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Experimental and Analytical Analysis of Exterior R.C Beam-Column Connection with Different Column Axial load level Under Cyclic Loading

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ملخص البحث

يهدف هذا البحث إلى عمل دراسة معملية ونظرية لمعرفة مدى تأثير تغير الحمل الرأسي على العمود في الوصلات بين الأعمدة والكمرات الطرفية على قدرة تحمل الوصلة في القص وفي هذا الصدد تم إعداد واختبار 4 عينات على شكل حرف(T) بمعمل الخرسانة المسلحة بالمعهد القومي لبحوث الاسكان والبناء وتم اختبار العينات تحت تأثير حمل ترددي عكسي في طرف الكمرة حتى الانهيار.
وكان المتغير الرئيسي زياده الحمل الرأسي على العمود ليمثل نسبة من الحمل الكلي الذي يتحملة العمود وقد تم تسليح العمود والكمرة حتى لايحدث بهما انهيار بحيث يكون الانهيار في منطقة الوصلة بها وتم رصد حمل كل كمرة وترخيمها وشكل الشروخ التي حدثت بالوصلة اثناء التحميل وتم تحليلها ومناقشتها علاوة على عمل تحليل عددي للتنبؤ بقيمة الحمل الذي تم عنده الكسر. فتبين انه بزيادة الحمل الراسي على العمود تزيد جساءة الوصلة وبالتالى تزيد قدرة التحمل كما ان الحمل العالى على الأعمدة أدي الى تاخر ظهور الشروخ إلا أنه يؤدي الى حدوث انبعاج في الأسياخ الرأسية في العمود وخاصة في المراحل المتأخرة بعد حدوث انهيار للوصله.

ABSTRACT: In the past decades a lot of research has been carried out to understand the shear behavior of beam-column connections. Many experimental results are available and several assessment models have been proposed to date. However, no general agreement on the shear behavior of beam- column connection has been reach yet in the scientific community.

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 reverse 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. The better bond capacity associated with higher axial load level delayed secondary joint strut cracking.

Keywords: Beam column joint, cyclic load, axial load level, Reinforced Concrete.

I. INTRODUCTION

Earthquakes are the most major cause of failure of concrete structures. In addition, most of this failure occurs in the beam-column joints. This research aims to investigate the behavior of reinforced concrete Beam-Column joints under cyclic loading.

To improve the safety of RC structures under seismic load, designers have to carefully consider the shear strength and the ductility performance of beam-column connections to ensure that brittle shear failure at the joint region is avoided.

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 was 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 an experimental study the strength decay in eight half scale and six full scale RC exterior beam-column joints 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 with 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) experimentally 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 scale Beam-Column joints under cyclic loading. They reported that envelope curve, stiffness, ductility, ultimate load were improved in column strong specimen than the column weak specimen. Many experimental results are available and several assessment models have been proposed to date. However , no general agreement on the shear behavior of beam- column connection has been reach yet in the scientific community. 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 variable 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 reinforcement of beam and column showing in Figures (1.a). The beam bars of group terminating at the joint were anchored within the core of the joint using a standard hook that satisfies the ACI 318-08 requirements.

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 test specimens were divided depending on axial load in column. 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.

Table 1: Geometry and mechanical properties of the test specimen

Specimens	Materials			Load	Geometry				Reinforcement				
No	fc (MPa)	fy long (MPa)	fy shear (MPa)	Load Level %	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
J1G1	20.20	360	240	10	200*300	200x200	200*300	1900x1000	7T12	7T12	5T12	5T12	R 8@85mm
J2G1	20.20	360	240	20	200*300	200x200	200*300	1900x1000	7T12	7T12	5T12	5T12	R 8@85mm
J3G1	23.30	360	240	30	200*300	200x200	200*300	1900x1000	7T12	7T12	5T12	5T12	R 8@85mm
J4G1	20.20	360	240	40	200*300	200x200	200*300	1900x1000	7T12	7T12	5T12	5T12	R 8@85mm

