 Specimens details

In order to accomplish the objectives of this work, three reinforced concrete beam column joints with compressive strength 37.8 MP were tested under reversed cyclic loading as show in figure (1). The description of the specimens in this study are summarized in Figure (2), the details of reinforcement of the joints are shown in Figure (3).

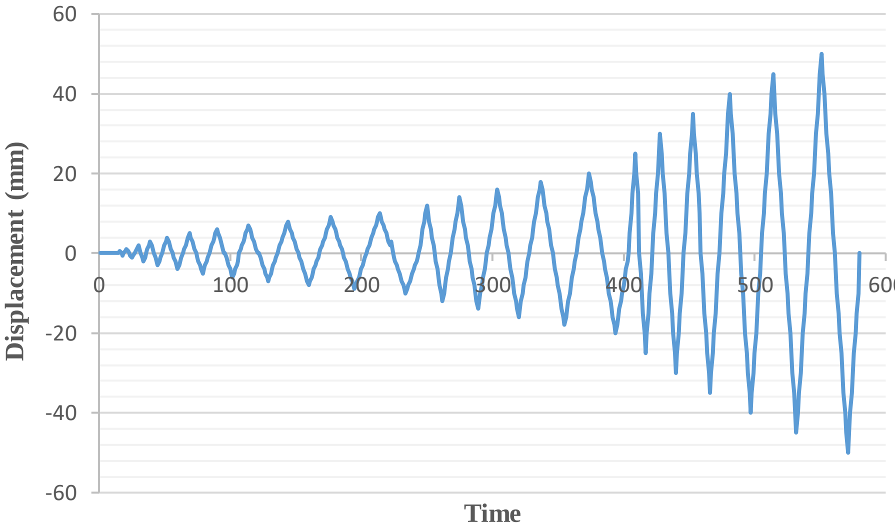

Figure (1): test loading history.

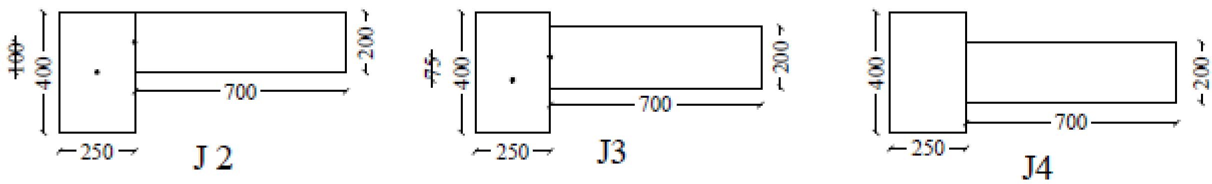

Figure (2): Diminution and shape of studied specimens.

International Journal of Engineering Research & Technology (IJERT)
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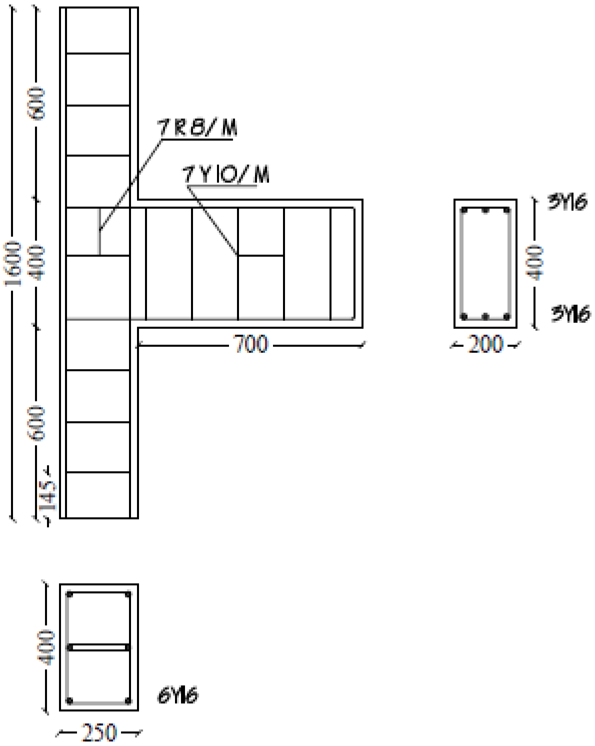

Figure (3): Steel reinforcement details of studied specimens.

