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Effect of Column Shape on the Behavior of Reinforced Concrete Beam Column Joints under Quasi-Static Loading

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***Abstract*:- This paper is concerned with experimental study of exterior reinforced beam-column joints subject to reverse cyclic loading. Four full scale beam-column joints (had the same moment of inertia) with concrete grade 35 Mpa were tested under reversed cyclic loading, applied in quasi-static cyclic condition, to study the effect of different column shapes on the behavior of reinforced concrete beam-column Joints, The results showed that all joints exhibited the same failure mode at the interface between beam and column, rectangular column (with same width of beam) and squared column shape were higher than the regular rectangular column and circular column in the loading capacity, displacement, stiffness degradation and strength decay.**

1. INTRODUCTION

A beam-column joint is a very critical part in reinforced concrete framed structures. [1-2] joints ensure continuity of a structure and transfer forces that are present at the ends of the members [2-3]. In reinforced concrete structures, failure in a beam often occurs at the beam-column joint making the joint one of the most critical sections of the structure [4]. Sudden change in geometry and complexity of stress distribution at joint are the reasons for their critical behavior [4]. The behavior of the connections between beams and columns is a significant parameter affecting the performance of reinforced concrete frames [5].

Over the last 30 years, many theoretical and experimental research works have been carried out in several countries, which led to the identification of critical features of joint behavior. Recommendations for design, which are often empirical, were given in the different codes [5].Most studies on the behavior of reinforced concrete (RC) beam-column joints focused on effect of concrete grade, different aggregate type, longitudinal reinforced bars and columns transverse reinforced ratio. Ramadan M. A. et al [5] studied performance of external reinforced concrete beam-column joints made of high strength concrete using 26 specimens, the main parameters were the details, type and amount of joint reinforcement, the type and amount of beam and column main reinforcement in the joint. The results showed that increasing the concrete compressive strength leads to an increase the joint shear resistance and deformation capacity. Flora Faleschini et al. [6] studied the influence of using Electric Arc Furnace (EAF) slag concrete in performance of reinforced beam-column joints using of three real scale joints under quasi-static cyclic loading study was carried out to understand the effects of column axial load, beam longitudinal reinforcement bar amount and column transverse reinforcement ratio. Results indicate that, in all the analyzed cases, the seismic performance of the joints made with EAF slag concrete is better than with conventional material.

ACI-ASCE Committee 318 [3] apply only to joints designed on strong column-weak beam philosophy where the column width is equal to or greater than the beam width. For ductile structures, it is necessary that the column should be strong than beams to ensure a desirable hierarchy of yielding. It is generally desirable to provide stronger columns and to allow the yielding of beams in flexure prior to possible yielding in columns, because column failure generally leads to the collapse of entire structure. However a few works have already been performed on real scale reinforced concrete beam-column joint to study the effect of columns shape on their behavior. In this work, four real scale beam-column joints were casted, with different shapes for column with the same reinforced ratio in all specimens. The joints were tested under reversed cyclic loading, applied in quasi-static conditions. The axial column load will be kept constant at a certain value (75 ton), which is less than 40 percent of the column ultimate axial load.

The main objective of this paper is to study experimentally the effect of column shape on the behavior of beam-column joint. The obtained results were analyzed and discussed. The experimental results were compared such as load-displacement, moment-curvature hysteretic responses, energy- displacement, stiffness degradation and crack pattern at different load levels until the failure loads.

2. MATERIALS CHARACTERIZATION:

2.1 Concrete

Ready mix of normal Portland cement concrete grade 30 Mpa was used and tested after 28 days. A dolomite aggregate (AGG1& AGG2) with size of ¾ inch (19mm), 1 inch (26.5mm) respectively was used throughout the specimens. (Table 1) lists the proportions of the concrete mix; the design average compressive strength for the mix is 30MPa. The cement used was standard Portland cement. Type (B) set retarding admixtures (7lit/m^3) were used, the cubes were tested after 28 days the results were average 37.8 Mpa.

For (1m^3) Concrete:

Table (1) the components of 1m3 of Ready mix concrete.

Cement	Fine aggregate	Coarse aggregate		water
		AGG1	AGG2	
401 kg	698 kg	594 kg	552 kg	190.4 kg

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 for 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

Four reinforced concrete beam column joints were tested under reversed cyclic loading as show in Figure (1). The description of the specimens in this study are summarized in table (2) and Figure (2), the details of reinforcement of the joints are shown in Figure (3).