The specimens were tested under a rigid steel frame as shown in Figure (1.b). Five LVDTs 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 tests are shown in Figure (1.d)

Figure 1-a: Steel Reinforcement

Figure 1-b TEST SET-UP

Figure 1-c: Location of LVDTs

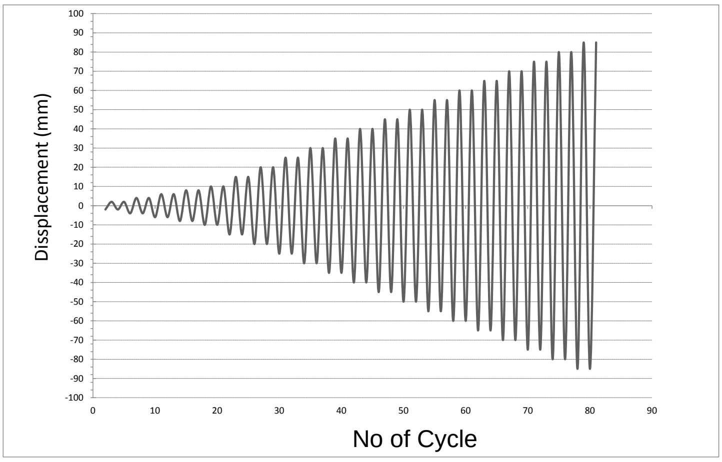


Figure 1-d : Loading pattern used for the tests

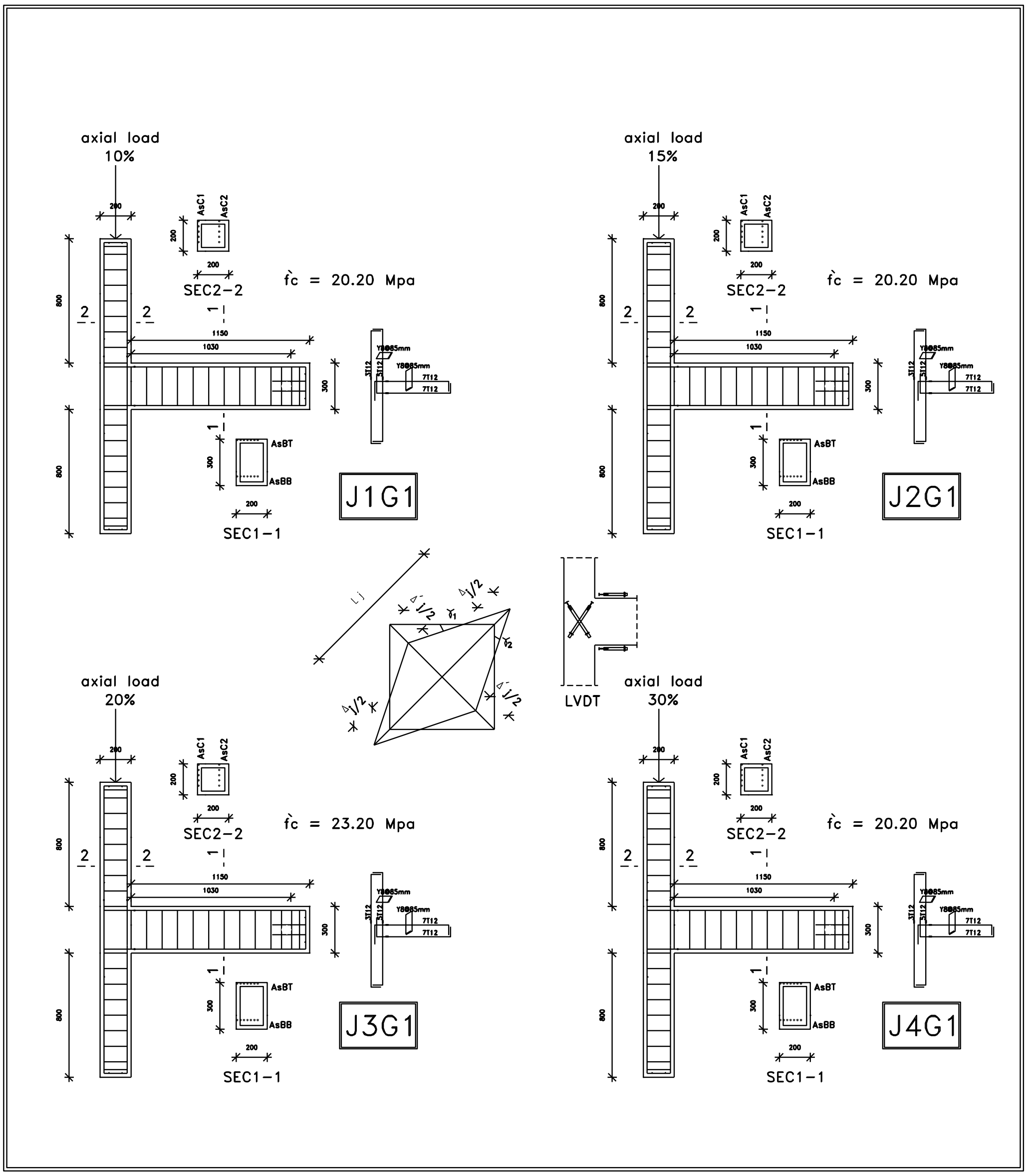


Figure 1-e: Details of Reinforcement

II. 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 43.96 KN and that in the negative direction was -42.29 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

Figures (3) compare backbone load-deflection relations and envelope curves of specimens (J1G1, J2G1, J3G1, J4G1). The increase of axial load induces an increase in load corresponding to the initial diagonal cracking and increase of ultimate shear strength. The average beam end load of joints (J2G1, J3G1, J4G1) was 6.70%, 24.37% and 26.94% higher than J1G1 respectively. The joint shear strength was enhanced due to higher axial load. The post-peak joint shear strength degradation, represented by softening slope of backbone curve, of joint J3G1, J4G1. In general the post-peak strength degradation due to high axial load was significantly higher than that in the case of low axial load.

C) Joint shear strength

The joint shear strength was enhanced due to higher axial load. The post-peak joint shear strength degradation, represented by softening slope of backbone curve, of joint J3G1, J4G1. In general the post-peak strength degradation due to high axial load was significantly higher than that in the case of low axial load. The joint shear strength of joints J2G1, J3G1, J4G1 was 2.10%, 30.1% and 40.8% higher than J1G1 respectively.

The joint shear strength of joints J2G1, J3G1, J4G1 was 2.10%, 30.1% and 40.8% higher than J1G1 respectively as shown in Figure (4).

