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IMPORTANCE OF WEB REINFORCEMENT IN BEAM COLUMN JOINT CONNECTIONS

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Abstract. The primary focus of this research is to determine the optimal stirrup configuration to prevent shear failure. This project aims to investigate the behavior of beam-column joint frames under concentrated loads. Specimens with dimensions of 700mm x 500mm and cross-sectional dimensions of 200mm x 100mm, using M30 Grade concrete, were prepared for this study. The specimen was tested in the linear, non-linear range and up to ultimate load limit for a concentrated load. The load responses are measured with LVDT & Data logger in this experimental work. The code of practice recommends (Bureau of Indian standards-13920-1993) the bond, shear, and ductility, reinforcement for shear and moment carrying capacity. This code aims to fulfill both bond and shear requirements. This paper provides a thorough review and offers recommendations on the design and detailing of beam-column joint connections. Analytical value of the load carrying capacity of the beam column joint was assessed using limit state method by eliminating the partial safety factors for the load and strength. The results were compared between experiments and analytical values and suggestions are presented in this paper.

1 Introduction

The beam-column joint is a critical area in a reinforced concrete moment-resisting frame. It experiences substantial forces during strong ground shaking, significantly affecting the structure's response. Assuming the joint to be rigid overlooks the impact of intense shear forces that occur within it. Shear failure of beam-column joints has been a primary factor leading to the collapse of numerous reinforced concrete frame buildings in recent earthquakes [1]. Evidence from recent earthquakes indicates that deficient beam-column joints can jeopardize the integrity of the entire structure. The brittle joint shear failure also significantly reduces the overall ductility of structures, resulting in dangerous failure mechanisms [6]. A variety of techniques have been developed to strengthen beam-column joints. These techniques include the use of steel and concrete jacketing. More than a decade ago, a new technique for strengthening structural elements emerged.

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2 Methodology

2.1 Materials

Cement, sand, bricks and iron rods (which are used to make the steel moulds).

2.2 Preparation of steel mould

For this project, two specimens were cast using moulds made from 3mm thick plates. Each specimen included a beam with a cross-section of 100×200×500 and a column with a cross-section of 100×200×700, interconnected using bolts and nuts.

Fig. 1. Preparation of mould.

2.3 Beam Column joint (IS 456:2000)

Breadth - 100 mm
Depth - 200 mm
Length - 500 mm
Fck - 30 N/mm^2
fy - 415 N/mm^2
Clear cover - 5mm
Effective cover - 20+5 = 25mm

2.4 Balance Section [0.48d]

According to code IS 456:2000, Clause 38.1, [xu/d] (limit) = 0.48 for fe415
According to code IS 456:2000, ANNEX- G 1.1(a),
[xu/d] = [0.87×f y× Ast [req]] / [0.36 ×fck× b× d] 0.48
= [0.87×415×Ast [req]] / [0.36 ×30 ×100 ×175]
Ast [req] = 251.267mm^2

2.5 Tension Reinforcement

According to code IS 456:2000, Clause 26.5.1.1(a),
The minimum tension reinforcement should not be less than the following,
As = 0.85bd / fy

As = 0.85×100×175/415
As=35.84 mm^2
According to code IS 456:2000, Clause 26.5.1.1(b)
The maximum area of tension reinforcement shall not exceed 0.04bD
= 0.04bD
= 0.04×100×200
= 800mm
Provide 2 no's of 10 mm diameter bar (Ast =157.08mm^2)
According to code IS 456:2000, ANNEX- G-1.1(a)
[xu / d] = [0.87×f y × Ast [provided]]/ [0.36×f ck×b×d]
= [0.87×415×157.08] / [0.36×30×100×175]
[xu / d] = 0.30
0.30 < 0.48

Hence design as under reinforced section According to code IS 456:2000, ANNEX- G-1.1(b)
Mu = 0.87×fy×Ast×d [1-(Ast×fy)/(b×d×fck)]
=0.87 ×415×157.08×175[1-(157.08×415) / (100×175 ×30)]
= 8.45kNm < 10.56kNm

Therefore, beam is under reinforced section.

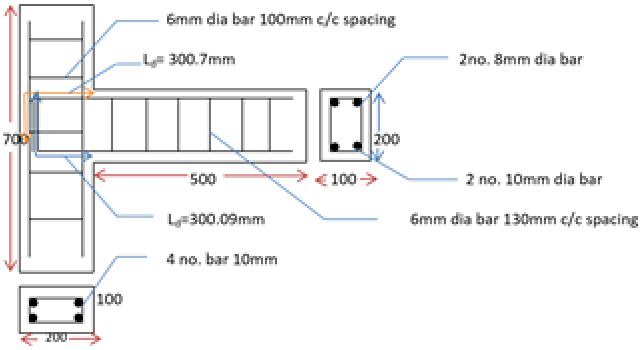

Fig. 2. Reinforcement detail of beam-column joint.

