EFFCT OF HOOPS AND COLUMN AXIAL LOAD ON SHEAR STRENGTH OF HIGH-STRENGTH FIBER REINFORCED BEAM-COLUMN JOINTS

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Abstract

A reinforced concrete frame is referred as "RIGID FRAMES". However, researches indicate that the Beam-Column joint (BCJ) is definitely not rigid. In addition, extensive research shows that failure may occur at the joint instead of in the beam or the column. Joint failure is known to be a catastrophic type which is difficult to repair.

This study was carried out to investigate the effect of hoops and column axial load on the shear strength of high-strength fiber reinforced Beam-Column Joints by using a numerical model based on finite element method using computer program ANSYS (Version 11.0). The variables are: diameter of hoops and magnitude of column axial load.

The theoretical results obtained from ANSYS program are in a good agreement with previous experimental results.

تاثير الأطواق وحمل العمود المحوري على مقاومة القص لمفصل العتبة-العمود المصنّع من خرسانة عالية المقاومة والمسلحة بالألياف.

الخلاصة

يطلق على الهياكل في المنشات الخرسانية المسلحة مصطلح " الهياكل الجاسئة ". في حين أظهرت البحوث بشكل جلي أن مفصل العتبة-عمود ليس جاسئا. بالاضافة الى ذلك فان البحوث المكثفة اوضحت أن الفشل قد يحدث في المفصل بدلا من العمود أو العتبة وهذا النوع من الفشل يصعب أعادة تأهيله.

في هذه الدراسة تمت دراسة تأثير الاطواق والحمل المحوري للعمود على مقاومة مفاصل عمود- عتبة عالية المقاومة ومسلحة بالالياف باستخدام نموذج عددي باعتماد طريقة العناصر المحددة وباستخدام برنامج (ANSYS) الاصدار الحادي عشر. وقد كانت المتغيرات قطر قضيب الطوق، مقدار الحمل المحوري.

لقد أظهرت النتائج المستحصلة من برنامج (ANSYS) والنتائج العملية من بحوث سابقة توافقا جيدا.

Keywords: Hoops, Column Axial Load, High Strength Concrete (HSC), Fiber Reinforced Concrete, Finite Elements, Beam-Column Joints (BCJ), ANSYS

1. INTRODUCTION

In building analysis and design, in general, the structures that contain slabs, beams and columns are referred as "Rigid Frames". However, researches indicate that, both reinforced concrete and structural steel frames, the beam-column joints are definitely not rigid; they are subjected to deformation under all types and stages of loadings. Moreover, extensive researches show that failure may occur at the joint instead of in the column or the beam. Thus, another way of looking at a joint is to be considered it as a member of the structure, as slabs, beams and columns etc [1].

In general, the adequate performance of beam-column joints depends primarily on providing the principal requirements for shear strength, confinement and anchorage of reinforcement passing through or terminating in the joint.

Some researchers studied the effect of using fiber reinforcement in the beam-column joints [2,3,4,5]. They show that the addition of fibers enhanced the ductility and strength of the beam-column joints.

With the production of High Strength Concrete, enhanced material properties such as higher compressive and tensile strength and elastic modulus.

This study was carried out to investigate the effect of hoops and column axial loads on the strength of high-strength fiber reinforced beam-column joints by using analytical model based on finite element method and using computer program ANSYS (version 11.0)[6]. The variables considered are: Diameter of hoops and magnitude of column axial load.

The comparison between the theoretical results obtained from the suggested model and the experimental results from previous research [1] shows a good agreement.

2. TESTING PROGRAM

The specimens are classified into three groups. Group.1 specimens includes three specimens with out fiber reinforcement, the first is without hoops while the others are reinforced with one hoop of (4 and 8mm) diameters. Group.2 includes three specimens having the same properties of group.1 except that they contain the optimum volume fraction of hooked fibers which equals 1% [1], all the two groups are tested under a constant column axial load equal to (100 kN). Group.3 includes two specimens contain 1% of fibers and without hoop reinforcement tested under (150 and 200 kN) column axial loads. **Table.1** shows the designation and properties of the specimens.

All the eight beam-column joints have identical beam and column sizes. **Fig.1** shows the details of the specimens, these dimensions were used previously by several investigators [7, 8, and 9]. The beams were 300mm depth by 150 mm width and the columns were 200 mm depth by 150 mm width.

All columns were reinforced with four 16 mm longitudinal bars and 8 mm closed ties at 85 mm centre to centre spacing. All beams were reinforced with three 18 mm bars on tension side and three 12 mm bars on compression side. This resulted in an under-reinforced beam with tension steel percentage slightly under 1.9%. Beam stirrups were 8 mm closed ones spaced at 130 mm centre to centre.

Ordinary Portland cement from Kubaysa factory was used. This cement conforms to Iraqi standards [10]. It has already been found that this cement was the most suitable for high strength concrete [11].

Fine aggregate passing through 4.75mm sieve conforming to ASTM C33 specifications [12] was used, the fineness modulus was 2.5 and the specific gravity was 2.6.

Natural coarse aggregate was used. Many references have shown that the smaller size aggregates produce higher strength values. Therefore maximum size was chosen to be 9.5 mm. Grading of these aggregates conforms to ASTM C33 specifications [12]. The bulk specific gravity of these aggregates was 2.7.

For high strength concrete production, water content of mix is reduced, and the associated reduction in workability is compensated for by using superplasticizer (Melment) which are chemical admixtures. The optimum dosage for this admixture was found to be 5% of weight of cement and the reduction of water for this dosage was 27.7%.

Three samples of reinforcing steel bars for each size of bars (8,12,16, and 18)mm were tested, the results of tests are shown in **Table.2**. Further tests on separate samples were made using the Instron testing machine. Results were automatically recorded by a plotter, which was attached to the testing machine. The purpose of these tests was to determine the stress strain relationship of the bars, which were used in the analytical model.

