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Effect of Joint Enlargement on the Performance of Exterior Beam-Column Joint

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Abstract: ***Reinforced concrete structures, built in zones of low- to-medium seismicity still do not take seismic effect into consideration. The reinforcement details of such structures, though conform to the general construction code of practice may not adhere to the modern seismic provisions. Structural engineers often consider current seismic code details for reinforced concrete framed structures impractical. A beam column joint becomes structurally less efficient when subject to large lateral loads, such as strong wind, earthquake, or explosion. In these areas, high percentages of transverse hoops in the core of joints are needed in order to meet the requirement of strength, stiffness and ductility. Provisions of high percentage of hoops cause congestion of steel leading to construction difficulties. The objective of the present study is to compare the effect of joint enlargement on behaviour of exterior beam-column joint sub-assemblages with transverse reinforcements detailed as per IS 456:2000.***

Keywords: Beam-column joint, RCC, Joint enlargement, ANSYS, Stress

1. Introduction

Past is a witness to many devastation and destruction of structures due to joint failures during earthquakes. Beam-column joint has not been area of research for many decades because scientists believes that beam column joint behave as rigid joint with no deformation contributed by it. Dead load and live load do not contribute much to the failure of beam-column joint as far as lateral loads (wind load, earthquake loads etc.) are concerned. This problem has not been solved completely till date. Severe reverse cyclic loading due to earthquakes causes large inelastic deformations in the beam column joints of high-rise buildings. If the joints are not designed and detailed properly, their performance can significantly affect the overall response of the moment-resisting frames. Due to the restriction of space available in the joint block, the detailing of joint reinforcement assumes more significance than elsewhere. The portion of the column where beam joins it is called beam-column joint. Beam column joints are classified into three types based on the number of beams ending into the column- (i) Interior Beam-Column joints; (ii) Exterior Beam-Column joints; (iii) Corner Beam-Column joints. Numerous researches were carried out on different retrofit techniques including the use of concrete jackets, bolted steel plates, and FRP sheets, which were considered in the structural upgrading, especially for columns and beam–column joints in the moment-resisting frames. Among these retrofit techniques, RC jacketing is widely used because it is more consistent with as-built RC structures than the other retrofit materials, such as steel or FRP jacketing, and the deficient beam– column joints can be easily repaired as well.

1.1 Objectives

1) The present work aims at carrying out an analytical investigation on the behavior of enlarged beam-column joints with transverse reinforcement detailed as per IS 456:2000.
2) To determine the reduction of stress in beam-column joints with enlarged joint area.

2. Details of the Specimen

The model prepared is detailed as per IS 456:2000 with U-bars provided in the joint as per SP 34:1987. All the beam-column joint models prepared had identical beam and column sizes. The beams are 150mm deep by 100 mm wide and columns are 150 mm deep by 100 mm wide. The specimen is one-third of full scale with 550 mm long beams measured from column face with an inter-storey height of 1000 mm. The specimens used for analysis are of two types; beam-column joint detailed as per IS 456:200 and beam-column joint with enlarged joint area. A 20mm joint enlargement is provided by enlarging the stirrup of the column at the joint region upto 10mm on all four sides, resulting into 20mm enlargement in the joint as compared with control specimen. The M30 grade concrete and Fe 415 grade steel were used. Steel bars of yield stress 432N/mm^2 were used as main reinforcement and stirrup. The axial load is applied on the top of the column with fixed base and a roller support at the top.

