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Experimental and Analytical Analysis of Exterior R.C Beam-Column Connection with different Aspect ratio Under Cyclic Loading

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ملخص البحث

يهدف هذا البحث إلى عمل دراسة معملية ونظرية لمعرفة مدى تأثير تغيرأبعاد الكمرة بالنسبة للعمود في الوصلات بين الأعمدة والكمرات الطرفية على قدرة تحمل الوصلة في القص وفي هذا الصدد تم إعداد واختبار 4 عينات بمعمل الخرسانة المسلحة بالمعهد القومي لبحوث الإسكان والبناء وتم اختبار العينات تحت تاثير حمل ترددي عكسي في طرف الكمرة وحمل رأسي ثابت على العمود بنسبة 10% من قدرة تحمل العمود الكلية حتى الانهيار.
وكان المتغير الرئيسي هو زيادة أبعاد الكمرة بالنسبة للعمود حيث تم الاختبار تحت نسبة بعد الكمرة للعمود (0.75 و1.00و1.50و1.75) وقد تم تسليح العمود والكمرة حتى لايحدث بهما اي نوع من انواع الانهيار بحيث يكون الانهيار في منطقة الوصلة وتم رصد حمل كل كمرة وترخيمها وشكل الشروخ التي حدثت بالوصلة اثناء التحميل وتم تحليلها ومناقشتها علاوة على عمل تحليل عددي للتبؤ بقيمة الحمل الذي تم عنده الكسر. فتبين انه زيادة بعد الكمرة بالنسبة الى العمود يؤدي الى زيادة القوة اللازمة لانهيار الوصلة ايضاَ يؤدي الى زيادة قدرة الوصلة على تبديد الطاقة.

ABSTRACT:

In RC buildings, portions of columns that are common to beams at their intersections are called beam column joints. Since their constituent materials have limited strengths, the joints have limited force carrying capacity. When forces larger than these are applied during earthquakes, joints are severely damaged. Repairing damaged joints is difficult, and so damage must be avoided. Thus, beam-column joints must be designed to resist earthquake effects.

The present paper investigates experimentally the behavior of RC beam-column connection under cyclic loading. In addition, theoretical analysis confirming the test results is presented. In this respect, 4 RC beam-column joints were prepared, cast and subjected to reversed cycle-loading up to failure at the reinforced concrete laboratory of the Housing and Building National Research Center (HBRC). The main parameter among the tested specimens was the column axial load level. The test results first showed expectedly, the increase of axial load induces an increase in load corresponding to the initial diagonal cracking and increase of ultimate shear strength.

Keywords: Beam column joint, cyclic load, analytical models, aspect ratio, Reinforced Concrete.

I. INTRODUCTION

Under earthquake shaking, the beams adjoining a joint are subjected to moments in the same (clockwise or counter-clockwise) direction. Under these moments, the top bars in the beam-column joint are pulled in one direction and the bottom ones in the opposite. These forces are balanced by bond and steel in the joint region. If the column is not wide stress developed between concrete enough or if the strength of concrete in the joint is low, there is insufficient grip of concrete on the steel bars. In such circumstances, the bar slips inside the joint region, and beams lose their capacity to carry load forces at top geometric distortion; one diagonal length of the joint and bottom ends, joints undergo elongates and the other compresses. If the column cross-sectional size is insufficient, the concrete in the joint develops diagonal cracks. This research aims to investigate the behavior of reinforced concrete Beam-Column joints under cyclic loading.