Cylindrical compressive strength (f'_c), modulus of rupture (fr), poison's ratio (v) and modulus of elasticity (Ec) for the concrete of the eight specimens are included in **Table.3**.

3. EXPERIMENTAL PROGRAM

The testing rig dimensions were (3x4)m with a depth of 1.1m. The testing rig consisted of a reinforced concrete mass with a special reinforcing bars used for fixing the large steel I-sections as reaction points for bracing the specimens and applying the loads. It was insured that the testing rig was stiff enough to resist all possible loadings [1].

The specimens were tested using two hand operating jacks; the first was used to apply the column axial load (N_u), while the second was used to apply the beam load (V). Ball and socket type hinges, designed and constructed especially for allowing rotation in the plane of the frame only, were used to brace the columns in the two sides and the bottom. However for the loading points under the two jacks, roller type hinges designed and constructed especially for allowing movement in the direction perpendicular to the applied load only, were used to eliminate fixity. All these details are illustrated in **Fig.2**.

4. ANALYTICAL MODELLING

Building the analytical model consists of:

4.1 Element Type

The beam-column joint was modelled in ANSYS 11.0 [6] with Solid 65, Solid 45 and Link 8 elements. Solid 65 element was used to model the concrete and Solid 45 was used to model steel plates at supports and under testing loads. These elements have eight nodes with three degrees of freedom at each node which is the translations in x, y and z directions. Link8 element was used to model reinforcement. This three dimensional bar element has two nodes with three degrees of freedom at each node which is translations in x, y and z directions.

4.2 Sectional Properties (Real Constants)

The real constants considered for Solid 65 were; volume ratio and angle of orientation of reinforcement. Since there was no smeared reinforcement, the real constants (volume ratio and orientation angles) were set to zero. No real constant sets exist for Solid 45 element. The real constant that considered for Link8 elements were sectional areas.

4.3 Material Properties

Parameters needed to define the material models are given in **Table.4**. As seen in this table, there are multiple parts of the material model for each element. Material model number 1 refers to Link8 element which is used to model reinforcing bars. Link8 requires linear and bilinear isotropic. **Fig.3** is used to define the bilinear stress-strain relationship which is important for the computer solution convergence[13]. For example the material properties of 12mm bar diameter are illustrated in **Table.2**, which are the modulus of elasticity, yield stress and ultimate strength.

Material model number 2 refers to solid65 element for specimen No.1 which was used to model concrete. Solid65 element requires linear isotropic and multi-linear isotropic material properties to properly model concrete. Ex is the modulus of elasticity of concrete (E_c), and PRXY is the Poisson ratio (v).For the normal weight concrete based on a dry unit weight (2200-2500 kg/m3); E_c was taken as in (ACI 318) [14]:

$$E_c = 4700\sqrt{f'_c} \tag{1}$$

According to Bangash [15], the value of poisons ratio can be taken equal to (0.2). In this study the values of the modulus of elasticity and poisons ratio are determined from tests and used in **Table.4**. According to Desayi and Krishnan [16], the compressive unixial stress-strain relationship for concrete model is obtained using equations (2), (3), and (4).

$$f = \frac{E_c\,\varepsilon}{1+\left(\dfrac{\varepsilon}{\varepsilon_o}\right)^2} \tag{2}$$

$$\varepsilon_o = \frac{2f'_c}{E_c} \tag{3}$$

$$E_c = \frac{f}{\varepsilon} \tag{4}$$

Where:

f = stress at any strain ε, N/mm2. ε = strain at stress f. ε_O= strain at the ultimate compressive strength f'_c. E_c= Modulus of elasticity for concrete (equation 1)

The multi-linear isotropic stress-strain implemented requires the first point of the curve to be defined by the user. It must satisfy Hooks law defined by equation (4). The multi-linear curve is used to help with convergence of the nonlinear solution algorithm. In this study, the concrete stress-strain relationship was determined from tests and used in **Table.4**

Concrete material model in ANSYS [6] requires that different constants be defined. These 9 constants are:

1. Shear transfer coefficients for an open crack;
2. Shear transfer coefficients for a closed crack;
3. Unixial tensile cracking stress;
4. Unixial crushing stress (positive);
5. Biaxial crushing stress (positive)
6. Ambient hydrostatic stress state for use with constants 7 and 8;
7. Biaxial crushing stress (positive) under the ambient hydrostatic stress state (constant 6);
8. Unixial crushing stress (positive) under the ambient hydrostatic stress state (constant 6);
9. Stiffness multiplier for cracked tensile condition.

Typical shear transfer coefficients range from 0.0 to 1.0, with 0.0 representing a smooth crack (complete loss of shear transfer) and 1.0 representing a rough crack (no loss of shear transfer). The shear transfer coefficients for open and closed cracks were determined using the work of Kachlakev, et al. [17] as a basis. Convergence problems occur when the shear transfer coefficient for the open crack dropped below 0.2. The presence of steel fibers in concrete mixture affects the value of this factor significantly because it increases the shear strength of concrete, thus in this study different values for this factor were used for each specimen to simulate the effect of type and volume fraction of steel on the beam-column joint model.

The unixial cracking stress is based upon the modulus of rapture. This value can be determined using the equation ACI code [14]:

$$f_r = 0.62\sqrt{f'_c} \qquad (5)$$

In this study the cracking stress was determined from tests and used in **Table.4**. The unixial crushing stress in this model is based on the unixial unconfined compressive strength (f'_c). In this study a value of (-1) is given to the crushing coefficient to turn off the crushing capability of the concrete element and prevent local failure. The other five coefficients were given the value 0.0.