Table 1: Details of the Specimen

Column Reinforcement	*Beam Reinforcement*	*Joint Reinforcement*
Longitudinal	Longitudinal	Transverse
Four 8-mm diameter and four 6-mm diameter	Two 8-mm diameter and two 6-mm diameter (at the top and bottom	Two 3-mm diameter U bars, with development length in tension extended to the beam
Transverse	**Transverse**	
3-mm diameter at 100 mm c/c	3-mm diameter at 35 mm c/c for a distance of 270 mm from the joint and 50 mm c/ c for the remaining length	

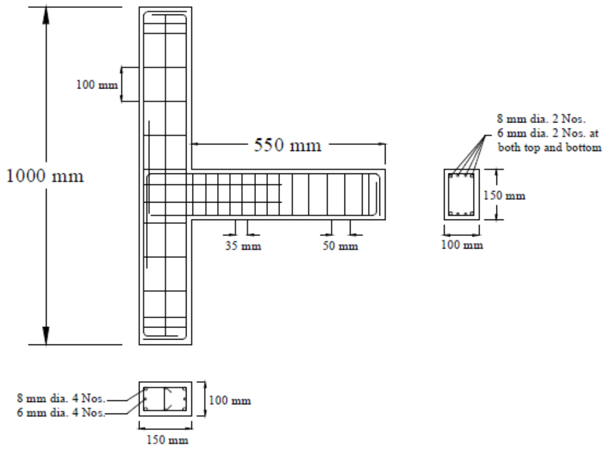

Figure 1: Reinforcement Detailing of Model (K.R Bindhu et. al)

3. Modeling

For the present study ANSYS workbench 15.0 is being used. Modelling of the beam-column joint without joint enlargement and with joint enlargement is done. The joint enlargement is done by enlarging the stirrup at the joint region. The uniaxial stress-strain relationship for concrete developed by Desayi and Krishnan, which is given by equation below, was adopted for modeling concrete.

$$f = \frac{E\varepsilon}{1+\left(\frac{\varepsilon}{\varepsilon_0}\right)^2}$$

Where, f = stress at any strain ε

ε_0= strain at the ultimate compressive strength f_c'

E = a constant (same as initial tangent modulus), E = $\frac{2f_c'}{\varepsilon_0}$

The specimen was subjected to an axial load of 3% column axial load capacity which is equal to 15.92 kN. The load on the beam is applied at an increment of 1.962 kN (K.R Bindhu et. al). The models were analyzed with monotonic loadings in the upward and downward direction.

Table 2: Material Properties of the Specimen

Material model No.	Element type	Material properties
1.	Reinforcement	Linear Isotropic Elastic Modulus 2.1×10^{11} N/m^2 Poisson's Ratio 0.3 Bilinear Kinematic Tangent Modulus 847×10^6 N/m^2
2.	Concrete	Linear Isotropic EX 3.252×10^{10} N/m^2 PRXY 0.15 Ultimate compressive strength 35.376×10^6 N/m^2 Uniaxial tensile cracking stress $3.71\text{x}10^6$ N/m^2