To understand the behavior of beam column connection, a large number of experimental and analytical studies have been conducted since the mid – 1960s. The first experimental study on beam-column connections were carried out by Hanson and Connor (1967) under simulated earthquake loading in the United States. Megget and Park (1971) performed experimental study of the external beam-column joint under seismic loading and low axial load. Scribner and wight (1980) conducted experimental study the strength decay in eight half scale and six full scale RC exterior beam-column joint under cyclic load to investigate the effect of intermediate longitudinal reinforcement on shear deterioration of flexural members subject to cyclic loading. Zhang and Jirsa (1982) Sarsam and Phipps (1985) Durrani and Wight (1985) investigated experimental study on performance of an interior Beam-Column connection under earthquake type of loading which less joint reinforcement than recommended by ACI-ASCE Committee 352. They reported that the joint shear stress had a pronounced effect on the behavior at large ductility levels and the joint hoop reinforcement. Abdel-Fattah and Wight (1987) investigated twelve full-size interior Beam-Column connection were tested under cyclic loads to study relocating of plastic hinge zone for earthquake –resistant design of RC buildings. Murty et al (2003) experimental studied exterior Beam-Column connection under displacement controlled cyclic loading to study the effectiveness of anchorage of longitudinal beam bars and the transverse reinforcement in the joint core. A.M Choudhury et al (2010) instigated Comparative study of full scaled Beam-Column joints under cyclic loading. They reported that envelope curve, stiffness, ductility, ultimate load were improve in column strong specimen than the column weak specimen. The main parameter among the tested specimens was the column axial load level.

II. TEST SPECIMENS

Four RC beam-column connections were loaded by applying constant compressive axial loads on the columns while the free end of the beams were subjected to displacement-controlled reversed increasing cyclic load in order to simulate the behaviour of RC beam-column connection under seismic action. The beam was provided with a hole at its tip to allow for application of cyclic load. The longitudinal steel of column consisted of five bars, of nominal yield strength of 360MPa , arranged in the cross section at each side. The longitudinal reinforcement of beam consisted of seven bars as shown in Figures (1.a,d). Table (1) lists the properties of specimens tested of all specimens and the variations of the investigated parameters. The table gives loading conditions, compressive strength of concrete at the time of testing, the properties and amount of longitudinal and transverse reinforcement of beam, column and joint for each specimen of group.

The transverse reinforcement configuration of the column and beam comprised a peripheral hoop, all ties were anchored with 135-degree bends 60mm into the concrete core from one side and 90-degree bends extending 80mm from the other side. The beam was provided with a hole at its tip to allow for application of cyclic load.

The test specimens were divided into four specimens depending on geometric aspect ratio.

Table 1: Geometry and mechanical properties of the test specimen

Specimens	Materials			aspect ratio	Geometry				Reinforcement				
No	fc (mpa)	fy long (MPa)	fy shear (MPa)	hb/hc	Beam wb*hb (mm)	Column hc*wc (mm)	Joint wj*hj (mm)	Length Hc/Lb/2 (mm)	Beam AsBB	Beam AsBT	Column AsC1	Column AsC2	shear rft
J1G2	20.2	360	240	0.75	200*150	200x200	200*150	1900x1000	7T12	7T12	5T12	5T12	R 8@85mm
J2G2	20.2	360	240	1.00	200*200	200x200	200*200	1900x1000	7T12	7T12	5T12	5T12	R 8@85mm
J3G2	20.2	360	240	1.50	200*300	200x200	200*300	1900x1000	7T12	7T12	5T12	5T12	R 8@85mm
J4G2	20.2	360	240	1.75	200*350	200x200	200*350	1900x1000	7T12	7T12	5T12	5T12	R 8@85mm

The specimens were tested under a rigid steel frame as shown in Figure (1.b). Five LVDT were used to evaluate the element deformation as shown in Figure (1.c). The beam end displacement cycles as per the loading protocol used in the testes are shown in Figure (1.d)