The experimental portion of the investigation consisted of testing three beam column joints specimens, The beams were cantilever supported and had a span of 650 mm and a total length of 700mm. Figure (4) showing the used reinforcement cages, form works. In addition six electrical strain gauges were fixed to the vertical, horizontal steel bar and stirrups before casting for every single joint, the position of this strain as shown in figure (5), eight 0.01-mm accuracy Linear Variable Distance Transducers (LVDTs) were placed as shown in figure (6) to measure the deflection and determine the distribution of deflection along the specimen.

Figure (4): Reinforcement cages, formworks of joints.

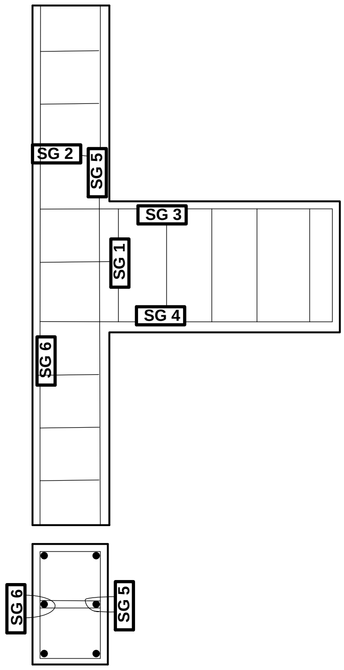

Figure (5): Location of steel strain gauges.

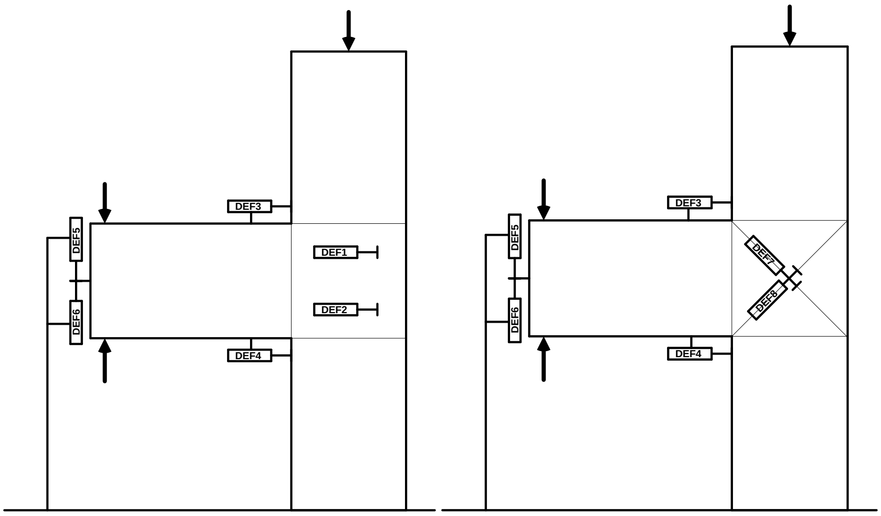

Figure (6): Locations of LVDTs

3.2 Test Set-Up

All specimens were tested to failure under quasi-static load as shown in Figure (7). The loading was manually applied using two hydraulic jacks of 300 kN capacity on the top and bottom of the beam by displacement control, The displacement increment was constant for all joint specimens at 1 mm rate until first 10mm displacement, 2mm rate until 20mm displacement and 5mm rate until failure, a third hydraulic jack applied a constant vertical load on the top surface of column, The loading was paused at different displacement levels to visually inspect the joint. Crack propagation was visually observed and the cracks were marked on the surface of the tested specimen.

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Figure (7) Test setup for all joints.

4. RESULTS AND DISCUSSION

Results for all specimens (joints) were listed in table (1). The result are presented in different forms such as load-displacement curves, crack patterns, envelope Load-displacement curves, Energy- Displacement. In addition to Stiffness Degradation was denoted by the initial flexural stiffness of the specimen (k_o) and Stiffness Degradation Rate (KDR). Also, Strength Decay was denoted by Strength Decay Rate (SDR).