Material model number 3 refers to solid45 element which is used to model steel plates at supports and under testing loads. It requires linear isotropic properties only.

4.4 Modeling of Joint

The beam-column joint was modeled by two solid models. The block model was used to model concrete and steel plates while lines were used to model reinforcement. After the solid model was constructed, it will be meshed to form the finite element model. **Fig. 4, 5 and 6** shows the solid model of the beam-column joint, reinforcement and the finite element model after meshing respectively.

The loads were applied on the columns and beams through the steel plates, the axial load applied on the center of the column, while the transverse (shear) force was applied at (0.2m) from the beam end. For nonlinear solution, the shear force was divided in to small parts (time stepping).

5. RESULTS AND DISCUSSION

5.1 Failure Load

All specimens failed in the joint as a shear failure, **Fig.7**. **Table.5** shows the analytical and experimental failure load and the ratio of analytical to experimental result.

5.2 Effect of Hoops on the Joint Strength

Fig.8 illustrates the effect of including hoops of different diameters, (0, 4mm and 8mm), but with a single mid-depth layer in the joint, on ultimate load capacity of the joint for the experimental and analytical results. In this work it was found from experimental results that the addition of a single mid-depth 8mm hoop for the beam-column joint with out fiber reinforcement increase the joint load capacity. The addition of this hoop bar increased the load capacity for SP-3 (reinforced with 8mm deformed hoop bar) upon

SP-1 (unreinforced) by 44.9%. It seems from this work that a preferred solution for joint strengthening might be with a combination of two factors (1% volume fraction of hooked fibers plus single mid-depth 8mm hoop bar, e.g. SP-6). As can be seen from the test results, that latter led to 114% strengthening of the beam column joint upon SP-1.

Previous research [9,21] supports the recommendation in this work and indicates beyond doubt that more layers of hoops in the joint leads to less stress development in them. Therefore it is expected, if adequate bond and confinement conditions are provided, that for higher hoop contribution increasing the size of a central hoop is more advantageous than increasing the number of layers.

Fig. 8 also shows that the analytical model represents accurately the effect of diameter of hoops on joint strength for both plain and fiber reinforced concrete beam-column joints, and it was in good agreement with the experimental results.

5.3 Effect of Column Axial Load

One of the primary conditions in the design of beam-column joints is maintaining the required axial load capacity [22]. Tests [8, 23] showed that the presence of axial compression load results in an increase in the shear strength of a beam-column joint. Therefore in a given joint and beam moment capacity an increase in axial compression in the column resulted in less joint shear reinforcement requirements [24]. **Fig.9** shows the effect of axial load on the joint strength. The increase of the column axial load from 100kN to 200kN will increase the joint strength by 21%.

Fig. 9 also shows that the analytical model succeeded in representing the effect of column axial load on the strength of the joint only with the (150 kN) load while it gave an obvious overestimation and underestimation for the (100 kN) and (200 kN) load, respectively.

6. CONCLUSIONS

Based on the results obtained in this study, the following can be concluded:

1- The results predicted by the analytical model were in good agreement with the experimental results. The maximum difference in predicting the failure load is 9%. This indicates that the analytical model to predict the effect of hoops and column axial load on the beam-column joint strength can be used instead of experimental model which may be expensive and leads to time consumption.

2- Transverse reinforcement (hoops) in the joint improves the strength. If one 8mm hoop bar is added for the joint without fiber reinforcement the increase in strength is 44.9% while if it is added to a joint reinforced by fibers (with 1% volume fraction), the increase is 114%.

3- Increasing the column axial load leads to an increase in the joint strength, for example the increase of this load from 100kN to 200 kN increases the strength by 21%

7. REFERENCES

1- Kani, Z.M.,"**Capacity of High Strength Fiber Reinforced Beam-Column Joints**", M.Sc thesis, University of Technology, Baghdad, Iraq, 1997

2- Gefken, P.R and Ramey, M.R., "**Increased Joint Hoop Spacing in Type 2 Seismic Joints Using Fiber Reinforced Concrete**", ACI Structural Journal, Vol. 86, No.2, March-April ,1989, pp. 168-172.

3- Jindal, R.L. and Hassan, K.A., "**Behaviour of Steel Fibers Reinforced Concrete Beam-Column Connections**", Fibre Reinforced Concrete, ACI Publication, SP-81, 1984, pp. 107-123.

4- Craig, R. J.,Mahadev, S., Patel, C. C., Viteri, M. and Kertesz, C., "**Behaviour of Joints Using Reinforced Fibrous Concrete**", Fibre Reinforced Concrete, ACI Publication, SP-81, 1984, pp. 125-167

5- Henager, C. H., "**Steel Fibrous, Ductile Concrete Joint for Seismic-Resistant Structures** ", Reinforced Concrete Structures in Seismic Zones, ACI publication, SP-53, 1997, pp. 371-386.

6- ANSYS, "**ANSYS Help**", Release 11.0, Copyright 2007.

7- Taylor, H. P. J.,"**The Behaviour of Insitu Concrete Beam-Column Joints**", London,Cement and Concrete Association, May, 1974, Technical Report No. 42.492, 32 pp.

8- Sarsam, K. F.," **Strength and Deformation of Structural Concrete Joints**", Ph.D. Thesis, University of Manchester Institute of Science and Technology, 1983, 340 pp.

9- Hadi Tuamma Al-Jubbori, " **The Effect of Hoops on The Shear Strength of Concrete Beam-Column Joints**", M.Sc Thesis, University of Technology, Baghdad, Iraq, 1986.

10- المواصفات القياسية العراقية/5 " سمنت بورتلاند الاعتيادي وسمنت بورتلاند سريع التصلب "، هيئة المواصفات والمقاييس العراقية ، مجلس التخطيط ، بغداد ، 1985، 8 صفحة .