2.6 Compression Reinforcement

According to code IS 456:2000, Clause 26.5.1.2,
The maximum area of compression reinforcement shall not ex=0.04bD
=0.04×100×200
=800mm^2
Provide 2 no's of 8 mm diameter bar (Ast =100.53mm^2)

2.7 Column Design

2.7.1 Longitudinal Reinforcement

As per IS 456:2000, Clause 26.5.3.1 (a), the cross-sectional area of longitudinal reinforcement in a column must be at least 0.8 percent and should not exceed 6 percent of the gross cross-sectional area of the column.
Provide 4 no's of 10mm diameter bars

$$Ast = 4 \times \frac{\pi}{4} \text{ x } 102$$

Percentage of steel [Pt] = 100×Ast / (b×d)
= 100×314.16 / (100×175) = 1.79
i.e.,0.8 > 1.79 < 6,
Hence within the limit.

2.7.2 Lateral Ties

According to code IS 456:2000, Clause 26.5.3.2 (c)
The diameter of the polygonal links or lateral ties should be a minimum of one-fourth the diameter of the largest longitudinal bar, and in no circumstance should it be less than 8 mm. [8].
Hence, use 8 mm diameter bars for the lateral ties, ensuring they are greater than one-fourth the diameter of the longitudinal bar, which is 10 mm in diameter.

2.7.3 Spacing of Lateral Ties

According to IS 456:2000, Clause 26.5.3.2 (c), the spacing of transverse reinforcement should not exceed the smallest of the following distances:
i) The least lateral dimension of the compression member = 100 mm
ii) Sixteen times the smallest diameter of the longitudinal reinforcement bar to be tied
= 16 × 10 = 160 mm
iii) 300 mm
Since the least of these dimensions is 100 mm, the spacing of lateral ties should be equal to or less than 100 mm center-to-center. Therefore, provide 8 mm diameter lateral ties at 100 mm center-to-center spacings

2.7.4 Casting of Beam Column

The beam column was casted with the same dimensions which were obtained as per design criteria with the framed specimens is 700mm x 500mm, with the cross sectional dimension of 200mm x 100mm

Fig. 3. Casting of Specimen.

3 Experimental Setup and Testing

The experimental setup includes a self-straining load frame, a hydraulic loading jack equipped with a load cell, and careful arrangement to ensure the concentrated force is applied precisely at the center of the beam specimen, avoiding any eccentricity during loading. A Linear Variable Differential Transformer (LVDT) is strategically positioned to measure deflections at specified points on the specimen. Each specimen is positioned on the loading frame and subjected to a central concentrated force. The resulting deflections are measured within the elastic range using a data logger. [4].

Fig. 4. Loading frame and Hydraulic jack attached to specimen.

Fig. 5. Cracks observed in specimen with Stirrups spacing -100 mm.

Fig. 6. Cracks observed in specimen with 70mm stirrups spacing.

Fig. 7. Cracks observed in specimen with 150mm stirrups spacing.

Failure is defined as the point when the specimen can no longer bear the load and the specimen collapses. The beam column specimen failed as shown in the figure.

4 Result and Discussion

The experimental and analytical results of the beam-column joint, considering various stirrup spacings, were presented in a load versus deflection figure and a corresponding tabular column.

To assess the impact of three different stirrup spacing configurations on the behavior of a reinforced concrete beam-column connection, three test specimens were subjected to identical loading conditions. Displacements were recorded for each specimen across the varying stirrup spacings. Throughout testing, observations were made on crack formations, failure patterns, and detailed explanations were provided on the modes of failure observed [5].

The beam-column joint specimens were analyzed, and deflections were recorded for the applied loads. Deflections were noted at mid-span of the beam, and load-deflection graphs were plotted accordingly. The key findings from the testing include understanding the load-deflection characteristics of each specimen and identifying the modes of failure observed. Below are the load vs. deflection plots for the two specimens: -
The maximum deflection in cantilever beam of span "l" m and loading at free end is "W" kN.
Maximum deflection (y) = Wl3/3EI
Load Vs deflection of the three specimens is given below: -

Table 1. Behavior of beam column joint with 70mm spacing of stirrups.