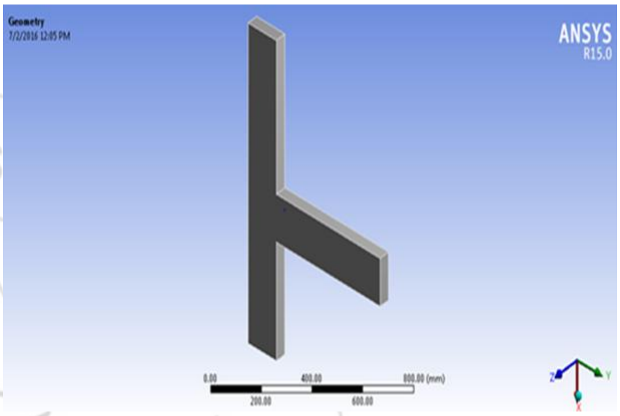

Figure 2: Model of Control Specimen

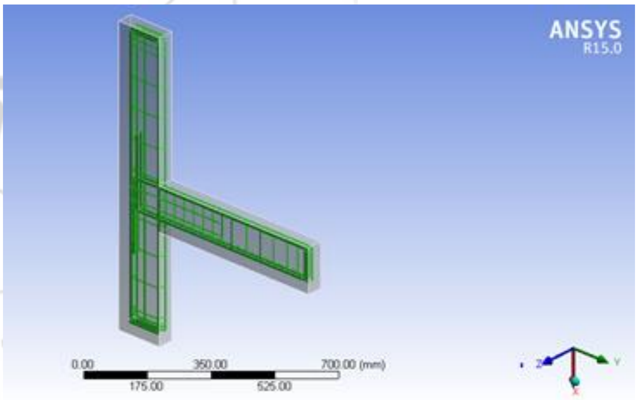

Figure 3: Reinforcement Details of Control Specimen

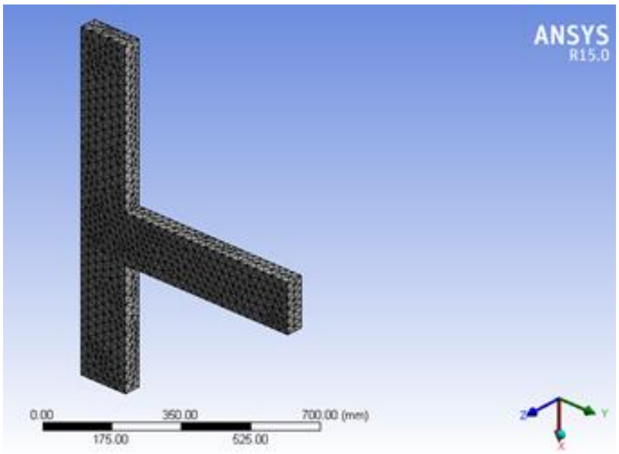

Figure 4: Mesh of Control Specimen Model

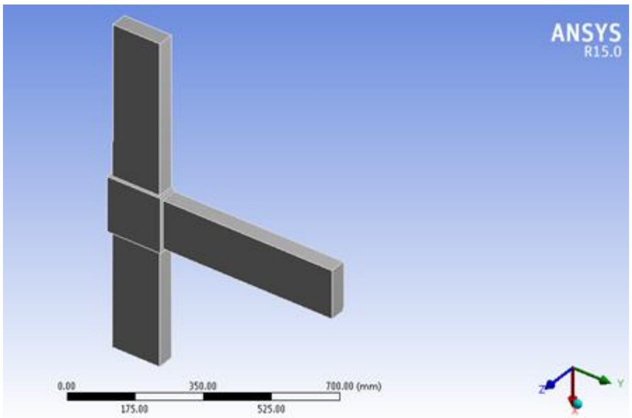

Figure 5: Model of Joint Enlarged Specimen

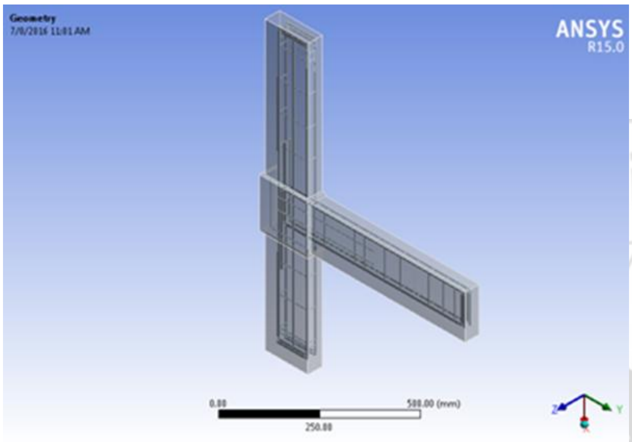

Figure 6: Reinforcement Details of Joint Enlarged Model

4. Analysis of Models

Model is analysed using Ansys Workbench 15 software. Deformation and stress on the application of load is found out. A 20mm joint enlargement when compared with the control specimen is adopted and the reduction in stress as well deformation is found out in the case of both upward and downward loading.