Table (1) displacement, failure load, Strength, Stiffness Measures for all test Joints

Joint	Lower Jack (KN)	Disp. (mm)	Upper Jack (KN)	Disp. (mm)	First crack Disp.(mm)		k_o kN/mm	SDR kN/mm	KDR %
					Beam	Joint			
J2	177.83	16.58	-167.292	-14.03	2	3	25.41	1.38	39%
J3	183.16	16.92	-174.93	-18.19	3	5	25.39	1.59	57%
J4	203.112	18.05	-190.38	-11.98	2	14	31.80	2.28	66%

* Numbering of J2, J3 and J4 is a part of study about investigation of behavior of RC Joint

4.1 Cracks patterns and failure mode

In this section the experimental results of global structural behavior of three real scale RC beam column joints are reported. The main objective of the tests was to assess the influence of beam poison on joints structural behavior, during the tests as show in Figure (8) diagonal cracks appeared along the beam, located particularly closed to the connection with the column. Some cracks occurred in the joint panel, failure occurred between beam and column face for joint (J4) and in the joint itself for joint (J2) and (J3) .yielding of steel reinforced bars in the beam occurred in early level of displacement, about 7 mm before than cracking in panel joint. The final failure mode for (J4) was due to the formation of the flexural plastic hinge in the beam end, adjacent to the column face. Cracking in (J2) and (J3) appeared initially as flexural cracks on the beam at displacement 2mm while for (J4) appeared initially as flexural cracks on the beam at displacement 3mm for both loading direction and followed by minor joint diagonal cracking formed at the joint core started at 3mm in (J2) then at 5mm in joint (J3) and 14mm in joint (J4). New joint-inclined cracks continued to form in (J2) until 45mm, in (J3) until 40mm, while this process continued up to 25mm in (J4).

In the case of joint J2 (eccentricity 100mm = 0.25 tc) the joint core started cracked at lower level displacement at 3mm, joint had a big damage and large number of cracks than any other joint in this test also the column out of joint core had a big damage from all of his sides because of eccentricity of the loading . While in joint J3 (eccentricity 75mm =0.18 tc) the joint core started cracked at low displacement level 5mm and it joint core and column had a big damage and large number of cracks like J2 although it had eccentricity less than J2. Joint core in joint J4 (zero eccentricity) started crack at high displacement level 14mm and had few number of cracks, column has no damage out of joint core and Joint core had less crack number than J2 and J3.

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Figure. (8) Cracks patterns and failure mode of joint (J2, J3 and J4).

4.2 Failure mode and load- displacement curves:

Results refer to the envelope curves of the joints hysteretic behavior in positive and negative branch, shown in figure (9). The envelope curves were built as the locus of the maximum points belonging to the load-displacement hysteretic loops, which contain the peak points from each cycle of each loading step. Small differences in maximum positive and negative loads are due to geometrical imperfections and steel reinforcement disposition .These envelope diagram show that with the increase in displacement in both positive and negative directions, the applied load was increased, and the load drop was not observed until

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average 18.48 mm in negative direction then 18.05 mm in positive direction this for joint J4 (zero eccentricity specimen). While joint J3 specimen with eccentricity 75mm (0.18 tc) the load drop was drop in 16.92 mm for positive direction ,18.19 mm for negative direction and for joint J2 specimen with eccentricity 100mm (0.25 tc) the load drop was drop in 16.54 mm for positive direction, 14.03 mm for negative direction.

