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Performance of RC Beam Column Joint with Varying Hoop Reinforcement

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Contents

Introduction:

➢**Beam Column Joint & It's types**

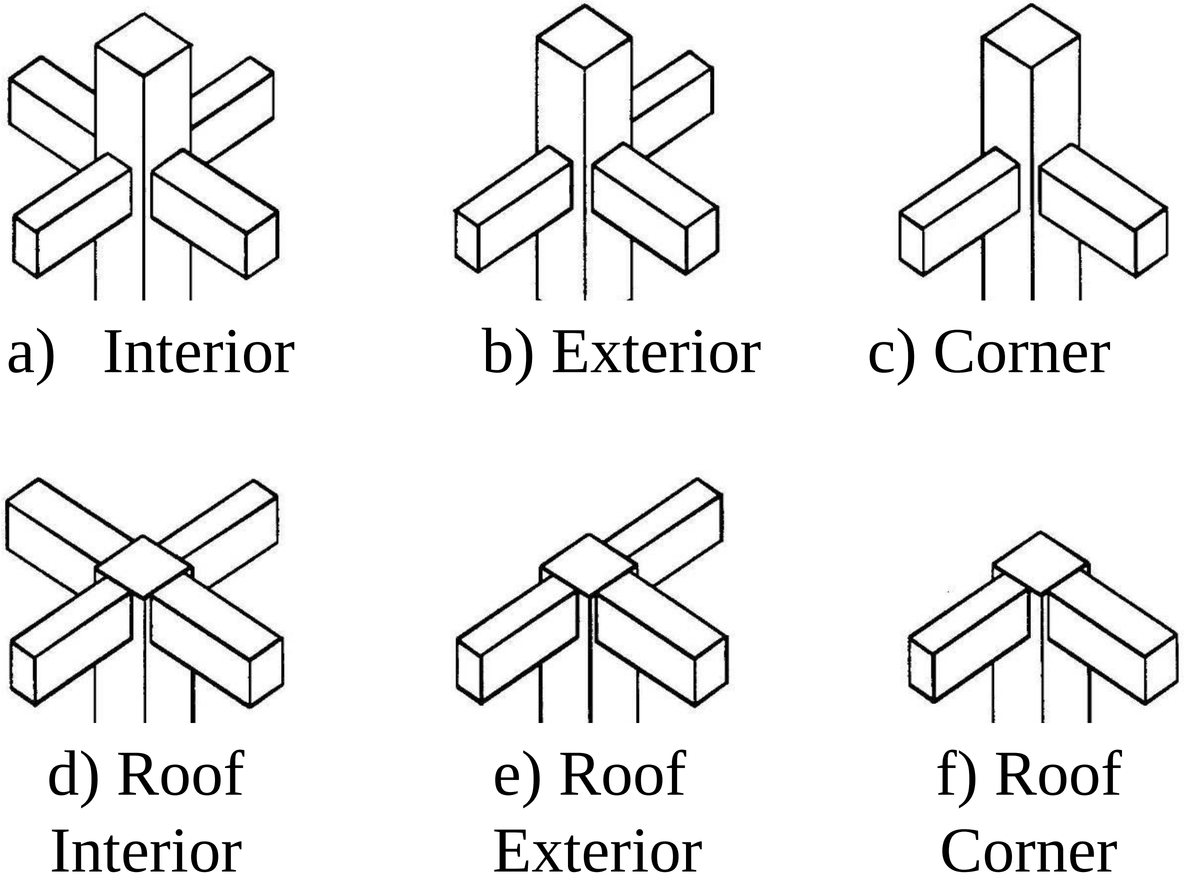


Fig. 1 – Types of Joint

➢**The performance of framed structures**

➢ Joints of irregular framed structures are more critical

➢ Beam-column joints are critical regions.