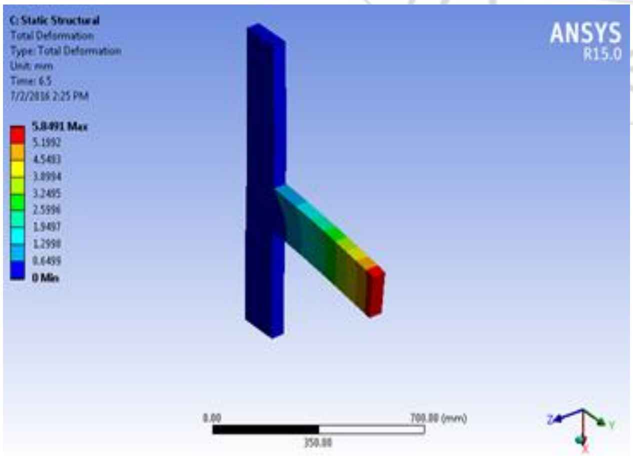

Figure 7: Total Deformation of Control Specimen

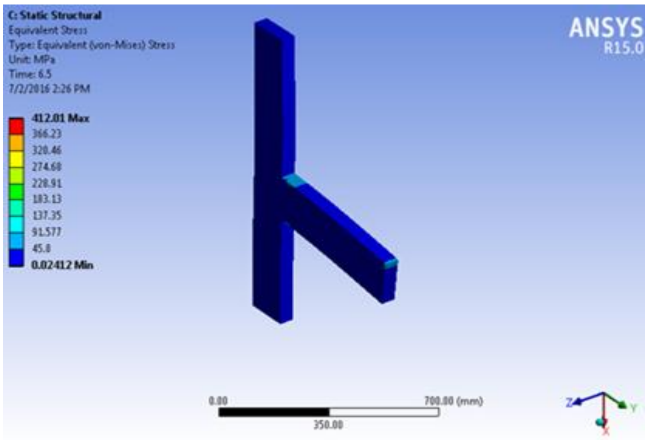

Figure 8: Von-Mises Stress of Control Specimen

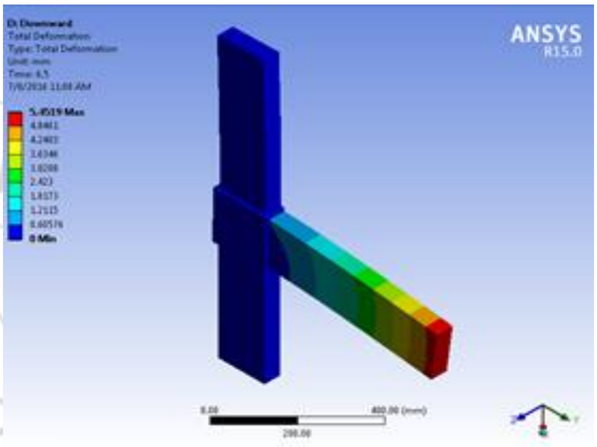

Figure 9: Total Deformation of Joint enlarged Model

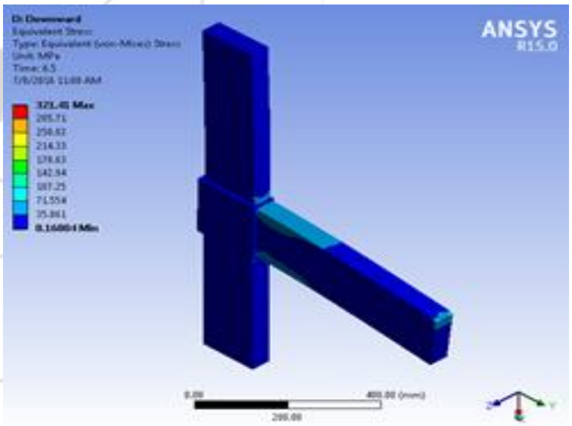

Figure 10: Von-Mises Stress of Joint Enlarged Specimen

Table 3 shows the comparison of stress levels on the application of load at the beam end for both control specimen and joint enlarged specimen for downward loading.