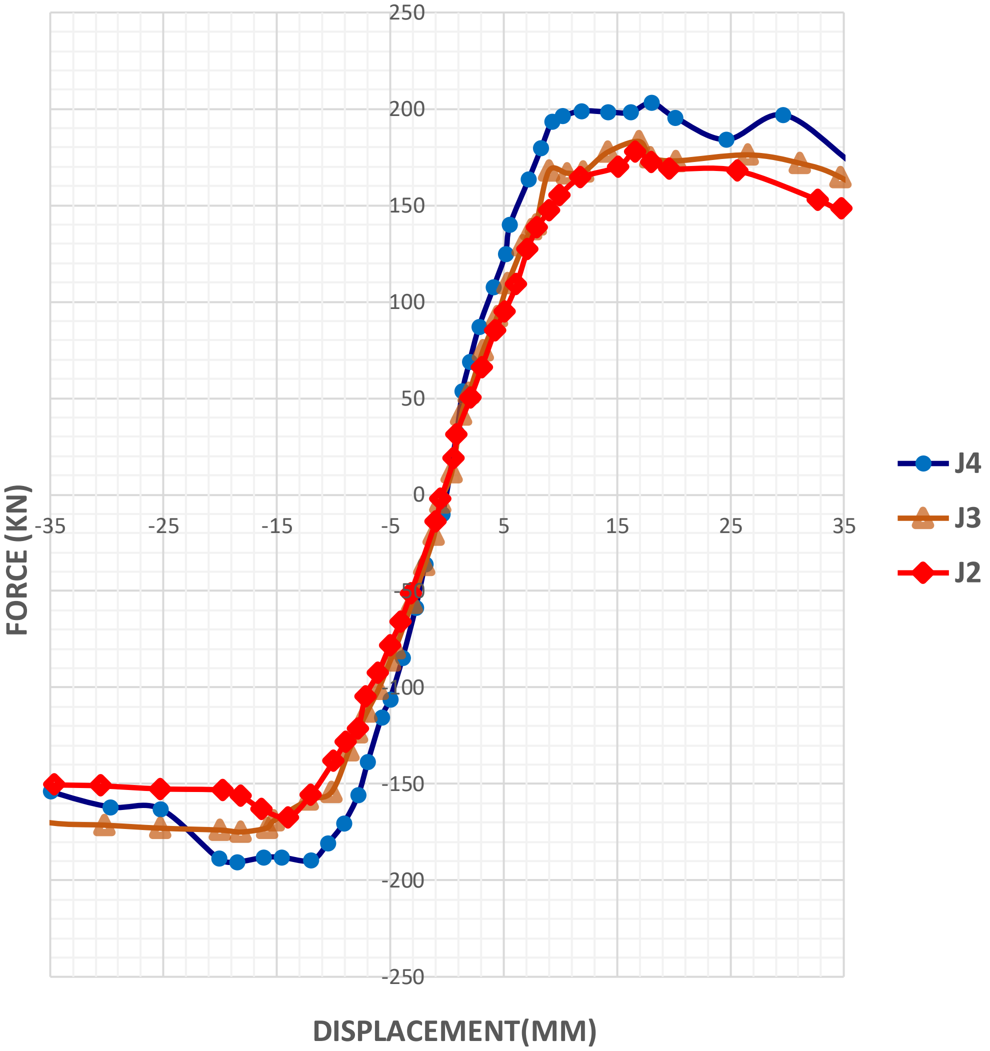

Figure (9): load- displacement curve (envelope) for joints.

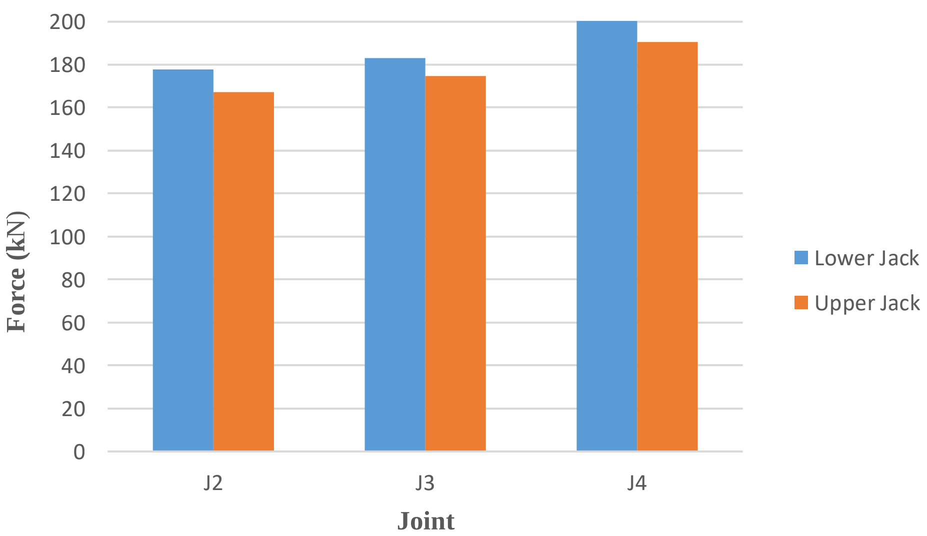

Figure (10): Ultimate lower, upper jack force for joint (J2, J3 and J4).