11- Abdullah, A.M.," **Shear Strength Of High-Strength Concrete Beams**", M.Sc Thesis, University of Technology, Baghdad 1987, 120 pp.

12- ASTM Designation C 33-86., "**Concrete Aggregates**", 1989 Annual Book of ASTM , Standard American Society for Testing & Materials , Philadelphia, Pennsylvania, Section4, Vol. 04-02, pp 10-15.

13- European Committee for Standardization (CEN), Eurocode 3, "**Design of Steel Structures**", Part 1.1: General Rules and Rules for Buildings, DD ENV 1993-1-1, EC3.

14- ACI Committee 318**,** "**Building Code Requirements for Structural Concrete (ACI 318M-2008) and Commentary (ACI 318RM-2008)**", American Concrete Institute, Farmington Hills, USA, 2008.

15- Bangash, M.Y.H., "**Concrete and Concrete Structures: Numerical Modelling and Applications**", Elsevier Science Publishers Ltd., London, England, 1989.

16- Desayi, P. and Krishnan, S., "**Equation for the Stress-Strain Curve of Concrete**", Journal of the American Concrete Institute, Vol. 61, March 1964, pp. 345-350.

17- Kachlakev, D., Miller, T. and Yim, S., "**Finite Element Modelling of Reinforced Concrete Structures Strengthened with FRP Laminates**", Final Report, SPR 316, May 2001, 99 p.

18- ACI-ASCE committee 352 Report; "**Recommendations for Design of Beam-Column Joints in Monolithic Reinforced Concrete Structures"**; ACI Journal, V.82, No.3, May-June, 1985, pp. 266-283.

19- Ehsani, M.R.,and Wight, J.K., "**Exterior Reinforced Concrete Beam –to- Column Connections Subjected to Earthquakes-type Loading",** ACI Journal, V.82, No.4, July-August, 1985, pp. 449-492.

20- Uzumeri, S. M., "**Strength and Ductility of Cast in Place Beam-Column Joints**", Reinforced Concrete Structures in Seismic Zones, ACI Publications, SP-53, 1977, PP. 293-350.

21- Park, R., and Paulay, T., "**Reinforced Concrete Structures**"; John Wiley and Sons, 1975, 769 PP.

22- Lee, D. L. N., Wight, J. K., and Hanson, R.D.; "**RC Beam-Column Joints under Large Load Reversals**", Journal of the Structural Division, V.103, No.ST-12, December, 1977, PP. 2337-2350.

23- Paulay, T., Park, R., and Pristley, M. J. M., "**Reinforced Concrete Beam-Column Joints under Seismic Actions**", ACI journal, Nov., 1978, PP. 585-593.

24- Marques, J. G. L., and Jirsa, J. O., "**A Study of Hooked Bar Anchorage in Beam-Column Joints**", ACI journal, V.72, No.5, May, 1975, PP. 198-209.

Table.1 Designation and Properties of Specimens

SP	**Type; V_f %**	D_H **(mm)**	N_u **kN**
1	0.0	-	100
2	0.0	4	100
3	0.0	8	100
4	H1.0	-	100
5	H1.0	4	100
6	H1.0	8	100
7	H1.0	-	150
8	H1.0		200

H = hooked fibers, V_f %= percentage of fiber volume fraction, D_H= Diameter of hoop and N_u= Column axial Load.

Table.2 Properties of Reinforcement

Diameter	Modulus of elasticity (GPa)	f_y MPa	f_u MPa
8	202.42	466	598
12	203.55	440	606
16	201.0	507	661
18	197.4	531	704

Table.3 Test Results of Material Samples

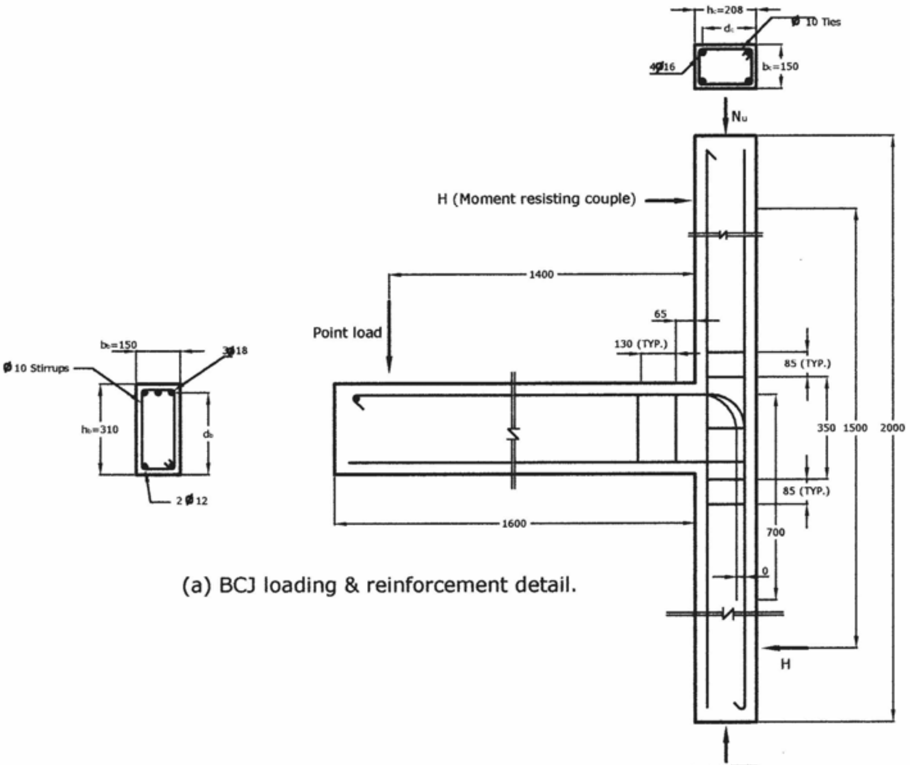
SP	$f'_c (MPa)$	$f_r (MPa)$	$v (mm/mm)$	$E_c\ (kN/mm^2)$
1	60.40	7.500	0.138	34.09
2	61.10	8.950	0.155	33.21
3	59.40	7.200	0.145	33.48
4	67.50	11.37	0.240	33.33
5	67.95	12.50	0.235	34.65
6	66.70	11.00	0.237	32.90
7	66.30	10.86	0.243	32.69
8	68.54	10.66	0.248	35.26