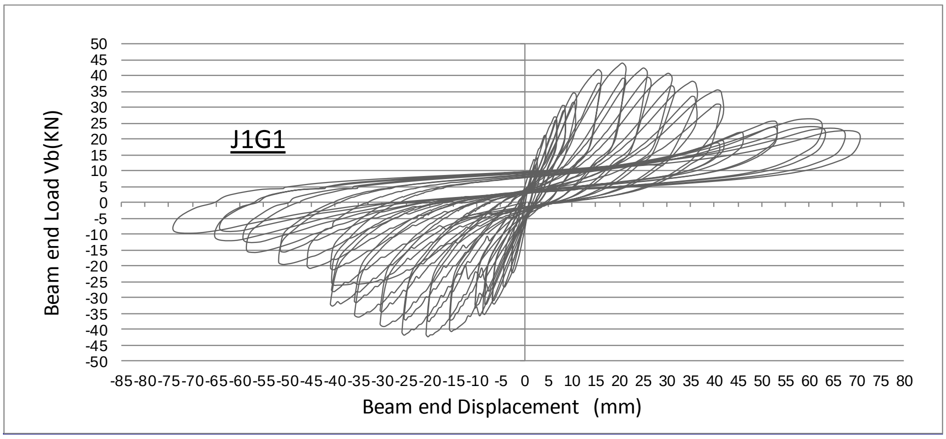


Figure 2: Hysteretic loops obtained from test on J1G1

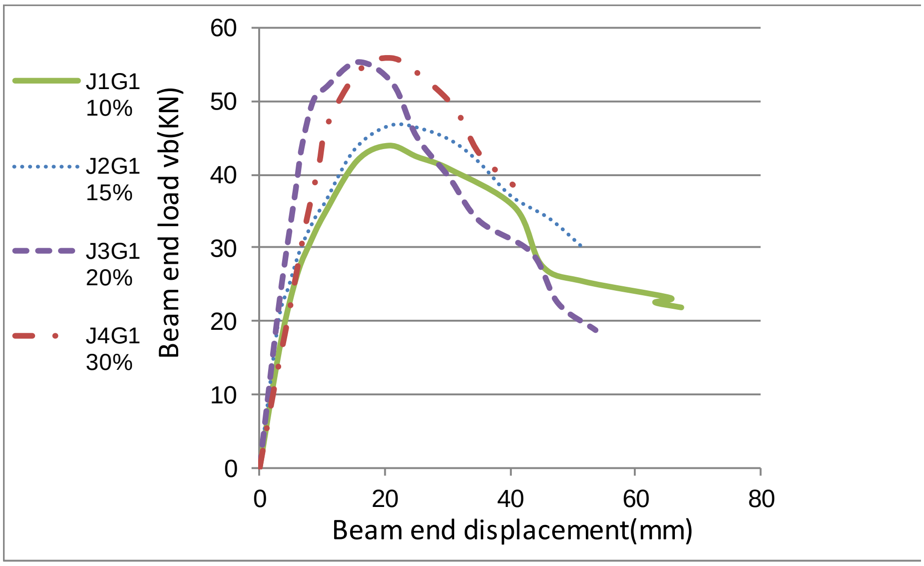


Figure 3: Backbone load deflection curve for all specimens

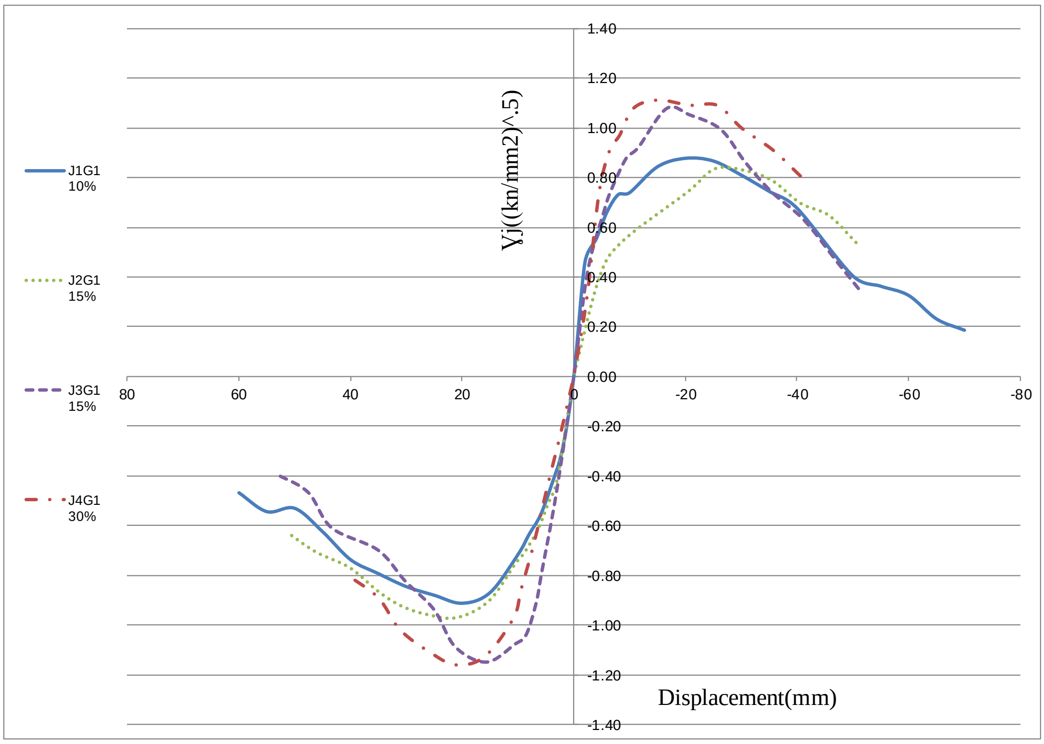


Figure 4: Max joint shear strength for all specimens

D) Crack pattern

Figure (5) displays the crack pattern at maximum joint shear strength loading for all specimens. It can be observed that joint J1G1 with lower axial load level was more cracked than joints with high axial load level. This is due to two main aspects. The first is the higher flexibility of the joint under low axial load level. It might be reasonable to think that the higher axial load level helped closing of non-major crack. The second aspect is the better bond capacity associated with higher axial load level that delayed secondary joint strut cracking.

E) Stiffness and stiffness degradation

From Figure (6) it can be observed that the initial stiffness of specimens with high axial load level started with high stiffness compared with different specimens. This indicates that the higher axial load is helpful to increase the pre-peak stiffness. However, this behavior is reversed in the post-peak stiffness. The higher axial load level tends to increase post-peak stiffness degradation. The initial stiffness of specimens J4G1, J3G1 was higher than that of J1G1, J2G1. The effective stiffness of specimens J2G1, J3G1, J4G1 is higher than that of specimens J1G1 by 31.95%, 46.15% and 57.40% respectively. This is an indication that the higher axial load level has improved the efficiency of the joint.

F) Energy dissipation

From Figure (7) it can be observed that the energy dissipation of all specimens started with almost the same energy dissipation. However, this behavior changes in the last stage. Under the same ductility at 20mm displacement, the energy dissipation capacity of joints with high axial load level was better than those with low axial load level. This indicates that the higher axial load is helpful to increase the bond behavior in the joint zone.