Figure 1-a: Steel Reinforcement of specimens

Figure 1-b TEST SET-UP

Figure 1-c: Location of LVDR

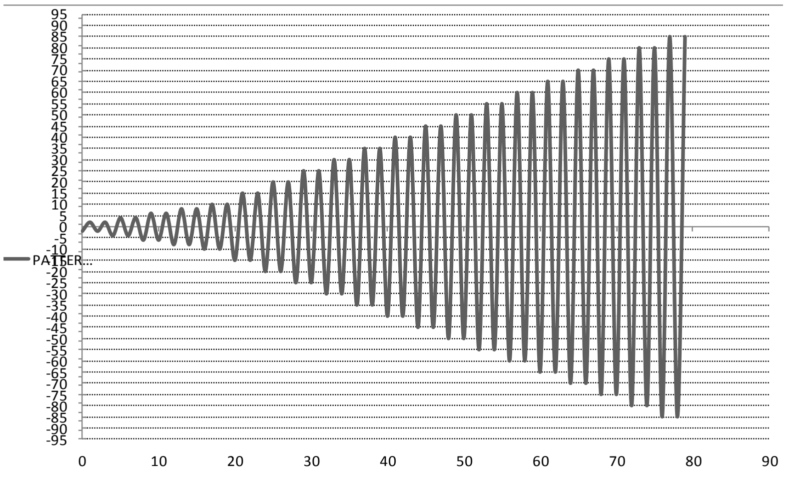


Figure 1-d : Loading pattern used for the tests

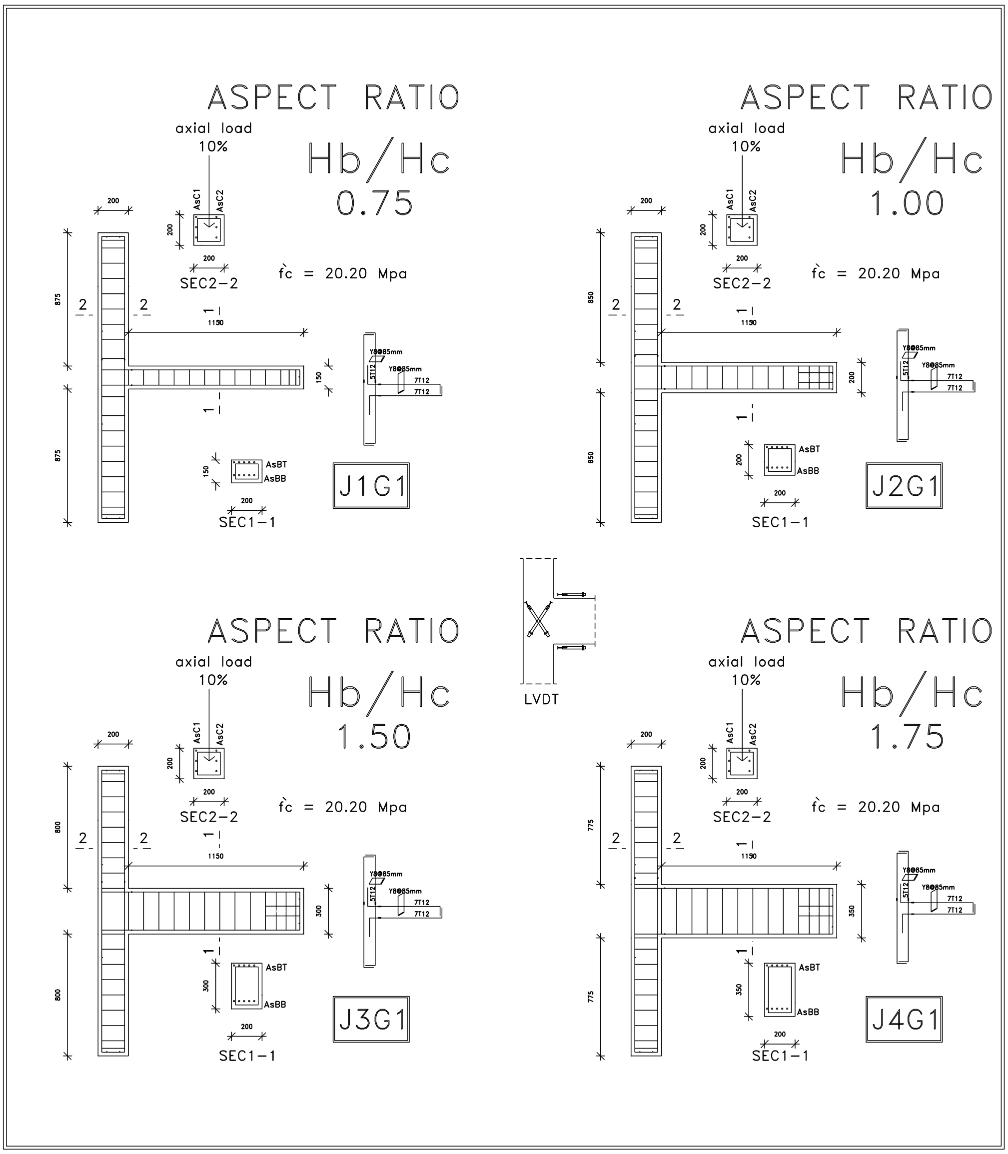


Figure 1-e: Details of reinforcement for all specimens

III. EXPERIMENTAL RESULTS

A summary of the results of the experimental program is presented in this section for each specimen. The results includes: hierarchy load-displacement relationship, backbone load deflection curve, maximum joint shear strength, the mode of failure, initial stiffness and stiffness degradation and energy dissipation will be shown.

A) Hysteretic load-deflection relationship

Figures (2) shows the hysteretic load-displacement curves obtained for the joint J1G1. In the plots, the load is considered as positive when the beam is pulled up and negative when pushed down. The peak load in the positive direction was obtained as 18.12 KN and that in the negative direction was -19.42 KN. In both sides, the peak load was obtained during 18mm cycle. The shows a practically symmetric behavior of the joint as is expected for a joint having symmetric reinforcement detailing.