Table.4 Material Models For the Elements

Material Model Number	Element type	Material Properties		
1	Link8	Linear Isotropic		
		EX	203550MPa	
		PRXY	0.3	
		Bilinear Isotropic		
		Yield stress	440MPa	
		Tangent modulus	20.3MPa	
2	SOLID65	Linear Isotropic		
		EX	34090MPa	
		PRXY	0.138	
		Multilinear Isotropic		
			Strain	Stress
		Point1	0.0005	17.5MPa
		Point2	0.001	34.5MPa
		Point3	0.0015	48.5MPa
		Point4	0.002	60.4MPa
		Point5	0.003	60.4MPa
		Concrete		
		ShrCF-OP	0.15	
		ShrCF-CL	0.6	
		UnTensSt	7.5MPa	
		UnCompSt	-1	
		BiCompSt	0	
		HydroPrs	0	
		BiCompSt	0	
		UnTensSt	0	
		TenCrFac	0	
3	SOLID45	Linear Isotropic		
		EX	200000MPa	
		PRXY	0.3	

Table.5 Test Results of Beam-Column Joint

SP	Type; V_f %	D_H (mm)	N_u kN	Ultimate Load (kN)		$\frac{\text{Analytical}}{\text{Experimental}}$
				Experimental	Analytical	
1	0.0	-	100	45.2	48.0	1.06
2	0.0	4	100	56.0	54.0	0.96
3	0.0	8	100	65.5	59.5	0.91
4	H1.0	-	100	77.5	82.0	1.06
5	H1.0	4	100	89.0	86.0	0.97
6	H1.0	8	100	96.5	90.0	0.93
7	H1.0	-	150	87.2	88.0	1.01
8	H1.0	-	200	93.5	88.0	0.94



(a) BCJ loading & reinforcement detail.

Figure.1 Detail of Specimens [1]

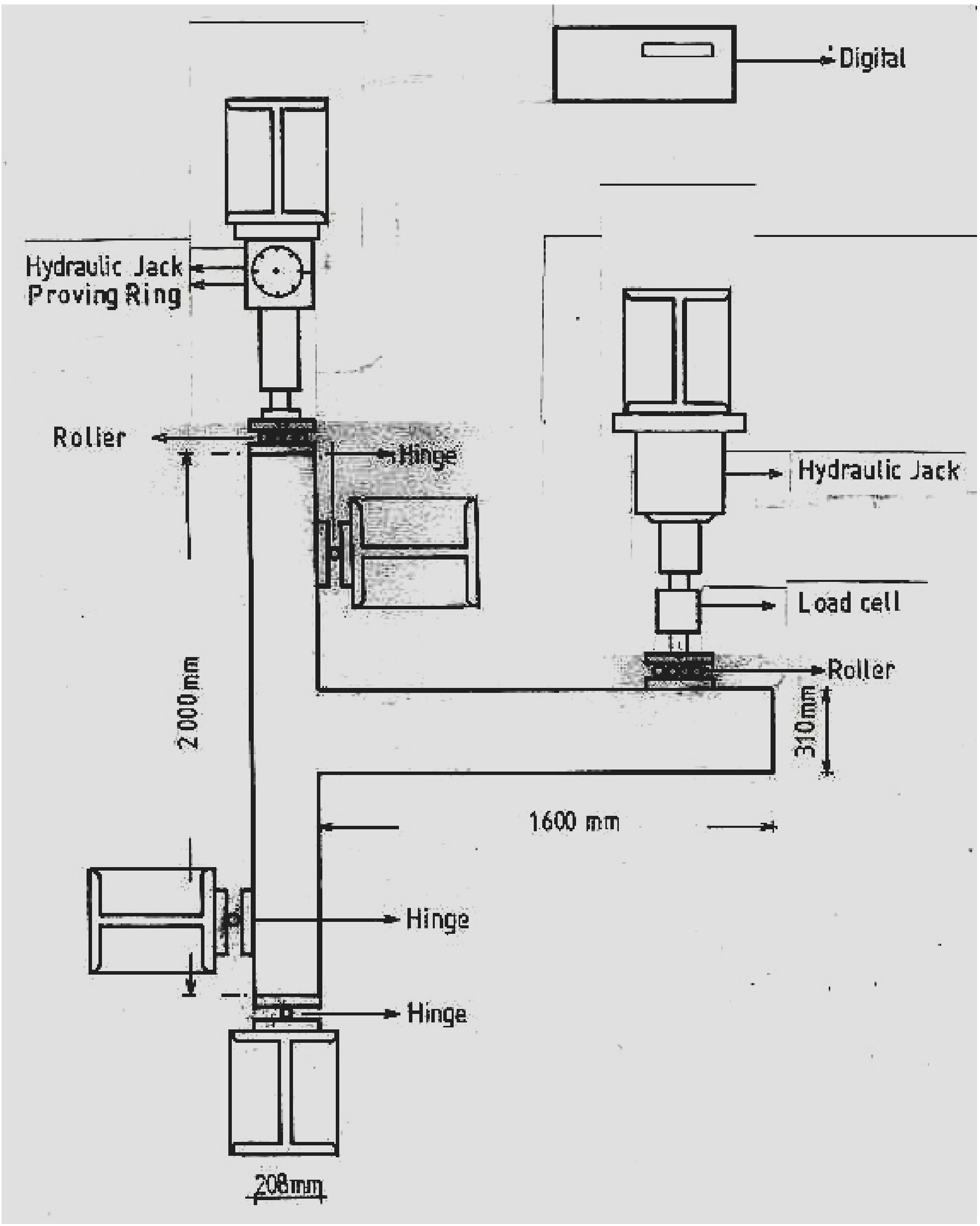


Figure.2 Testing Instrumentation [1]