➢ A beam column joint becomes structurally less efficient

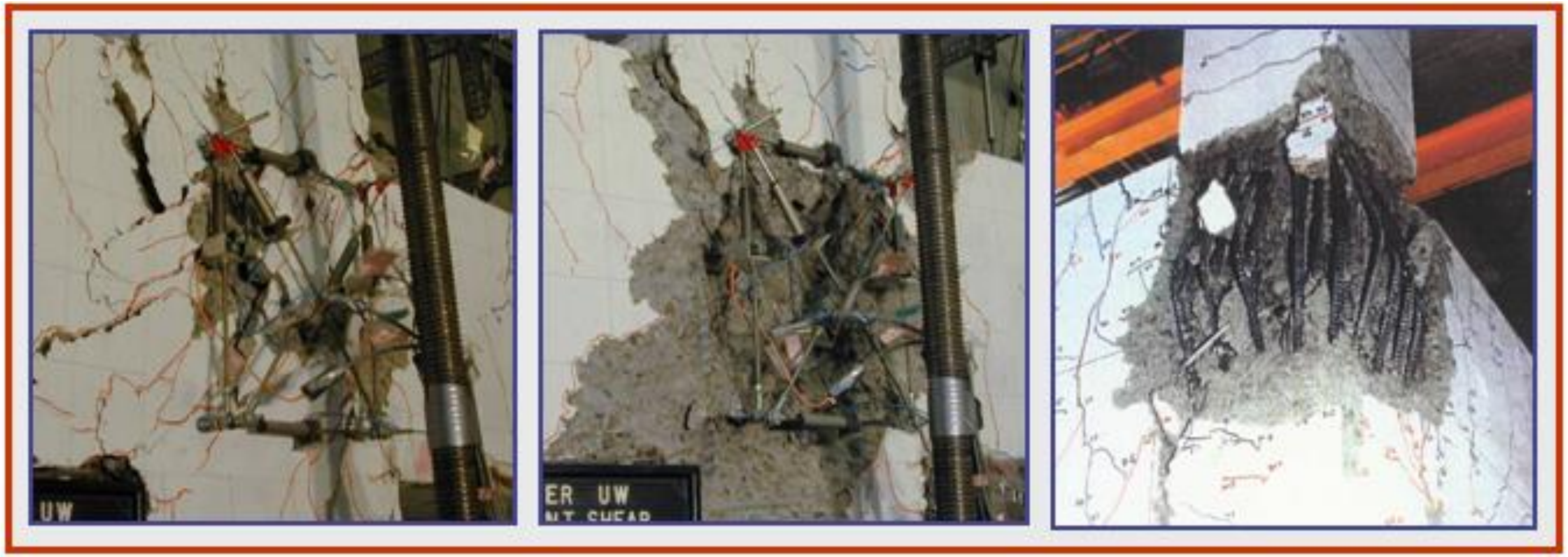


Fig. 2 – Failure in Joints

- **The innovative joint designs**
- **ACI-352 (2002) recommends T-headed bar**
- **The horizontal hoop reinforcement**
- **Hoops carry a substantial portion of the joint shear**
- **Transverse hoops in a joint contribute to the shear resistance**

- **The conflicting views about the function of transverse reinforcement**

- **Joint shear strength, stiffness, displacement ductility, crack patterns etc.**

- **The objective of the experimental study**

System Developments

- ACI codes details out to prerequisites
- The anchorage capacity of a headed bar
- A tests were conducted to investigate the part of joint hoops

System Developments

- **As per section 21.7.4, nominal shear strength (Vn) is based on**

$$V_n = 15\,A_j\sqrt{f'_c} \qquad (1)$$

- **The design shear force, Vjh,u based on capacity design concept, can be estimated using**

$$V_{jh,u} = T - V_{col} = 1.25\,(A_{st} f_y - A_{st} f_y\, jd/L_c) \qquad (2)$$

Test program

- **Six exterior beam-column joint specimens**

Material properties

- **The concrete mix with medium workability**
- **Portland Pozzolana Cement and natural sand with specific gravity 2.72 of grading zone I are used as fine aggregate.**
- **Course aggregates of a maximum size of 20 mm and specific gravity 2.78 are used.**
- **HYSD bars of Fe 450 grade 8 mm dia. and Fe 250 grade 6mm dia. bars are used**

Test specimens

Table 1 Specification details of test specimen

Sr. No.	Specimen Designation	Specification
1	J_1	Control specimen using headed bars
2	J_{11}	Specimen using headed bars with extra single tie in joint
3	J_{12}	Specimen using headed bars with extra two ties in joint
4	J_{13}	Specimen using headed bars with extra three ties in joint
5	J_{14}	Specimen using headed bars with extra single stirrup in joint
6	J_{15}	Specimen using headed bars with extra two stirrup in joint