B) Backbone load deflection curve

Figure (3) compare backbone load-deflection relations and envelope curves of specimens (J1G1, J2G1, J3G1, J4G1). The increase of joint aspect ratio induces an increase in load corresponding to the initial diagonal cracking and an increase of ultimate shear force. The average beam end load of joints J2G1, J3G1 and J4G1 is 6.80%, 56.48% and 58.47% higher than J1G1 respectively.

C) Joint shear strength

The joint shear strength Ɣj increase due to increase the joint aspect ratio as shown in Figure (4). The joint shear strength of specimen (J1G1) is 11.11% lower than (J2G1) and 98.0% lower than (J4G1) respectively. The post-peak joint shear strength degradation, of joint J1G1, J2G1 and J4G1 is almost identical. This indicate the negligible effect of joint aspect ratio on the post beak strength degradation of unconfined corner beam-column connections.

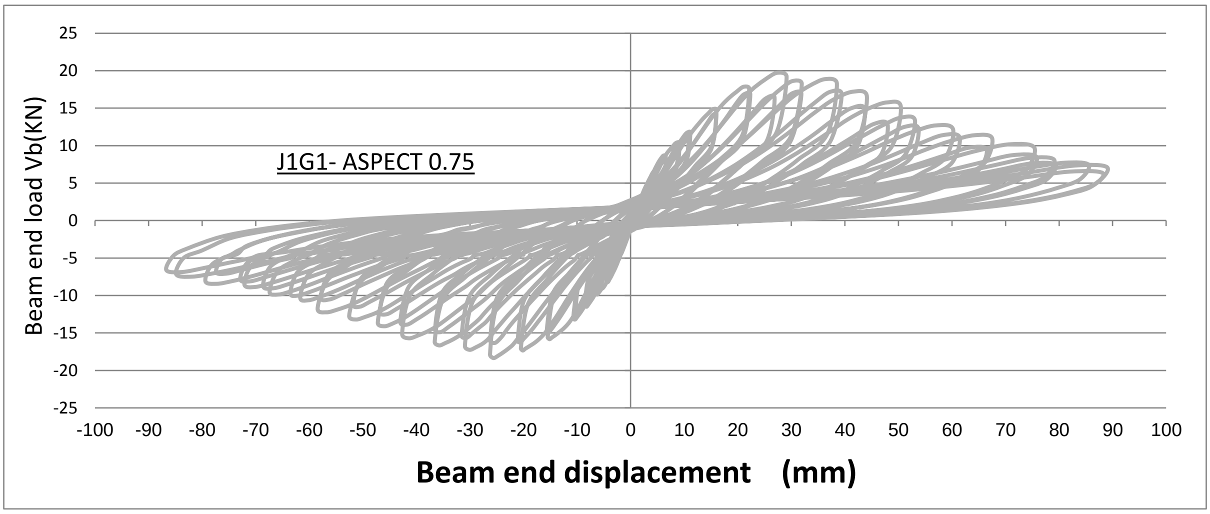
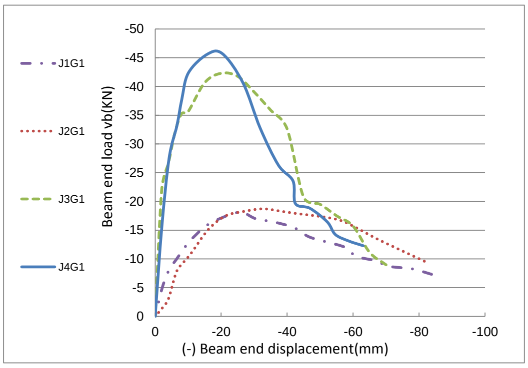