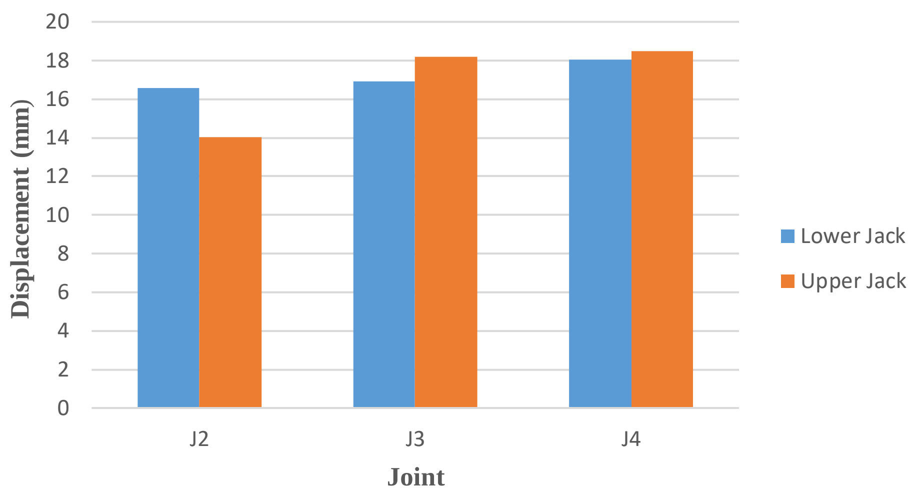

Figure (11): Disp. at ultimate lower, upper jack force for joint (J2, J3 and J4).

4.3 ENERGY DISSIPATION

Energy dissipation capacity was calculated for all the specimens to estimate the ability of the joints to absorb energy during the reversed cycling loading history. The ability of dissipating the inelastic deformation energy is significant factor for evaluating the performance of column beam joints subjected to lateral loads.

The energy dissipated by the specimen during an individual cycle, Ei was defined as the area enclosed within the load-displacement hysteresis loop. The total energy dissipated was then estimated as the sum of the cumulative dissipated energy during each cycle of the tests specimens. As the displacement level increases, the energy dissipated per cycle increases.

The comparative relationship is shown in Figure (13) Clearly, up to a displacement level of 10 mm, nearly similar trends and values observed in the cumulative energy dissipation by all joints, The cumulative energy dissipated by specimens J2, J3, and J4 is 17.55, 18.87, and 21.355 KN.m respectively, J4 and J3 is 7.5%, 21.6% more than J2 respectively. The centric of beam position caused an increase in energy dissipation.