Figure 5: Crack pattern of all specimens

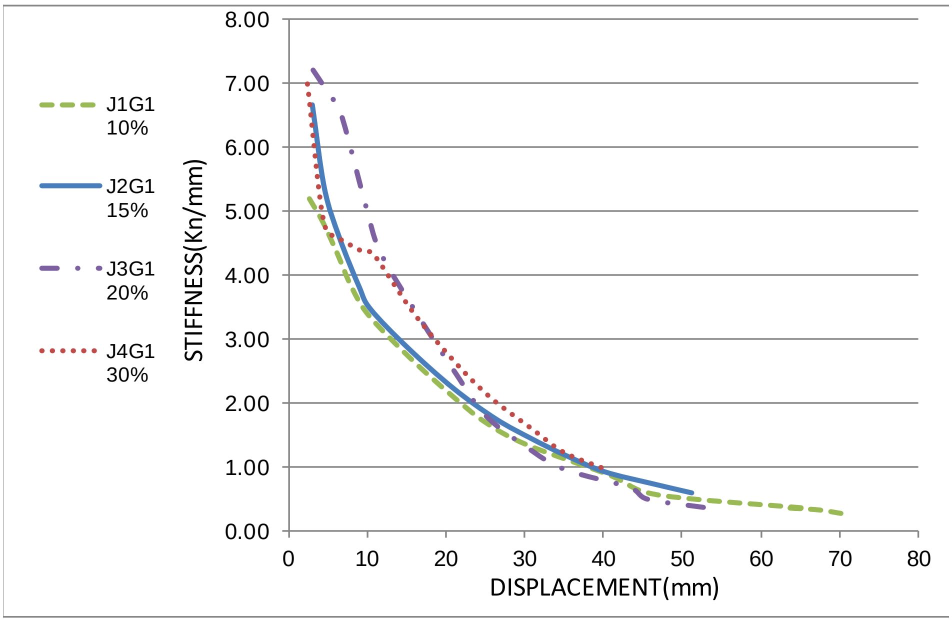


Figure 6: Stiffness degradation of all specimens

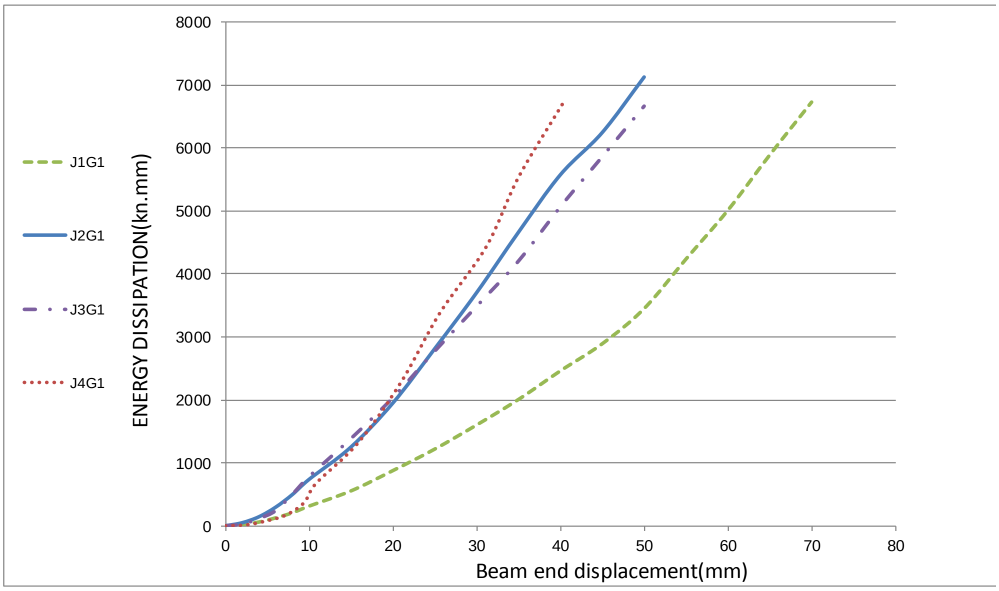


Figure 7: Energy dissipation of all specimens

III. ANALYTICAL STUDY

The analytical phase of this study includes a rational analysis to predict the effect of column axial load. 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.

3.1 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,

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

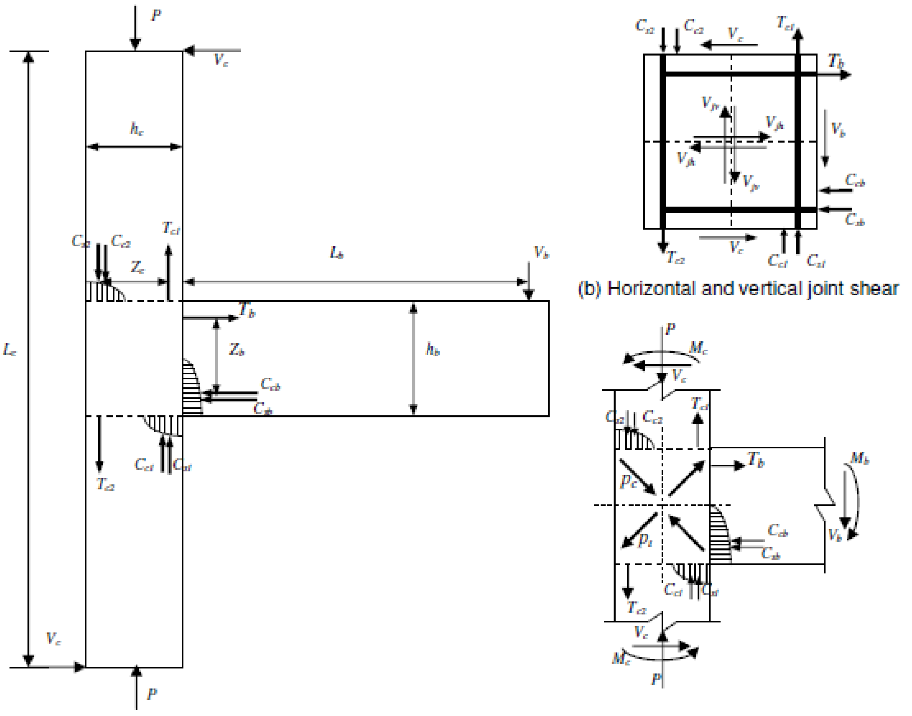
The principal tensile stress is given by (Tsonos 2007).