Figure 2: Hysteretic loops obtained from test specimen (J1G1)



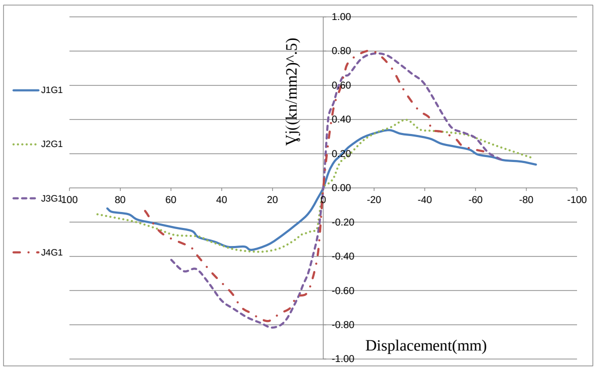


Figure 3: Backbone load deflection curve

Figure 4: joint shear strength for all specimens

D) Crack pattern

Figure (5) displays the crack pattern at maximum joint shear strength loading for specimens of group 1. It can be observed, that the diagonal shear crack in the core becomes steeper.

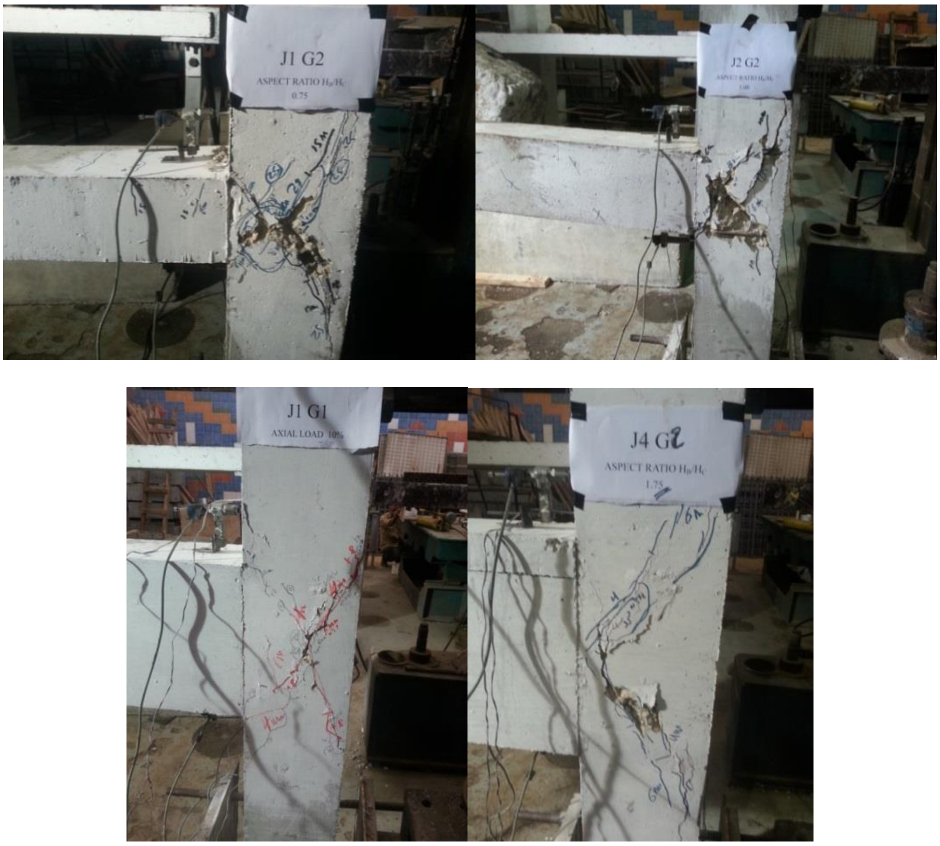


Figure 5: Crack pattern of all Specimens

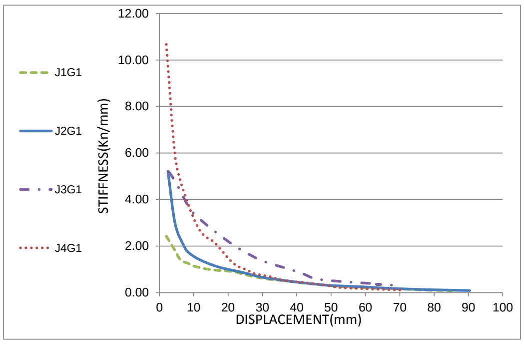


Figure 6: Stiffness Degradation of all Specimens

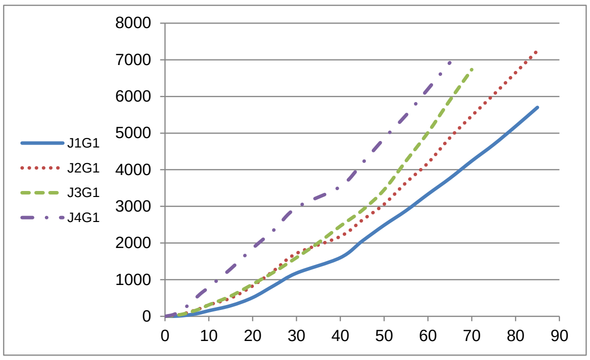


Figure 7: Energy Dissipation of all specimens

E) Stiffness and stiffness degradation

From Figure (6) it can be observed that the initial stiffness of specimens with high aspect ratio started with high stiffness compared with different specimens. This indicates that the higher aspect ratio is helpful to increase the pre-peak stiffness. However, this behavior is reversed in the post-beak stiffness. The higher aspect ratio tends to increase post-peak stiffness degradation. The initial stiffness of specimens J4G1, J3G1 and J2G1 higher than that of J1G1.

The peak to peak stiffness degradation curves are shown in Figure 6. It can be described that, for the first few cycles, the effective stiffness of specimens J4G1, J3G1 and J2G1 is higher than that of specimens J1G1, However, this effective stiffness enhancement due to higher aspect ratio decreases as the loading cycles proceeded towards reaching maximum shear strength after which the effective stiffness of specimens J4G1 started to decline below that of specimens J3G1.

F) Energy dissipation

From Figure (7) it can be observed that under the same ductility at 30mm displacement the energy dissipation of specimens with aspect ratio 1.75 have better energy dissipation capacity than those with (0.75, 1.00, 1.50) respectively.

IV. ANALYTICAL STUDY

The analytical phase of this study includes a rational analysis to predict the effect of column axial load and joint aspect ratio. An assessment regarding some of the existing Code provisions and models from the literature to predict the internal stresses, forces, corresponding applied load also included.

IV.1 SECTION ANALYSIS OF JOINT WITH AXIAL LOAD ON COLUMN

Let the axial load on the column be (p). In this case, σ is the vertical joint shear stress given by,

$$\sigma = \frac{V_{jv}+P}{h_c b_c} = \frac{V_{jv}}{h_c b_c} + \frac{P}{h_c b_c} \qquad [1]$$