Test specimens

- **Headed bars are used in place of conventional reinforcing**
- **A bar with a short head**
- **Minimum clear cover for all headed bars is 2db and provided clear cover is 20 mm**

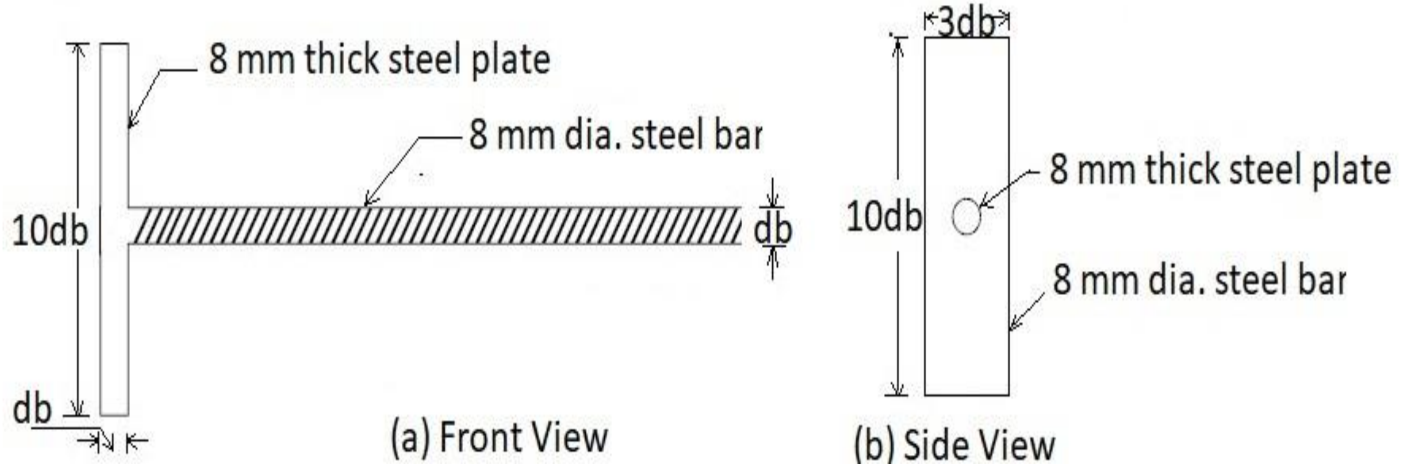
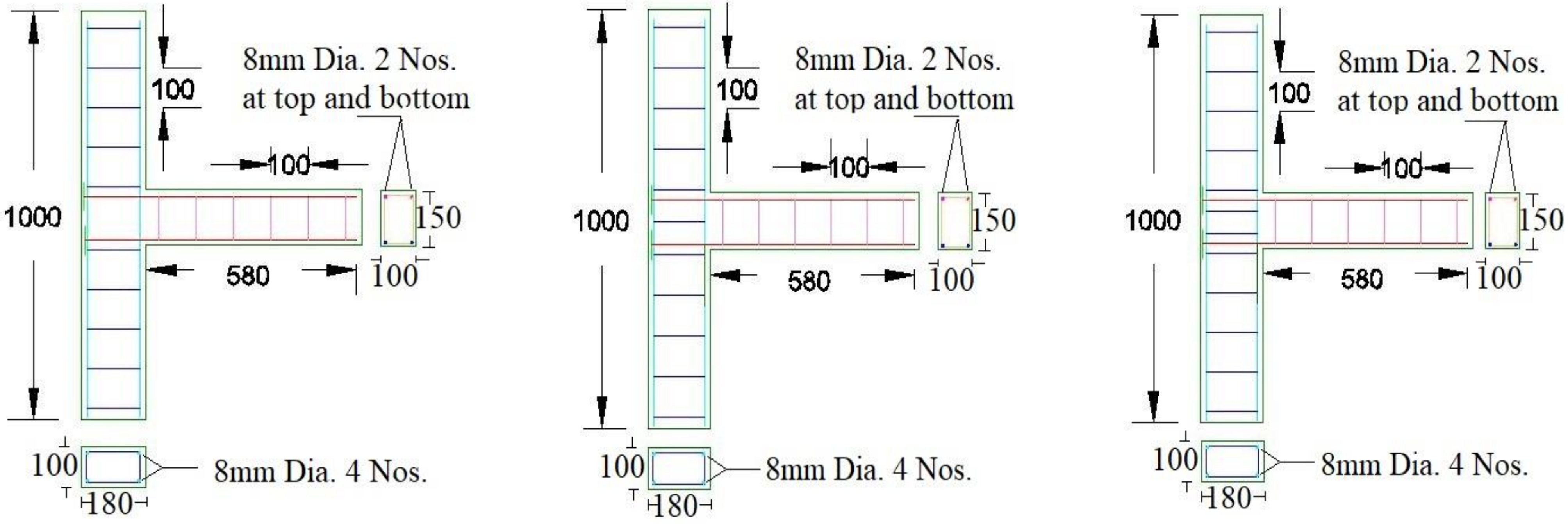