Table (2) Diminution and shape of studied specimens (SI units)

Specimen	**Column Dimensions**(mm)	**Column shape**
J1	(360x360)	Square
J5	(250x400)	Rectangle
J6	(Dim.410)	Circle
J9	(200x430)	Rectangle

* Numbering of J1, J5, J6 and J9 is a part of study about investigation of behavior of RC Joint
J: joint for column

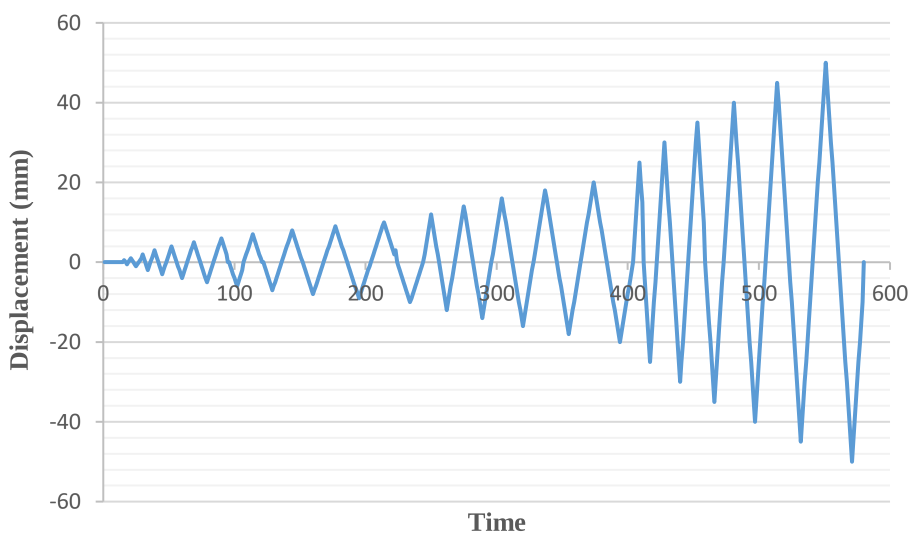

Figure (1): cyclic load history.

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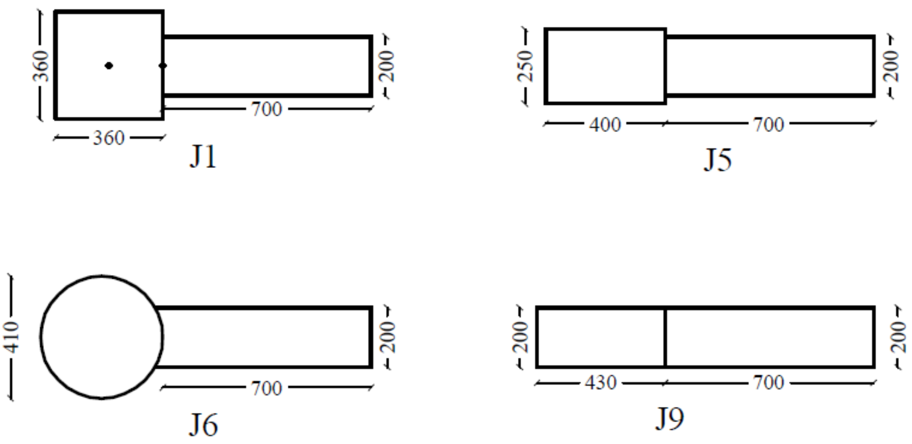

Figure (2): Diminution and shape of studied specimens.