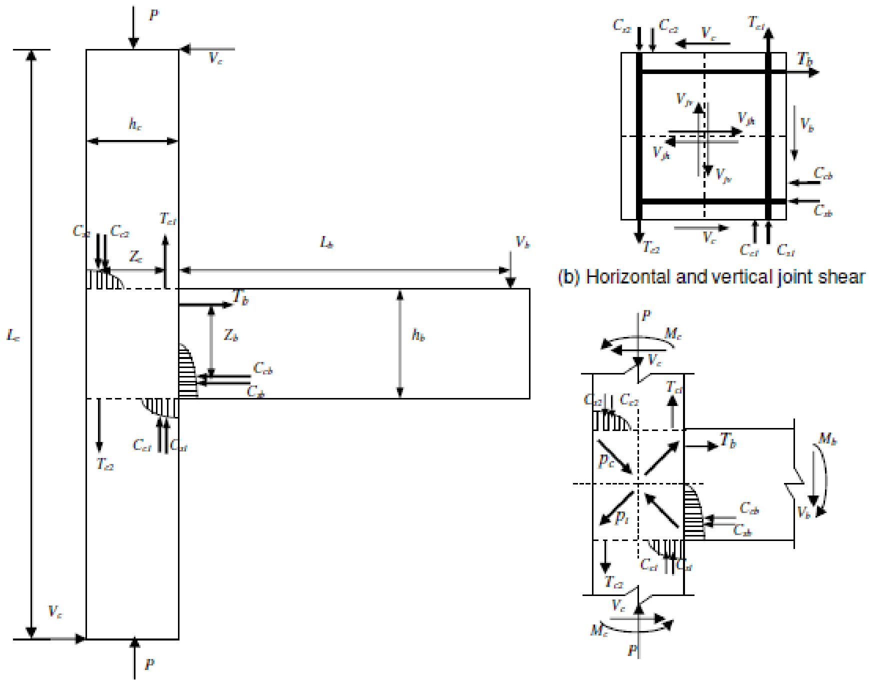
The principal tensile stress is given by (Tsonos 2007).

$$p_t = \frac{\sigma}{2} - \frac{\sigma}{2}\sqrt{1 + \frac{4\tau^2}{\sigma^2}} \qquad [2]$$

And τ is horizontal jont shear stress given by,

$$\tau = \frac{V_{jh}}{h_c b_c} \qquad [3]$$

Using equation (1), (2), we get



(b) Horizontal and vertical joint shear

(a) External actions and forces in beams and columns

(c) Principal stresses in joint

FIGURE 8: Action and forces of exterior connection

$$\sigma = \frac{V_{jv}}{V_{jh}} * \tau + \frac{P}{h_c b_c} \qquad [4]$$

Also, it is shown (Park and paulay, 1975; CEN 250; Paulay and park, 1984; Tsonos,2007) that

$$\frac{V_{jv}}{V_{jh}} = \frac{h_b}{h_c} = \alpha \qquad [5]$$

To calculate, V_c corresponding to V_{jh}, we need to follow an iterative procedure as given below,

1. Calculate moment in beam, Mb v/s tensile force in the beam bar, Tb curve for beam section in case of exterior joints and Mb v/s (Csb +Ccb + Tb), for interior joints (Same procedure as followed for obtaining moment v/s curvature diagram).
2. Assume a value of Tb or (Csb +Ccb + Tb), as appropriate.
3. Calculate column shear using eq 6.7 or 6.8, as appropriate
4. Calculate beam shear from global equilibrium of the joint

   $$Vb = \frac{Vc*Lc}{Lb+\frac{h_c}{2}} \text{ (for exterior joint)} \qquad [6]$$
5. Calculate moment in the beam,

Mb = Vb* Lb [7]

6. From Mb v/s Tb diagram or Mb v/s (Csb +Ccb + Tb) find the value of Tb or (Csb +Ccb + Tb)
7. If the value obtained in step 6 is close to the corresponding assumed value in step 2, then the obtained value of Mb corresponding to Vjh is correct. Else, go to step 2 and iterate.

By this iterative procedure, we can obtain the value of Vc and Mb corresponding to V_{jh} (and in turn corresponding to ρ_t). corresponding to agiven value of γ_s, we can calculate δc = γ_s*hb/2. Thus, we can have a Vc v/s δc relationship for shear hinge in column region of the joint and Mb v/s γ_s relationship for rotational hinge in beam region of the joint.