Fig. 3 - Details of Headed bar

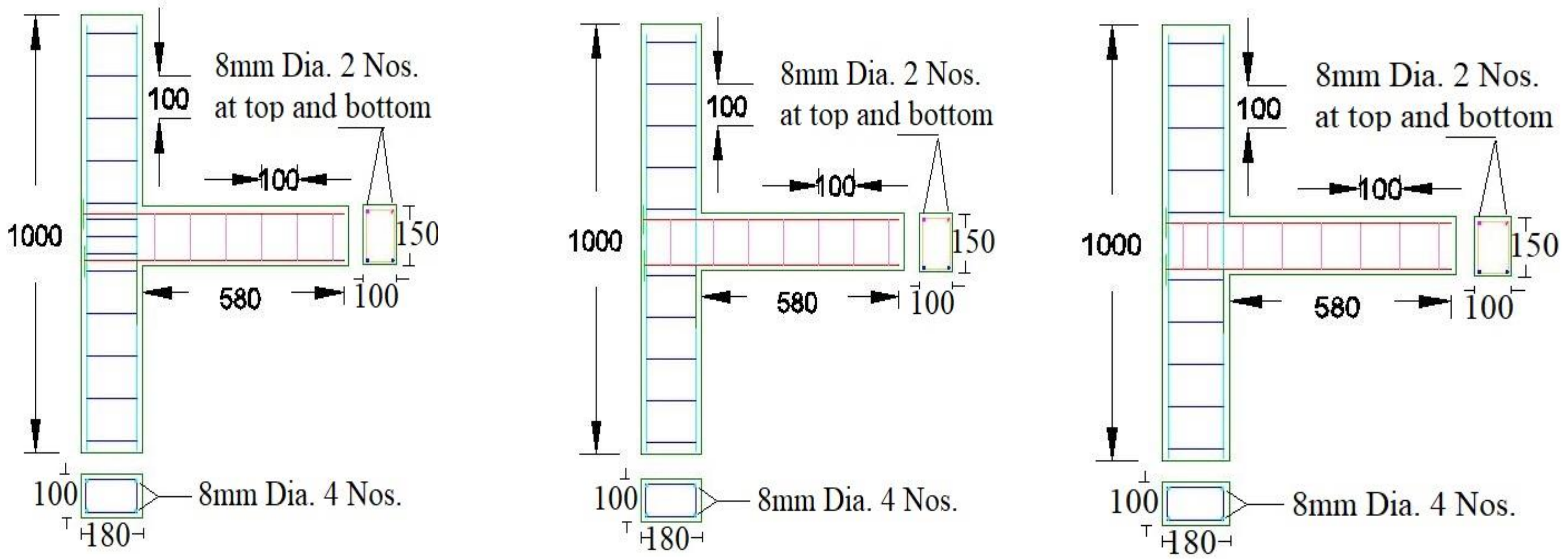
Test specimens

- Development length available is equal to 160 mm i.e 20db
- The beam and column are provided with stirrups and lateral ties of 6 mm in diameter.