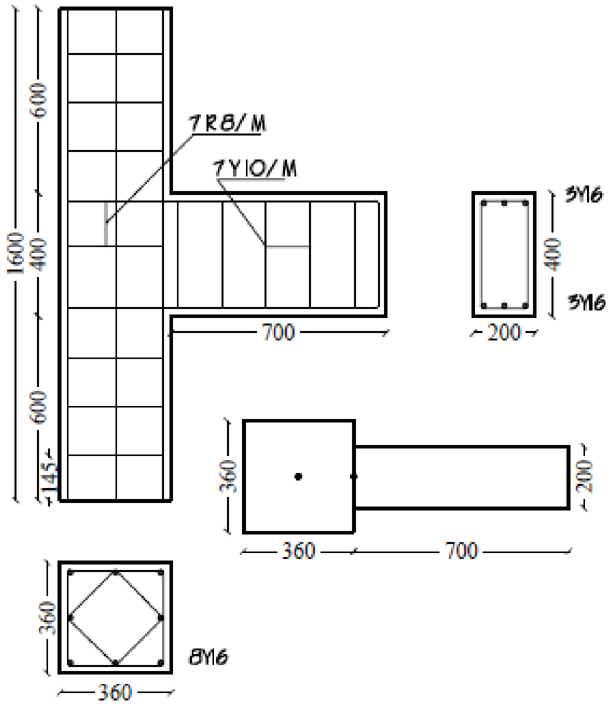

Figure (3): Steel reinforcement details of (J1).

The experimental portion of the investigation consisted of testing four beam column joints specimens, the beams were cantilever supported and had a clear span 700 mm. The columns were variables in shape but they have the same moment of inertia about the x and y axes. Figure (4) shows the used reinforcement cages and form works. Six electrical strain gauges were fixed to the vertical, horizontal steel bars and stirrups before casting of concrete for every single joint, as shown in figure (5). Eight linear variable Distance Transducers (LVDTs) with 0.01-mm accuracy were fixed as shown in figure (6) to measure the required displacement.

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

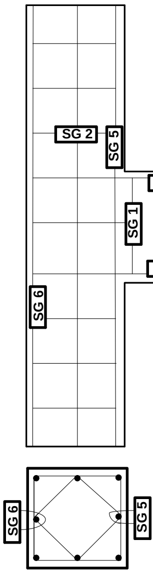

Figure (5): Location of steel strain gauges.

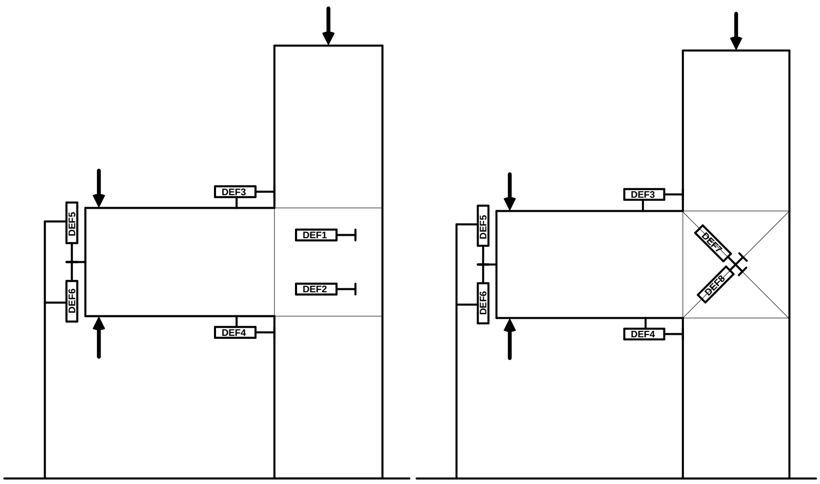

Figure (6): Locations of LVDTs

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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 1mm 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.

Figure (7) Test setup for all joints.

4. RESULTS AND DISCUSSION

Results for all specimens (joints) were listed in table (3), the results 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 (3) 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			
J1	192.2	13.86	-184.356	-16.45	2	10	25.98	1.83	0.40
J5	170.65	9.26	-166.155	-11.94	2	5	25.75	1.12	0.45
J6	178.06	10.75	-162.936	-11.5	2	6	30.42	1.39	0.35
J9	173.62	12.54	-172.4	-14.55	2	6	25.17	2.33	0.46

4.1 Cracks patterns and failure mode

During the tests, as show in Figure (8) a diagonal cracks appeared along the beam, located particularly close to the connection with the column. Some cracks occurred in the joint panel, failure occurred between beam and column face .Yielding of steel reinforced bars in the beam occurred in early level of displacement, about 6mm before than cracking in panel joint. The final failure mode was due to the formation of the flexural plastic hinge in the beam end, adjacent to the column face. Cracking in these specimens appeared initially as flexural cracks on the beam at displacement 2mm in all joints for both loading direction and followed by minor joint diagonal cracking formed at the joint core started at 5mm in J5 then at 6mm in both joint J6, J9 and 10mm in joint J1. New joint-inclined cracks continued to form in J5 until 14mm, in J1 until 18mm, while this process continued up to 20mm in J6 and J9.