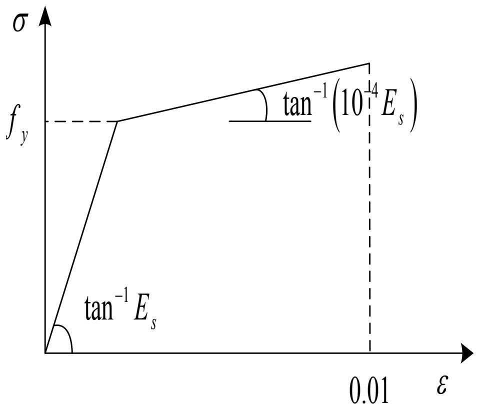


Figure.3 Bilinear stress-strain relationship of steel bars for computer calculations [13]

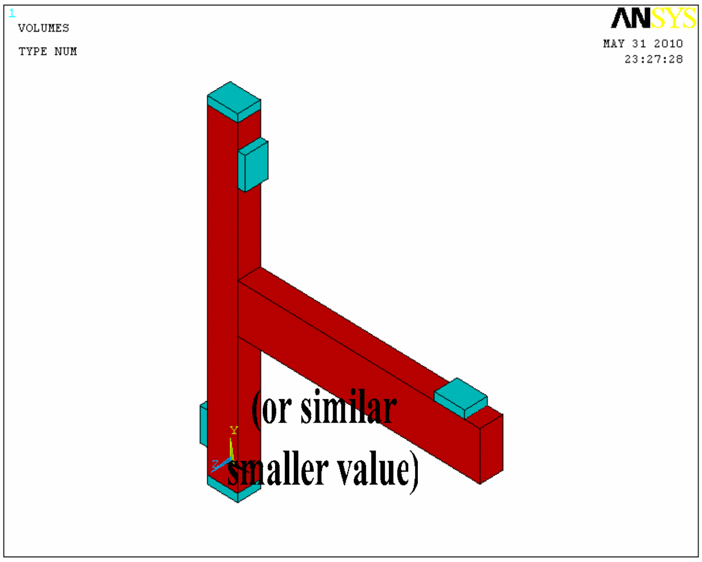


Figure.4 Solid model of beam-column joint

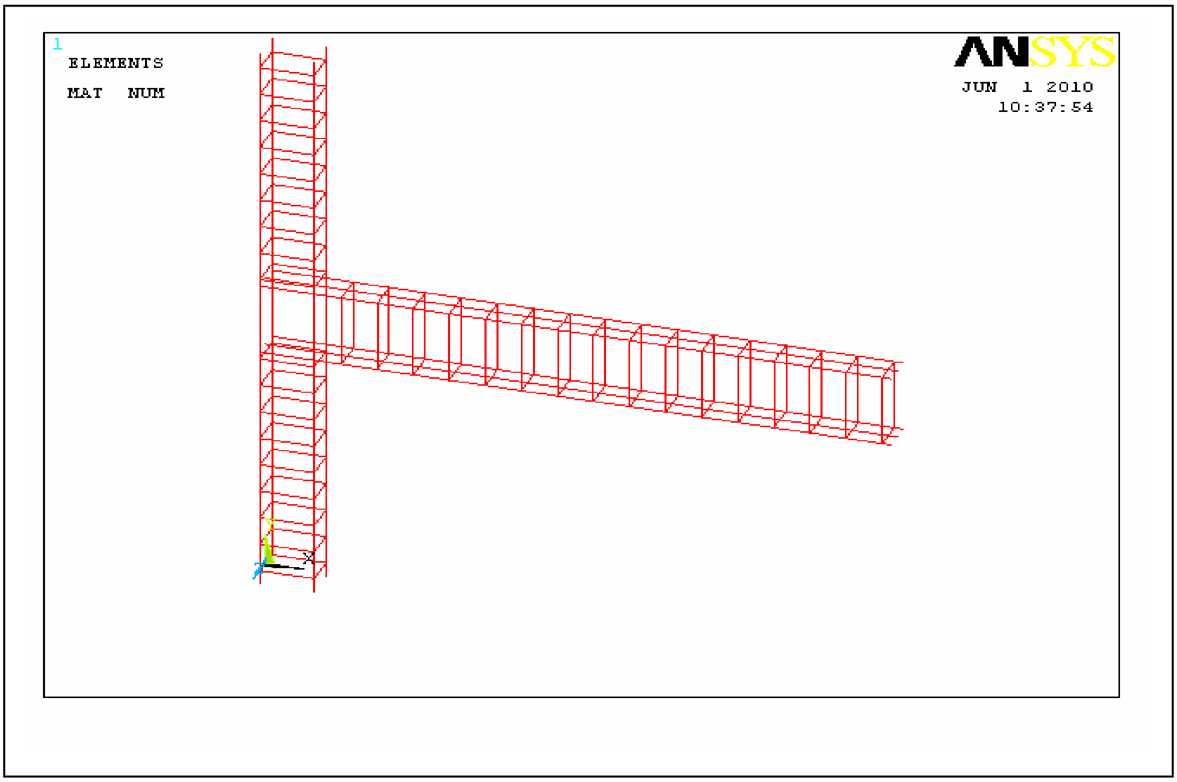