Load (kN)	**Experimental Investigation (mm)**	**Analytical Deflection** (mm)
0	0	0
2.0	1.43	0.9125
2.5	2	1.1406
3.0	2.56	1.3688
3.5	3.36	1.5968
4.0	4.46	1.8250
4.5	6.23	2.0531
5.0	8.5	2.2813
5.0	10.5	2.2813

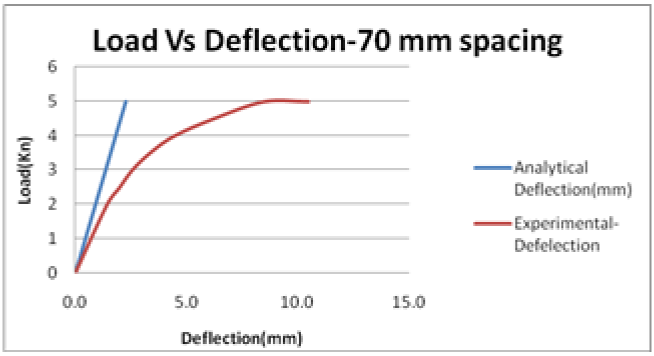

Fig. 8. Load Vs Deflection for 70 mm spacing of stirrups.

Fig.1 shows Load Vs Deflection Graph for the Experimental Specimen 70 mm spacing of stirrups (shear Reinforcement) [1]. The corresponding Load Vs Deflection profiles are shown in figure -1 The figure indicates that actual Deflection are more when compared to Analytical

Deflections. Figure 1 also implies that the experimental deflection closely follows the Analytical Deflections up to 2.0 kN. The Variation is 5-8% and also follows the Linear Behavior up to 2.0 kN. After 2.0kN Load small minor hair cracks were observed and specimen behaviors non-Linearly w.r.t Load increments and shows Large Displacement up to 4.0 kN [2].
The specimen develops large displacement up to 4.0 kN and the specimen develops many cracks in tension Zone. The cover concrete of specimen develops many cracks and behavior is in the in-elastic range. No appreciable increment in the load was observed even though deflections were increasing continuously. Hence it was understood that the specimen has yielded completely approaching the failure state. Due to very large deflection beyond the Range of LVDT the testing was stopped [7].

Table 2. Behavior of beam column joint with 100mm spacing of stirrups.

Load (kN)	**Experimental Investigation (mm)**	**Analytical Deflection** (mm)
0	0	0
2.0	1.69	0.9125
2.5	3.15	1.1406
3.0	4.16	1.3688
3.5	5	1.5968
4.0	5.98	1.8250
4.5	7.575	2.0531
5.0	9.5	2.2813
5.0	11	2.2813

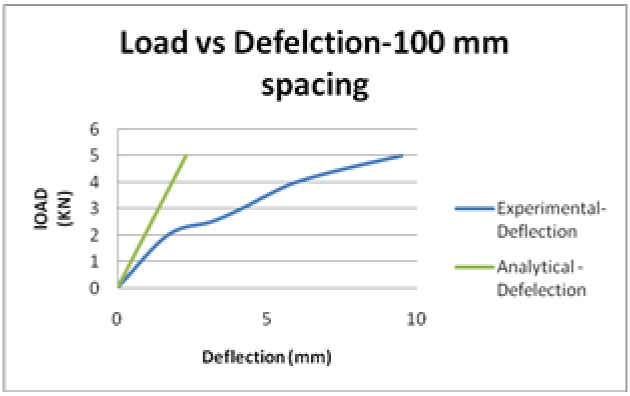

Fig. 9. Load Vs Deflection for 100 mm spacing of stirrups.

Fig.2 shows Load Vs Deflection Graph for the Experimental Specimen having 100 mm spacing of stirrups (shear Reinforcement). The specimens behaviors similar to specimen 1, expect the variation of Theoretical deflections and Actual deflections was between 7-10%. Marginally more Specimen [10].

Table 3. Behavior of beam column joint with 150mm spacing of stirrups.

Load (kN)	Experimental Investigation (mm)	Analytical Deflection (mm)
0	0	0
2.0	1.95	0.9125
2.5	2.52	1.1406
3.0	3.56	1.3688
3.5	4.64	1.5968
4.0	6.5	1.8250
4.5	9.5	2.0531
5.0	13.5	2.2813
5.0	15	2.2813

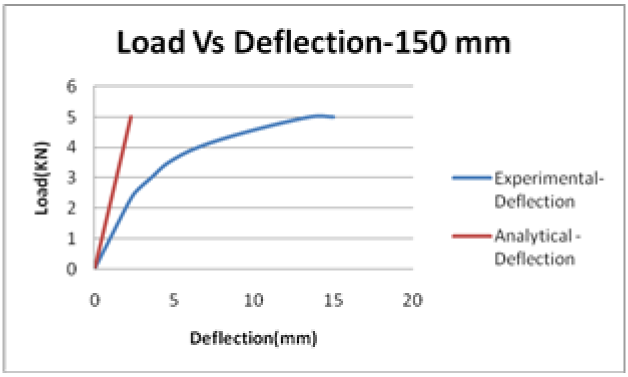

Fig.10. Load Vs Deflection for 150 mm spacing of stirrups.