Joint J1 (squared column) the joint core started cracked at high level displacement at 10 mm, joint had a few damage and less number of cracks than any anther joint in that test .. While in joint J5 (rectangular column) the joint core started crack at low displacement level 5mm and it had more damage and concrete crushing more than any joint. J6 (circular column) started crack at 6mm but Joint core of J5 had more crack number than in J6. Although all the columns sections have the same moment of inertia, the squared section column of joint J1 has capacity for resist load and moment higher than other sections, and rectangular section of J5 was the lowest capacity one, these related to the section dimensions, the area and position of steel. For all joint the point of

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load and moment due to the displacement in the edge of beam was at the interaction diagram curve of each column section, near to balanced failure point.

Figure (8) Cracks patterns and failure mode of joint (J1, J5, J6 and J9).

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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 in the squared rectangular column specimen (J1), with the increase in displacement in both positive and negative directions, the applied load was increased, and the load drop was not observed until average13.86 mm this due to uniform stress distribution due to his squared shape. In the specimen J9 (rectangular column with same width of beam), a similar trend was observed in the both directions, but the load drop in the started at the average 12.54 mm. In the specimen J5 (rectangular column), a similar trend was observed in the both directions, but the load drop in positive direction first at 9.26 mm then in negative direction at 11.01 mm. The same behavior observed in J6 (circular column) load drop in positive direction first at 10.75 mm then in negative direction at 11.5 mm, this related to irregular connection face between column and beam.