(a) (b) (c)

Test specimens

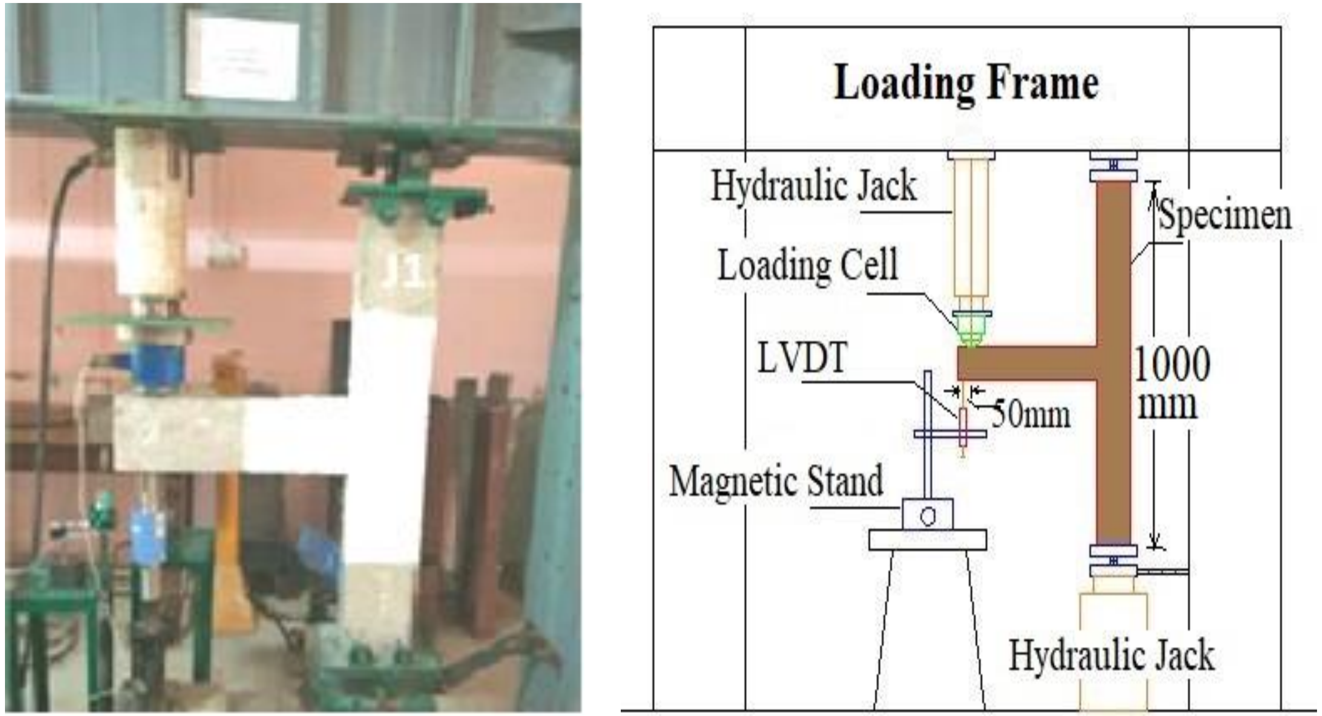


(d) (e) (f)

Fig. 4 - Reinforcement details of specimens **(a)** J_1, **(b)** J_{11}, **(c)** J_{12}, **(d)** J_{13}, **(e)** J_{14}, **(f)** J_{15}

Test setup and loading procedure

- **All the six specimens are tested using reaction frame**
- **Cyclic and reverse cyclic loading to simulate earthquake loading.**
- **An axial load using hydraulic jack**
- **The column ends are supported with hinge supports**