Table 3: Comparison of Stress for Downward Loading

Load (kN)	Stress (MPa)		Percentage Reduction (%)
	Control Specimen	20mm Joint enlarged specimen	
0	0	0	-
1.962	30.764	28.571	7.13
3.924	54.731	45.752	16.41
5.886	81.923	62.939	23.17
7.848	109.13	83.151	23.81
9.81	136.36	103.88	23.82
11.772	163.62	124.71	23.78
13.734	190.93	145.71	23.68
15.696	218.4	167.13	23.47
17.658	247.34	190.8	22.86
19.62	280.53	218.51	22.11
21.582	320	250.46	21.73
23.544	364.35	285.01	21.78
25.506	412.01	321.41	22

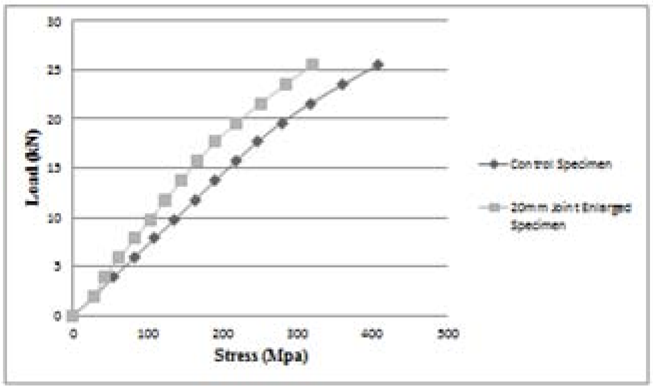

Figure 11: Comparison of Load-Stress Diagram for Downward Loading

Table 4 shows the comparison of stress levels on the application of load at the beam end for both control specimen and joint enlarged specimen for upward loading.

Table 4: Comparison of Stress for Upward Loading

Load (kN)	Stress (MPa)		Percentage Reduction (%)
	Control Specimen	20mm Joint enlarged specimen	
0	0	0	-
1.962	28.252	28.26	-
3.924	53.944	41.283	23.47
5.886	81.088	61.784	23.8
7.848	108.22	82.28	24
9.81	135.56	102.82	24.15
11.772	162.51	123.39	24.1
13.734	189.69	144.28	24
15.696	217	165.52	23.72
17.658	245.54	189.49	22.82
19.62	278.19	217.98	21.64
21.582	316.93	249.93	21.14
23.544	360.62	283.7	21.33
25.506	407.6	318.93	21.75

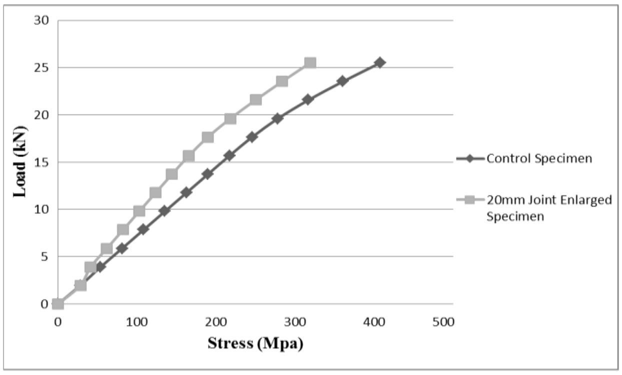

Figure 12: Comparison of Load-Stress Diagram for Upward Loading

From the figures 11 and 12, it can be seen that a small enlargement of 20mm of the joint stirrup has reduced the stress level much than the control specimen. Table 5 shows the comparison of deformation on the application of load at the beam end for both control specimen and joint enlarged specimen for downward loading.

Table 5: Comparison of Deformation for Downward Loading

Load (kN)	Deformation (mm)		Percentage Reduction (%)
	Control Specimen	20mm Joint enlarged specimen	
0	0	0	-
1.962	0.435	0.41	5.75
3.924	0.845	0.79	6.5
5.886	1.25	1.176	5.92
7.848	1.67	1.57	6
9.81	2.08	1.95	6.25
11.772	2.504	2.35	6.15
13.734	2.93	2.75	6.14
15.696	3.36	3.15	6.25
17.658	3.815	3.57	6.422
19.62	4.287	4.01	6.46
21.582	4.78	4.47	6.48
23.544	5.3	4.95	6.6
25.506	5.85	5.45	6.84

Table 6 shows the comparison of deformation on the application of load at the beam end for both control specimen and joint enlarged specimen for upward loading.