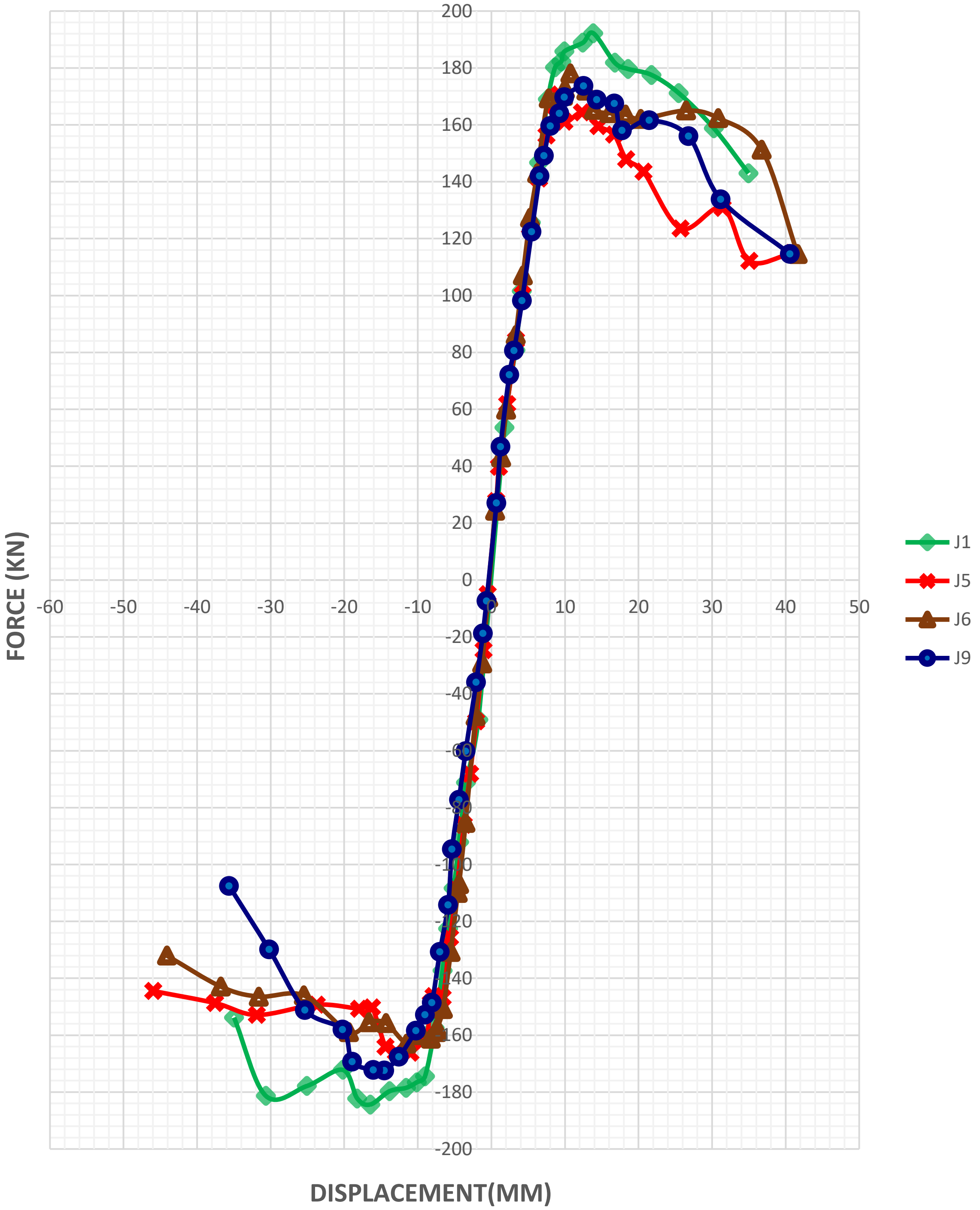

Figure (9) load- displacement curve (envelope) for joints.

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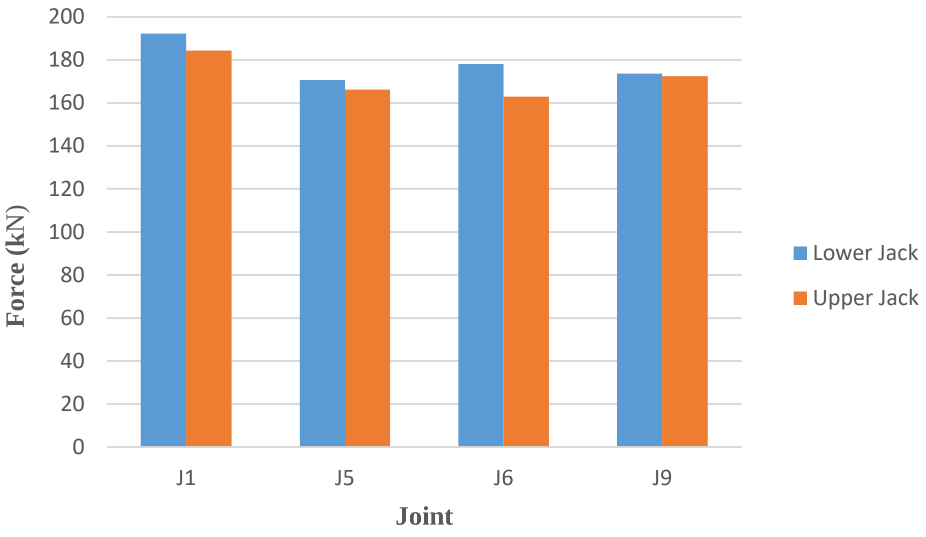

Figure (10) Ultimate lower, upper jack force for joint (J1, J5, J6 and J9).