Figure.5 Solid Model of Beam-Column Reinforcement

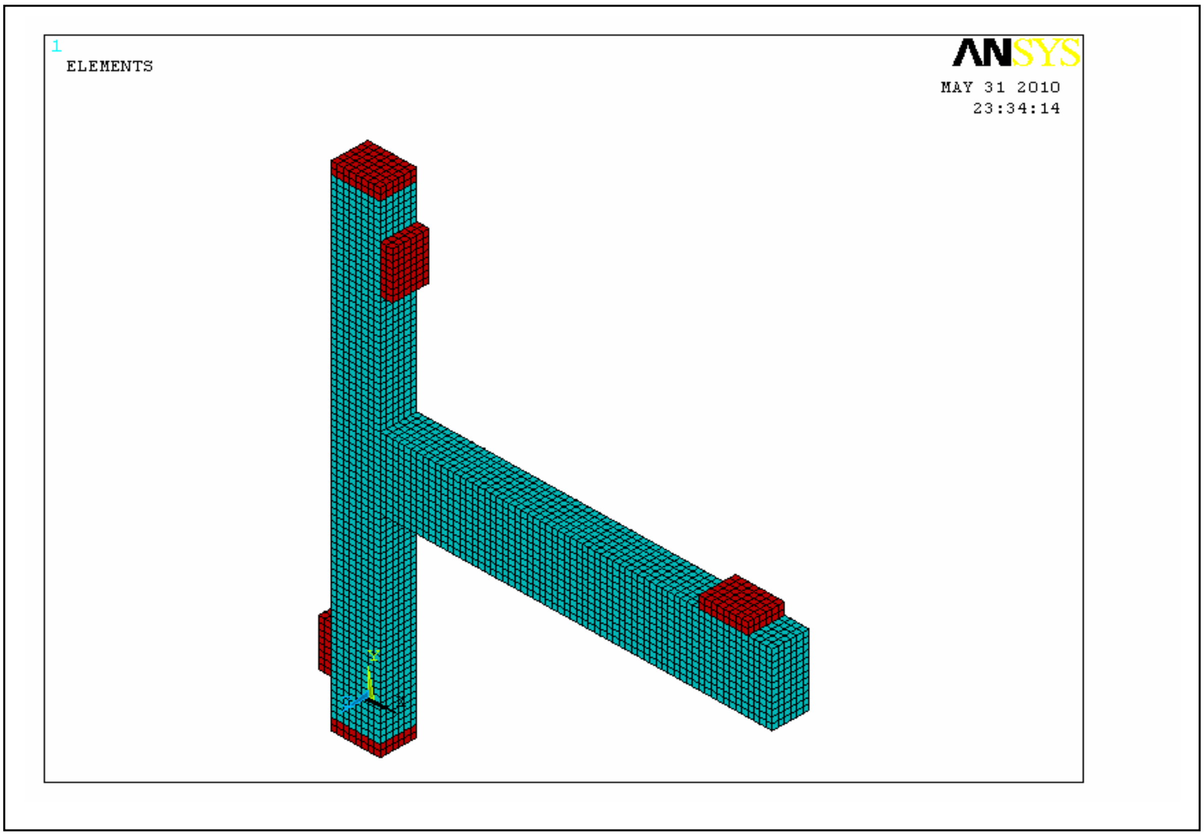


Figure.6 Finite Element Model of Beam-Column Joint

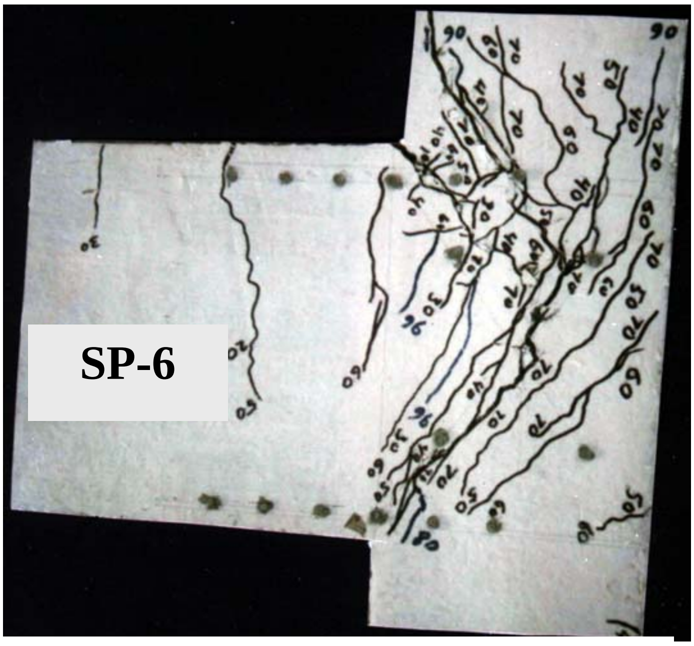


Figure.7 Cracked Specimen after Failure [1]