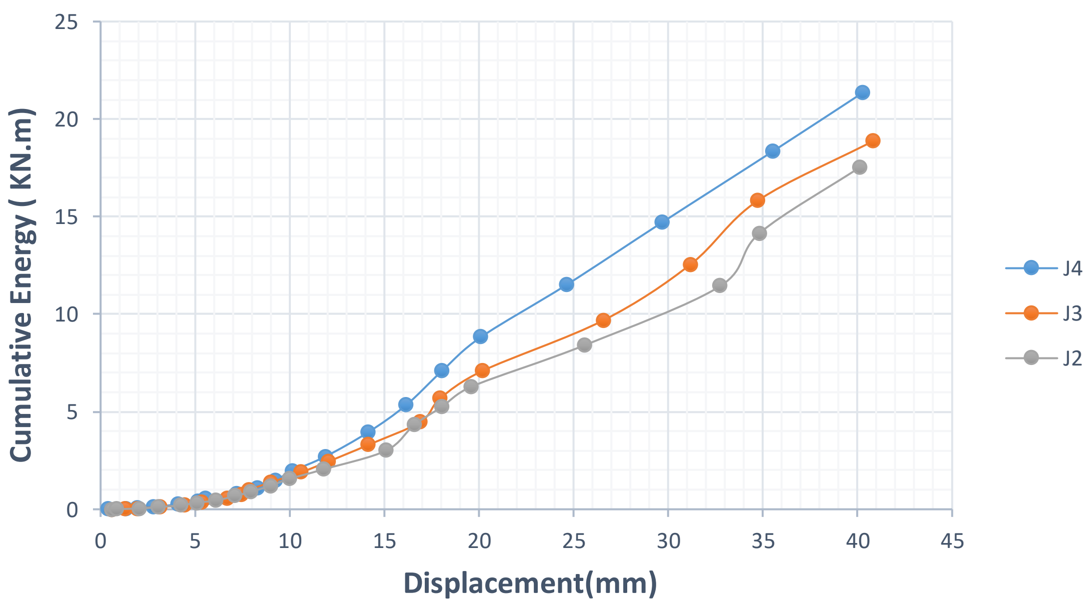

Figure (13): Cumulative Energy Dissipated by Joints.

4.4 STIFFNESS DEGRADATION

The decay of the structural resistance to the seismic load can be evaluated based on the loss of stiffness through loading cycles. Stiffness loss increases at a varying rate with the increase in peak displacement as indicated by the reductions in the slopes of the load-displacement hysteresis loops.

The cycle stiffness of specimen at a certain displacement level was considered as the average of the stiffness in the positive and negative loading directions. The stiffness calculated at each cycle for each specimen. The stiffness degradation is attributed to the propagation and widening of flexural cracks, the softening of the initial elastic modulus of concrete, the deterioration in the concrete strength and bond, and the localized slippage of column longitudinal reinforcement. Initial stiffness values and the degradation of the stiffness at ultimate load level was evaluated using the stiffness degradation rate KDR.

……………………………..….. (1) $\boldsymbol{K} = \frac{P}{\Delta}$

………………….....……………….. (2) $\boldsymbol{KDR} = \frac{K_o - K_u}{K_o}$

Where:

k_o The flexural stiffness of the specimen at initial.

k_u The flexural stiffness of the specimen at ultimate load level.