Where

ρ_t = The principal tensile stress
σ = The vertical joint shear stress
V_{jv}= vertical joint shear force
V_{jh} = horizontal joint shear force
h_c = depth of the joint core
b_c = breadth of the joint core
h_b = depth of the beam
α = the aspect ratio of the joint
Csb = Force of the compressive steel reinforcement;
Ccb = Force of the compressive concrete;
Tb = Force of tensile steel reinforcement
Vc = Column reaction
Mb = Moment at the inter face between column and beam
γ_s = joint shear distorsion
Lb = Beam length
δc = column displacement at top

IV.2 COMPARISON BETWEEN EXPERIMENTAL AND ANALYTICAL RESULTS

The following subsections present a comparison between the experimental results and the analytical results obtained using the model discussed in the previous subsections. Comparisons will be based on the loads at failure measured experimentally and calculated from the previous model.

Self-developed excel sheets were adopted to calculate the strain and the capacity of the tested joints using the previously mentioned analytical model.

GROUP(1): Figure 9 Shows the comparison between the experimental and the calculated capacity loads. The difference between measured and calculated capacity loads were 7.00% for J1G1, 4.0% for J2G1, 3.0% for J3G1 and 5.00% for J4G1.

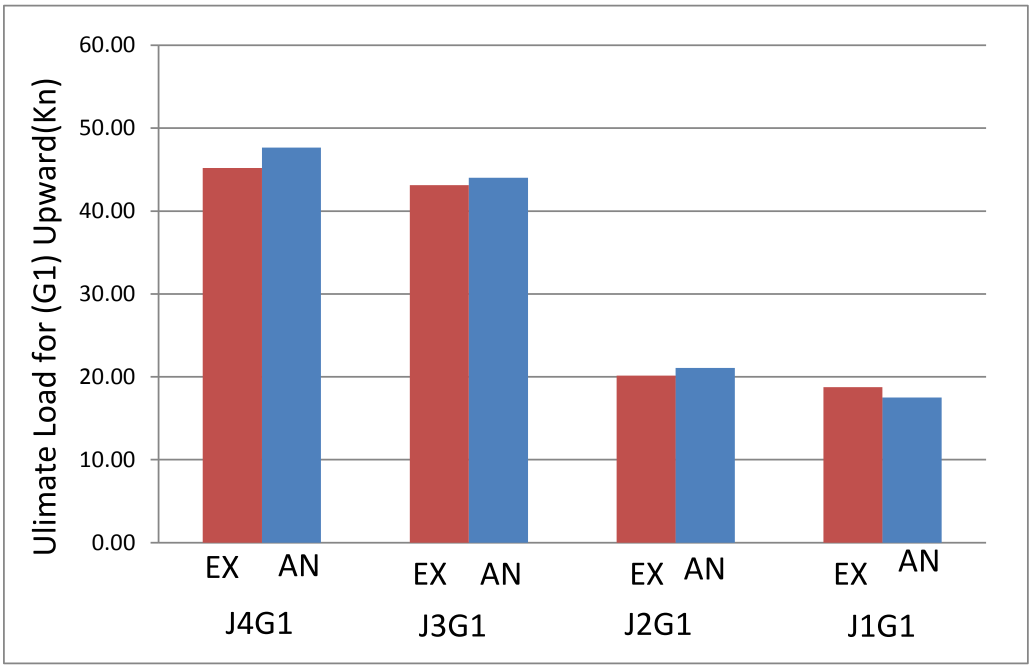


Figure 9: Comparison between the Calculated and the Measured Load capacity

V. CONCLUSIONS

The present study investigated the effect of column joint aspect ratio on the behavior of beam column connection under cyclic loading. The following summarizes the finding of this investigation:

1. The increase of joint aspect ratio induces an increase in load corresponding to the initial diagonal cracking and an increase of ultimate shear force
2. The negligible effect of joint aspect ratio on the post beak strength degradation of unconfined corner beam-column connections.
3. The initial stiffness of specimens with high aspect ratio started with high stiffness compared with different specimens. This indicates that the higher aspect ratio is helpful to increase the pre-peak stiffness.
4. The higher aspect ratio tends to increase post-peak stiffness degradation
5. under the same ductility at 30mm displacement the energy dissipation of specimens with aspect ratio 1.75 have better energy dissipation capacity than those with 0.75
6. The analytical model closely predicts the experimental behavior of beam column joint.

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