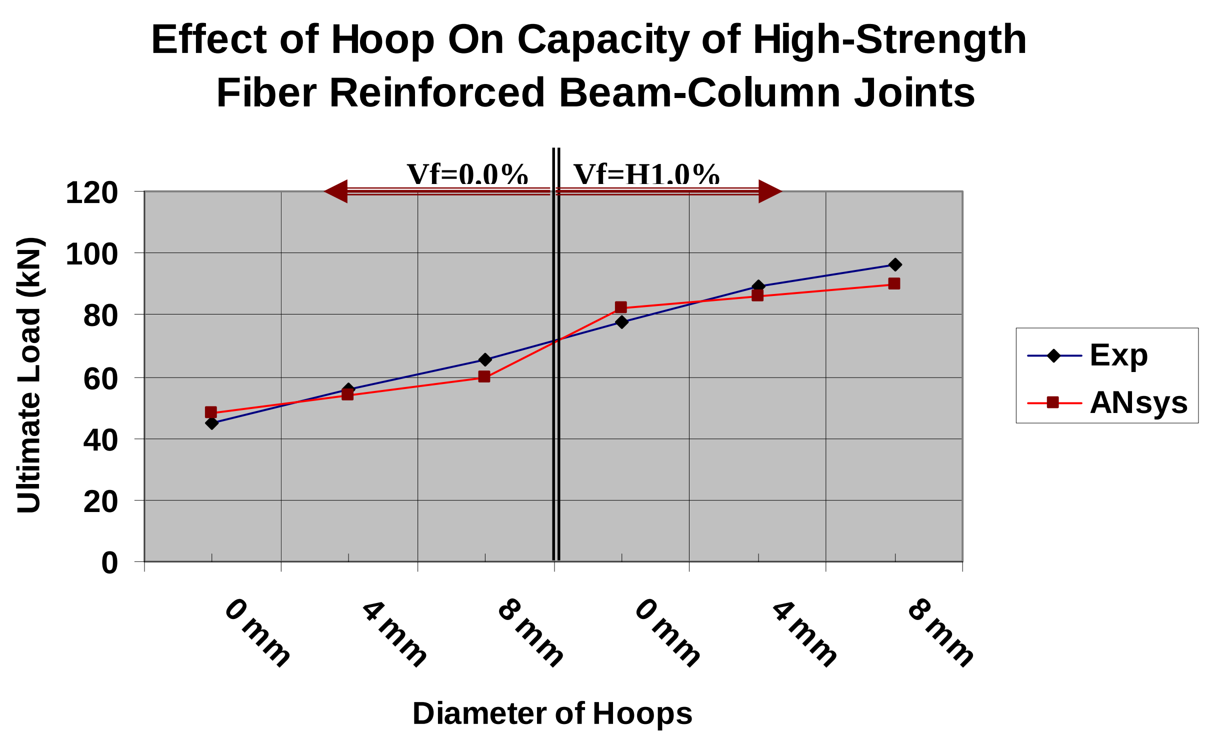


Figure.8 Effect of Hoop Diameter on Joint Strength

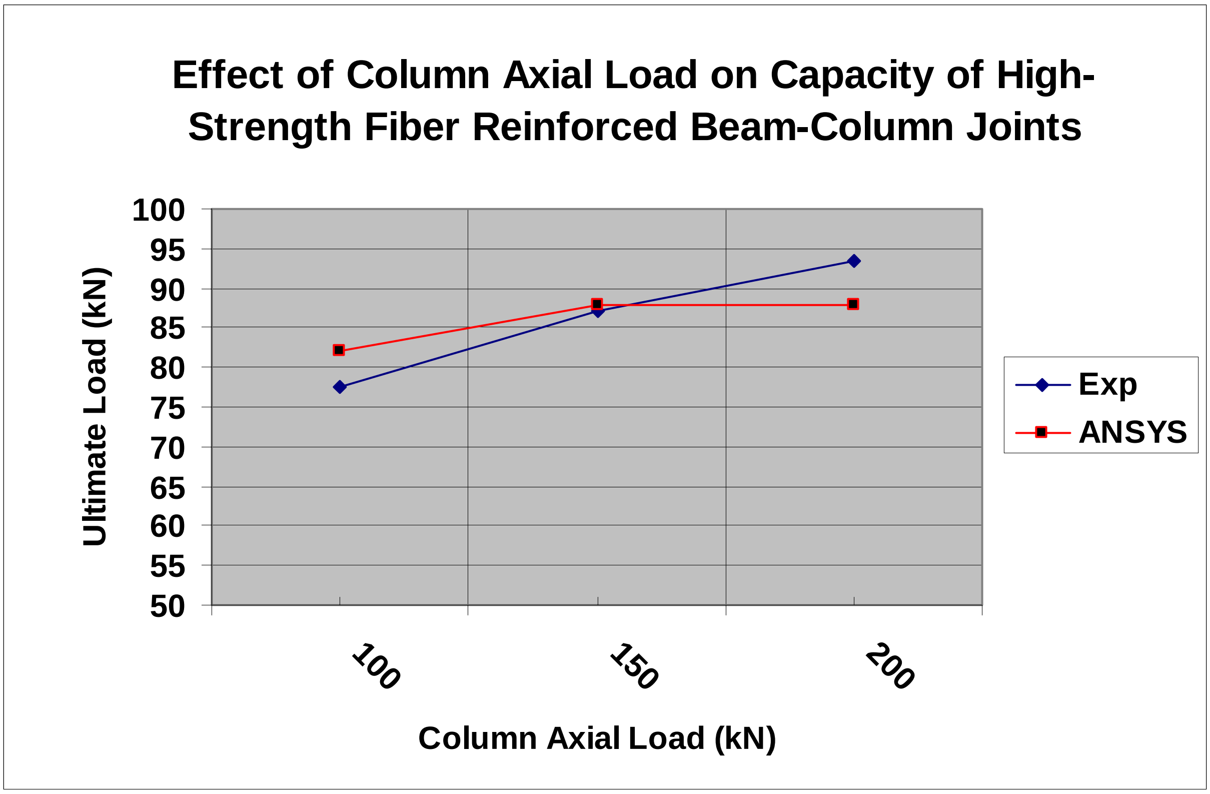


Figure. 9 Effect of Column Axial Load on Joint Strength