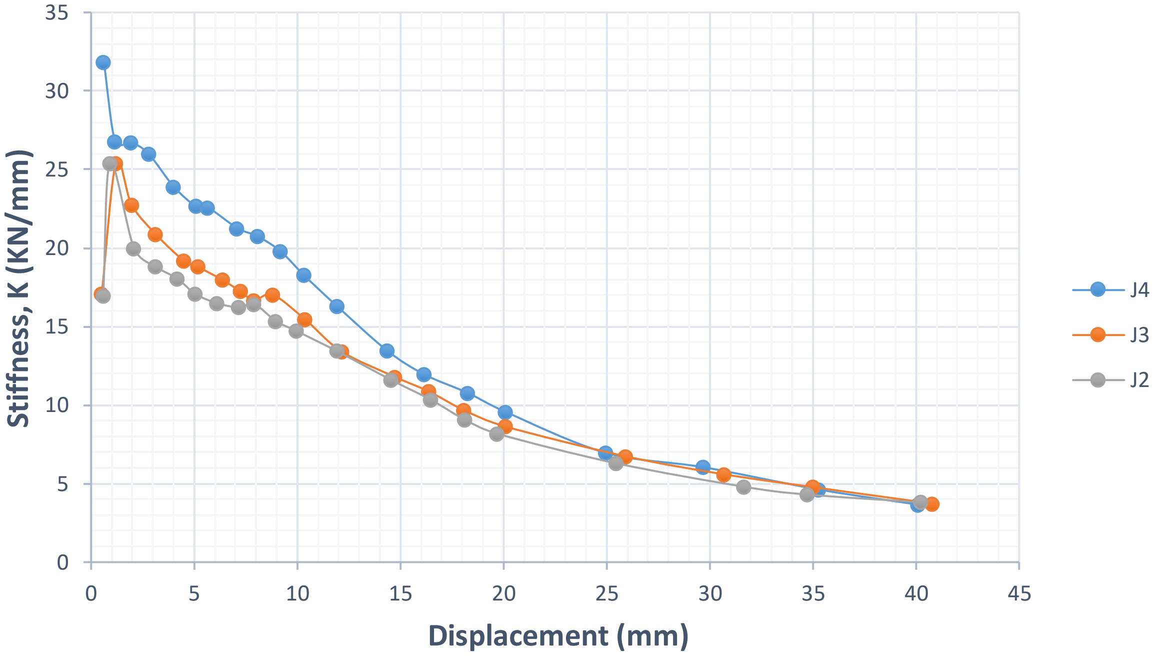

Figure (14): Stiffness Degradation of Joints.

Figure (14) presents stiffness degradation for all the specimens versus their displacement. Joint (J4) which had zero eccentricity exhibited stiffness degradation rate KDR 66%.While, Joint with eccentricity = 0.18 tc (J3) recorded stiffness degradation rate KDR 57% The specimen J2 (higher eccentricity joint), recorded stiffness degradation rate KDR 39% .J4 and J3 more than J2 by 69.2% and 46.1% respectively. The centric of beam position caused an increase in Stiffness Degradation of Joint.

4.5 STRENGTH DECAY

Reinforced concrete beam-column joints exhibit progressive loss of strength under cycles of inelastic deformations. As noticed from the load-displacement hysteresis loops, the peak strength increased as the applied displacement increase until ultimate capacity level was achieved. Beyond this level a decay in the loop peak strength was observed. The degree of strength decay depends on many parameters including the dominant response mode confinement and strength of concrete, history of cyclic load and level of axial load rapid strength decay produces significant adverse effects on hysteretic response.

To examine the ability of the beam-column to maintain carrying capacity in the post-elastic range, the loop peak load at maximum-recorded level was compared to ultimate load of the specimen. This comparison was quantified using the strength decay rate SDR.

$\boldsymbol{SDR} = \frac{P_u - P_m}{\Delta_m - \Delta_u}$ …………………………………….. (4-5)

Where:

P_u The associated load at Δ_u.

P_m The associated load at Δ_m.

Δ_u The displacement at ultimate level.

Δ_m The maximum record displacement.

The strength decay by all the specimens is given in Table 1. The strength decay by specimens J2, J3 and J4 is 1.38, 1.59 and 2.28 KN/mm .J4 and J3 more than J2 by 65.2% and 15.2% respectively. The centric of beam position caused an increase in strength decay.

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5. CONCLUSIONS

The present study was designed and implemented to investigate the effect of beam transverse position on the behavior of reinforced concrete beam-column Joints. The study also aimed to provide more experimental data on these areas of interest. For this purpose, three beam-column connections were constructed and subjected to lateral cyclic quasi-static loading tests with constant column axial load of 750 kN. The following conclusions may be drawn from the experimental results obtained:

1. Concentric specimen had displacement before failure higher than any other specimens with eccentricity.
2. The final failure mode of concentric specimen was due to the formation of the flexural plastic hinge in the beam end, adjacent to the column face which followed by spelling and crushing of the beam concrete occurred near the beam-column interface which is the one recommended by the design philosophies, while in the specimens with eccentricity were occurred in the joints herself and columns had same damages out of joint area.
3. Cumulative energy dissipation of all specimen were nearly similar form the first loading cycles and small variation occurred later, generally increasing in eccentricity decreasing Cumulative energy dissipation.
4. Stiffness degradation represented by stiffness degradation rate KDR of Non-eccentricity Specimen was higher than any other specimens with eccentricity. However, increasing in eccentricity decreasing stiffness degradation rate KDR.
5. Strength decay represented by strength decay rate SDR of Non-eccentricity Specimen was higher than any other specimens with eccentricity. However, increasing in eccentricity decreasing strength decay rate SDR.
6. Eccentricity of beam in beam column joint cause decreasing Cumulative energy dissipation, stiffness degradation rate KDR and strength decay rate SDR.

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