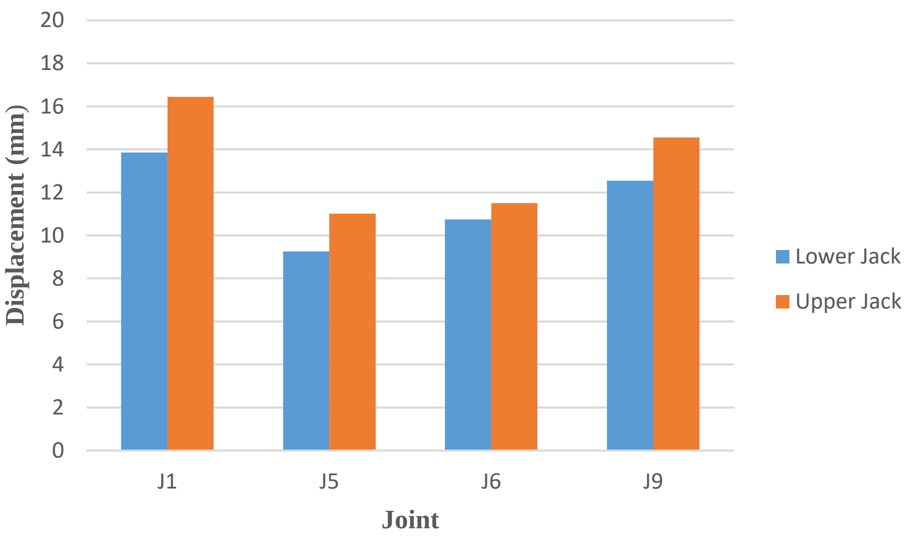

Figure (11) Disp. at ultimate lower, upper jack force for joint (J1, J5, J6 and J9).

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.

Cumulative relative energy dissipation versus displacement curve are plotted for all the specimens in Figure (12). Clearly, up to a displacement level of 22mm, nearly similar trends and values observed in the cumulative energy dissipation by all joints, cumulative energy dissipation of joint (J1) had higher energy dissipation rates than any other joint. Comparison of the energy dissipated by joint (J9) in the same figure reveals decreases during the last displacement.in general view Cumulative relative energy dissipation for all joints were nearly similar.

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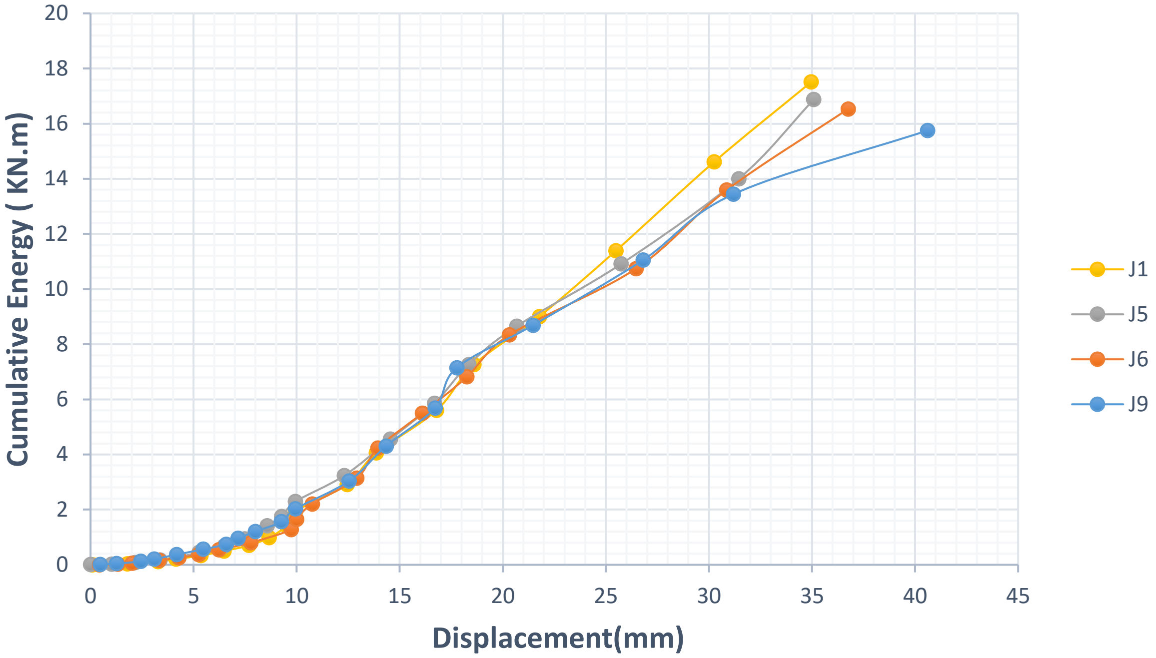

Figure (12) Cumulative Energy Dissipated by Joints.

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 of J9 higher than those of J1, J5 and J6. The degradation of the stiffness at ultimate load level was evaluated using the stiffness degradation rate KDR.

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

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

Where:

k_o The flexural stiffness of the specimen at initial.

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

Figure (13) presents stiffness degradation for all the specimens versus their displacement. Joint (J1) which had squared column section exhibited stiffness degradation rate KDR 40%.While, Joint with circular column (J6) recorded stiffness degradation rate KDR 35% The joint J9 (rectangular column with same width of beam), J5 (regular rectangular column) showed relatively similar secant stiffness values during the test until the end, values of KDR for these two specimens were 46% and 45% respectably. Changing the shape of column from squared to circular reduce stiffness degradation rate 14%, while changing to rectangular increase stiffness degradation rate 15%.