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

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


(a) External actions and forces in beams and columns

(b) Horizontal and vertical joint shear

(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,

   $$Mb = Vb* Lb \qquad [7]$$

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

3.2 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 2.00% for J1G1, 5.0% for J2G1, 3.0% for J3G1 and 6.00% for J4G1.

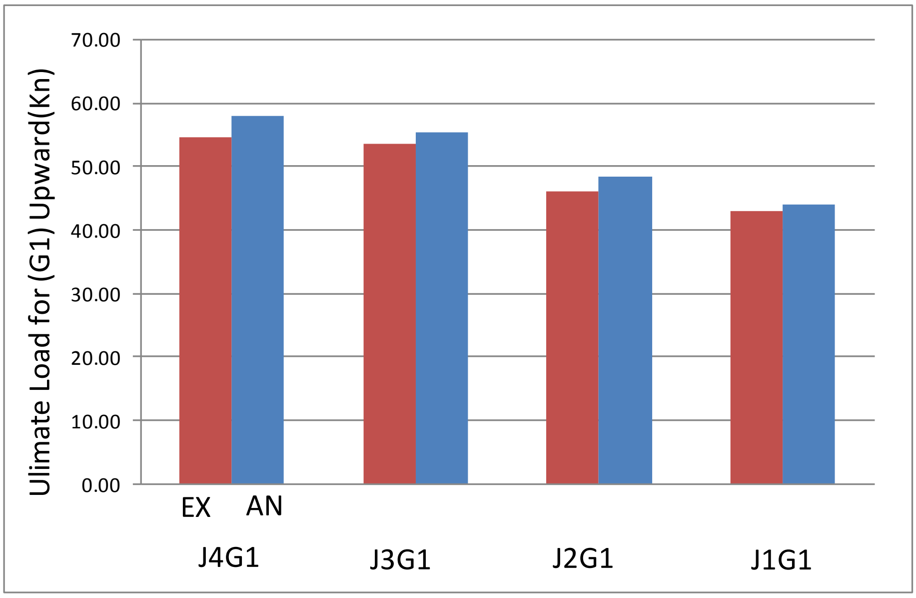


Figure 9: Comparison between the Calculated and the Measured Load capacity

IV. CONCLUSIONS

The present study investigated the effect of column axial load level on the behavior of beam column connection under cyclic loading. The following summarizes the findings of this investigation:

1. The increase of axial load induces an increase in load corresponding to the initial diagonal cracking and increase of ultimate shear strength.
2. The post-peak strength degradation due to high axial load was significantly higher than that in the case of low axial load.
3. The better bond capacity associated with higher axial load level delayed secondary joint strut cracking.
4. The higher axial load is helpful to increase the pre-peak stiffness
5. The higher axial load level tends to increase post-peak stiffness degradation.
7. The energy dissipation capacity of joints with high axial load level was better than those with low axial load level.
6. The analytical model closely predicts the experimental behavior of beam column joint.

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