Table 6: Comparison of Deformation for Upward Loading

Load (kN)	Deformation (mm)		Percentage Reduction (%)
	Control Specimen	20mm Joint enlarged specimen	
0	0	0	-
1.962	0.38	0.36	5.26
3.924	0.793	0.74	6.68
5.886	1.203	1.13	6.07
7.848	1.614	1.515	6.134
9.81	2.029	1.91	5.86
11.772	2.45	2.3	6.12
13.734	2.874	2.69	6.4
15.696	3.306	3.1	6.23
17.658	3.75	3.51	6.4
19.62	4.22	3.95	6.4
21.582	4.713	4.4	6.64
23.544	5.23	4.88	6.69
25.506	5.77	5.37	6.93

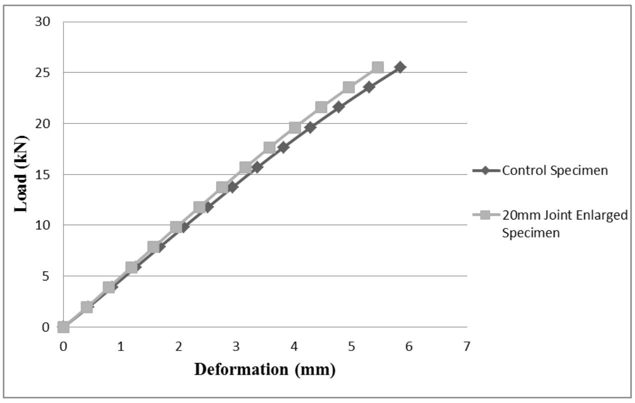

Figure 13: Comparison of Load-Deformation Diagram for Downward Loading

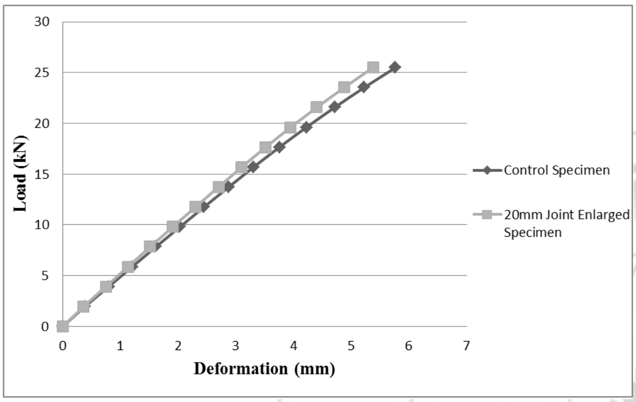

Figure 14: Comparison of Load-Deformation Diagram for Upward Loading

From the figures 13 and 14, it can be seen that a small enlargement of 20mm of the joint stirrup has helped to reduce the deformation compared to the control specimen.

5. Conclusion

The effect of joint enlargement on exterior beam-column joint has been studied. The joint region was enlarged 20mm than the control specimen by enlarging the stirrups in the joint region. The results yield the following conclusions.

1) Enlargement in joint region reduced the stress.
2) As the load value increased, the joint enlargement helped to reduce stress in higher amount.
3) It also helped to increase the stiffness of the specimen.
4) The specimen with 20mm joint enlargement showed maximum stress reduction of 22% for downward loading and 21.75% for upward loading when compared with control specimen.
5) Also the joint enlarged specimen showed maximum deformation reduction of 6.84% for downward loading and 6.93% for upward loading when compared with control specimen.
6) It is an economical way since the joint enlargement is done by the using the stirrups used for the column section alone.

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