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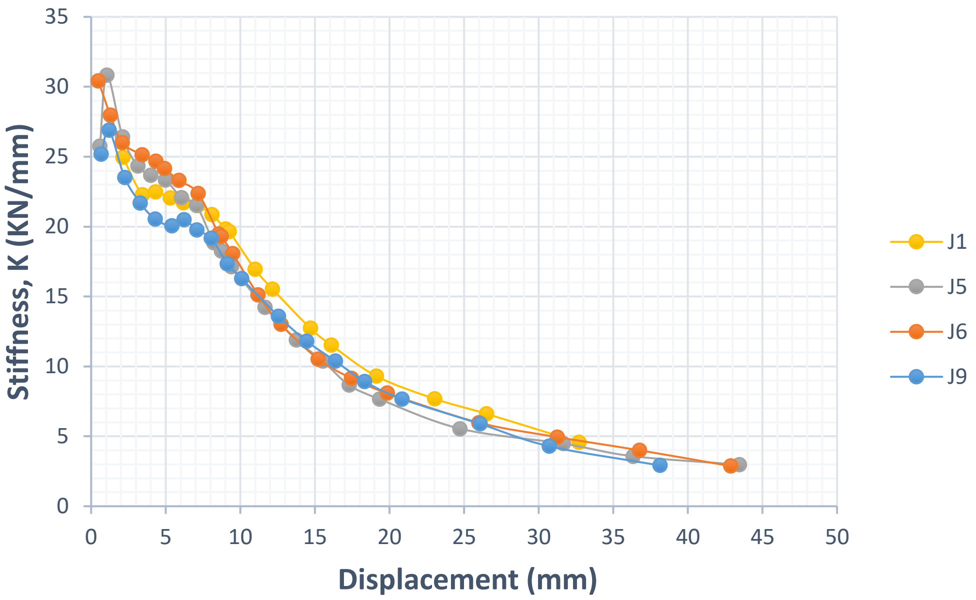

Figure (13) Stiffness Degradation of Joints.

4.5 STRENGTH DECAY

As noticed from the load-displacement hysteresis loops, the peak strength increased as the applied displacement increase until ultimate capacity level was achieved. Reinforced concrete beam column joints exhibit progressive loss strength under cycles of inelastic deformations. 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 the hysteretic response.

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

$$\boldsymbol{SDR = \frac{P_u - P_m}{\Delta_m - \Delta_u}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(1)}$$

Where:
Δ_u The displacement at ultimate level.
Δ_m The maximum record displacement.
P_u The associated load at Δ_u.
P_m The associated load at Δ_m.

Table (1) presents strength decay rate SDR for all the specimens. Joint (J9) which had rectangular column with same width of beam exhibited a higher strength decay rate SDR 2.33.While, Joint with rectangular column (J1) recorded strength decay rate SDR 1.83.The specimens J6 (circular column), J5 (regular rectangular column) showed relatively similar strength decay rate SDR 1.39 and 1.12 respectably. Changing the shape from rectangular with same width to square reduce strength decay rate 27%, while changing to circular or rectangular with long width reduce strength decay rate to 67%, 108% respectively.

5. CONCLUSIONS

The present study was designed and implemented to investigate the effect of different column shapes on the behavior of reinforced concrete beam-column Joints. The study also aimed to provide more experimental data on these areas of interest. Conclusions may be drawn from the experimental results obtained:

1. The load-carrying capacities of the specimen which had square column was higher than any other specimens, on the other hand specimen which had regular rectangular column was lower than any other column shape this related to decrease of its effective width.

2. Square column was had the highest force and displacement before failure.

3. Failure mode of all specimens was due to the formation of the flexural plastic hinge in the beam end, adjacent to the column face which was followed by spalling and crushing of the beam concrete occurred near the beam-column interface.

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4. Cumulative energy dissipation of all specimen were nearly similar form the early loading cycles with small variation occurring later in the loading steps.

5. Changing the shape of columns doesn't have any remarkable effect on Stiffness degradation represented by stiffness degradation rate KDR of the beam column joint

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