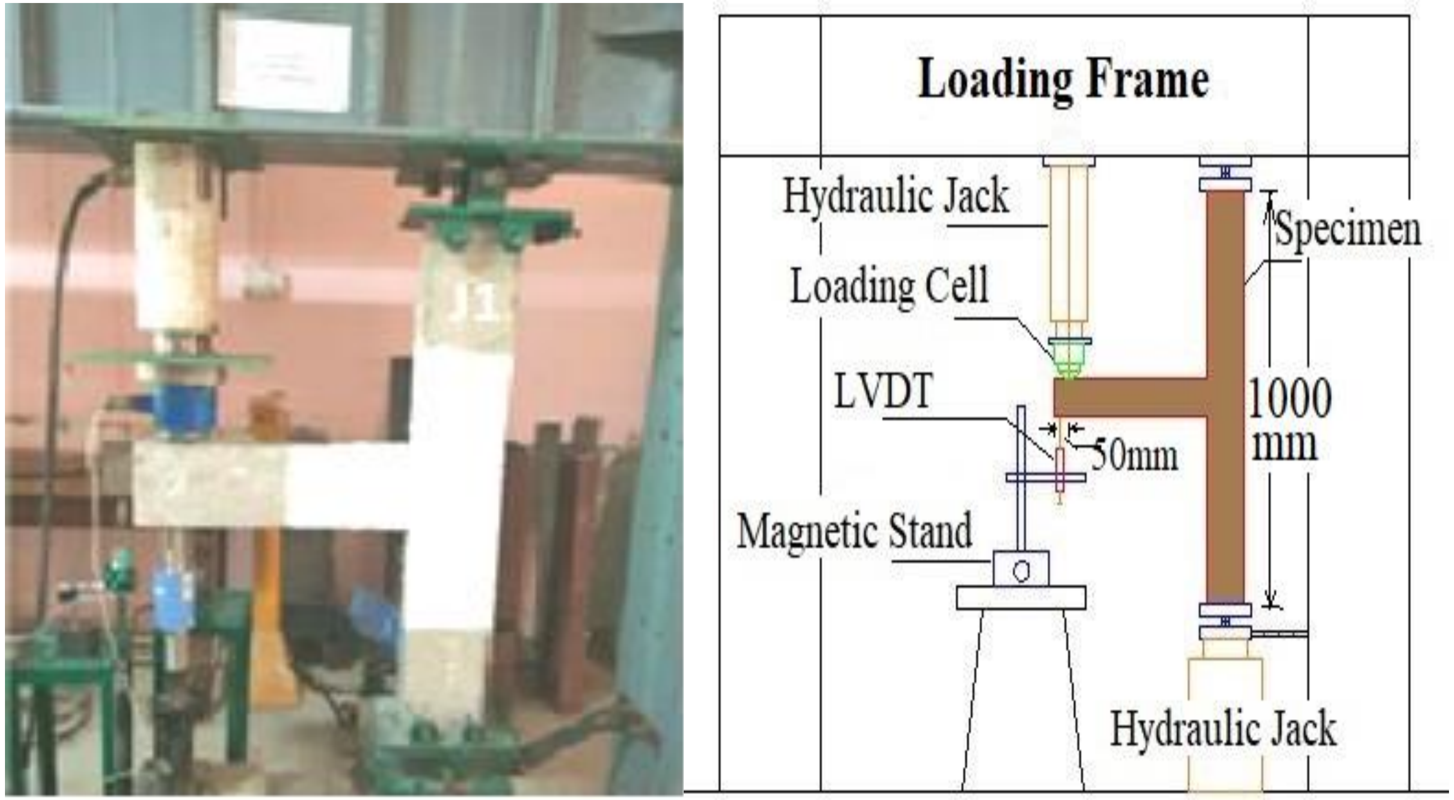
(a) (b)

Fig. 3 – (a) Photograph of Experimental setup, (b) Schematic diagram of set up

➢Two jacks are used to apply cyclic and reverse cyclic load to the beam, loading cell is inserted in between jack and beam.

➢Test is displacement controlled

➢Linear variable differential Transducers (LVDTs)



(a) (b)

Fig. 3 – (a) Photograph of Experimental setup, (b) Schematic diagram of set up

Strength predictions and cracking behavior

- Joint shear failure, Beam flexure failure and Beam Joint Failure or a combination thereof.
- Specimen J11, J12, J13 and J15 shows the vertical flexure cracks
- Failure is recognized by steady loss of load-conveying limit
- Beam joint failure is observed in specimen J1 and J14 as shown in Fig. 5(a) – 5(b).

➢Failure of joint specimen.

➢Horizontal crack is due to shear and vertical crack is due to flexure.

(a) (b) (c) (d)

Fig. 4 - Beam flexure failure (BF) in specimens (a) J11, (b) J12, (c) J13, (d) J15

➢Failure of joint specimen.

➢Horizontal crack is due to shear and vertical crack is due to flexure.