Fig.3 shows Load Vs Deflection Graph for the Experimental Specimen 3 having 150 mm spacing of stirrups (shear Reinforcement) [3]. The specimens behaviors similar to specimen 1& 2, expect the variation up to Maximum of 10%.

Table 4. Comparative Load Vs Deflection (70 mm, 100mm &150 mm spacing of stirrups).

Load (kN)	Experimental Deflection of 70mm spacing of stirrups (mm)	Experimental Deflection of 100mm spacing of stirrups (mm)	Experimental Deflection of 150mm spacing of stirrups (mm)	Analytical Deflection (mm)

0	0	0	0	0
2.0	1.43	1.69	1.95	0.9125
2.5	2	3.15	2.52	1.1406
3.0	2.56	4.16	3.56	1.3688
3.5	3.36	5	4.64	1.5968
4.0	4.46	5.98	6.5	1.8250
4.5	6.23	7.575	9.5	2.0531
5.0	8.5	9.5	13.5	2.2813
5.0	10.5	11	15	2.2813

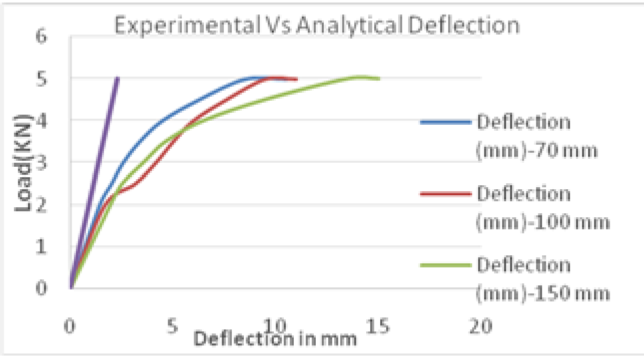

Fig.11. Comparative Load Vs Deflection (70 mm, 100mm &150 mm spacing of stirrups).

Figure 4 shows the Analytical and Deflections of profiles of all the specimens (spacing of stirrups 70mm,100mm,150mm) [4] so it was observed that the specimen 1 is close to Analytical values and followed by the specimen. The specimen 3 determine more from the Analytical values. The slope of the curves which represents the stiffness of the specimen -1very much near to Analytical value of stiffness. The specimen 2 & 3 having lesser stiffness than specimen -1. This may be an indication of the specimen reduces its stiffness due to increasing of the spacing of more the stirrups [9].

The specimen 2 &3 may be more flexible than specimen 1, however specimen 3 is having large displacement when compared to specimen 2, hence specimen 2 may be having more flexibility and tolerable level of stiffness also.

The cracks observations of tested specimen indicated the specimen 1 having less cracks width when compared to other 2 specimens. the specimen 3 crack width was found to be more when compared specimen1&2 Hence spacing of shear reinforcement in specimen 1 may be recommended to improving the shear strength of the beams [3].

5 Conclusion

The following conclusions are drawn from the test results.

i) Investigated the impact of varying stirrup spacing's (70mm, 100mm, and 150mm) on reinforced concrete beam-column connections.
ii) Analyzed load-deflection profiles to understand specimen response under applied loads, noting that experimental deflections generally aligned with analytical predictions up to a certain load level.
iii) Observed crack formations during testing, with failure occurring when specimens could no longer withstand the load, with larger stirrup spacing's correlating with more pronounced cracks.
iv) Compared experimental and analytical deflections, noting variations and differences in stiffness among specimens, with smaller stirrup spacing's exhibiting closer alignment with analytical values.
v) Recommended smaller stirrup spacing's, such as 70mm, for improved shear strength and reduced crack width based on observations during testing.
vi) Noted a trade-off between flexibility and stiffness, with larger stirrup spacing's increasing flexibility but decreasing stiffness, while specimens with smaller spacing's showed a balance between the two.
vii) Emphasized the significant influence of stirrup spacing on beam-column connection behavior, particularly regarding shear strength, crack formation, and structural stiffness.

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