(a)

(b)

Fig. 5 - Beam Joint Failure (BJF) in specimens (a) J1, (b) J14

Force-Drift Study

➢ **Displacement ductility (μ) i.e. du/dy**

➢ **The different strength parameters of individual specimens are accounted for and analyzed in Table 2.**

Specimen	P_{max} (kN)	Nominal Flexural Strength, M_n (kNm)	Yielding Displacement in mm (d_y)	$V_{jh,test}$ (kN)	Displacement Ductility Factor, $\mu = (d_u/d_y)$	Stiffness (Initial) kN/mm	Stiffness (Final) kN/mm
J_1	12.01	4.74	2.24	50.29	5.36	5.36	1.00
J_{11}	13.03	4.74	1.73	54.56	6.94	7.54	1.05
J_{12}	16.04	4.74	1.63	67.16	7.36	9.84	1.09
J_{13}	13.75	4.74	1.43	57.57	8.39	9.62	1.15
J_{14}	12.58	4.74	1.98	52.68	6.07	6.37	1.05
J_{15}	12.99	4.74	2.21	54.39	5.44	5.89	1.12

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J_{14}	12.58	4.74	1.98	52.68	6.07	6.37	1.05
J_{15}	12.99	4.74	2.21	54.39	5.44	5.89	1.12

- **Specimen J1 displayed lower displacement ductility and poor execution**

- **Addition of hoop reinforcement improves displacement ductility values**

Specimen	P_{max} (kN)	Nominal Flexural Strength, M_n (kNm)	Yielding Displacement in mm (d_y)	$V_{jh,test}$ (kN)	Displacement Ductility Factor, $\mu = (d_u/d_y)$	Stiffness (Initial) kN/mm	Stiffness (Final) kN/mm
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J_{15}	12.99	4.74	2.21	54.39	5.44	5.89	1.12

- **Specimen J13 exhibited large displacement ductility values 56.53% more**
- **Specimen J15 shows least improvement amongst the other confined specimens and 8.15% more than control specimen J1.**

- **Horizontal hoops (ties) contribute to compression strut**
- **Confinement due to horizontal ties is more effective as compared to vertical stirrups.**

Comparisons of predictions of Experimental responses

- **Drift ratio (DR)**

- **In hysteresis curves the load is plotted against displacement.**

- **Specimens exhibited a satisfactory response as shown in Fig. 6.**

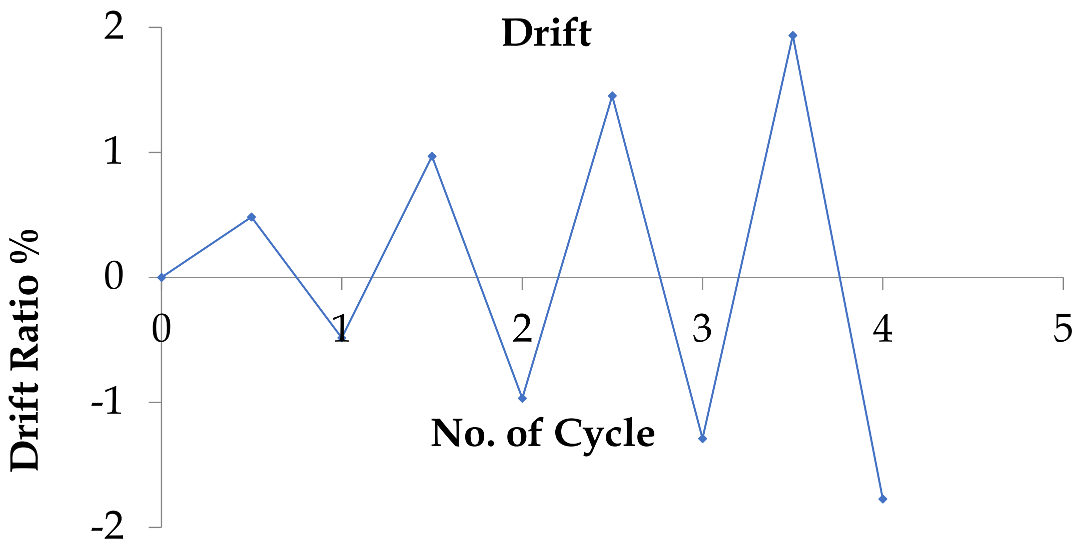
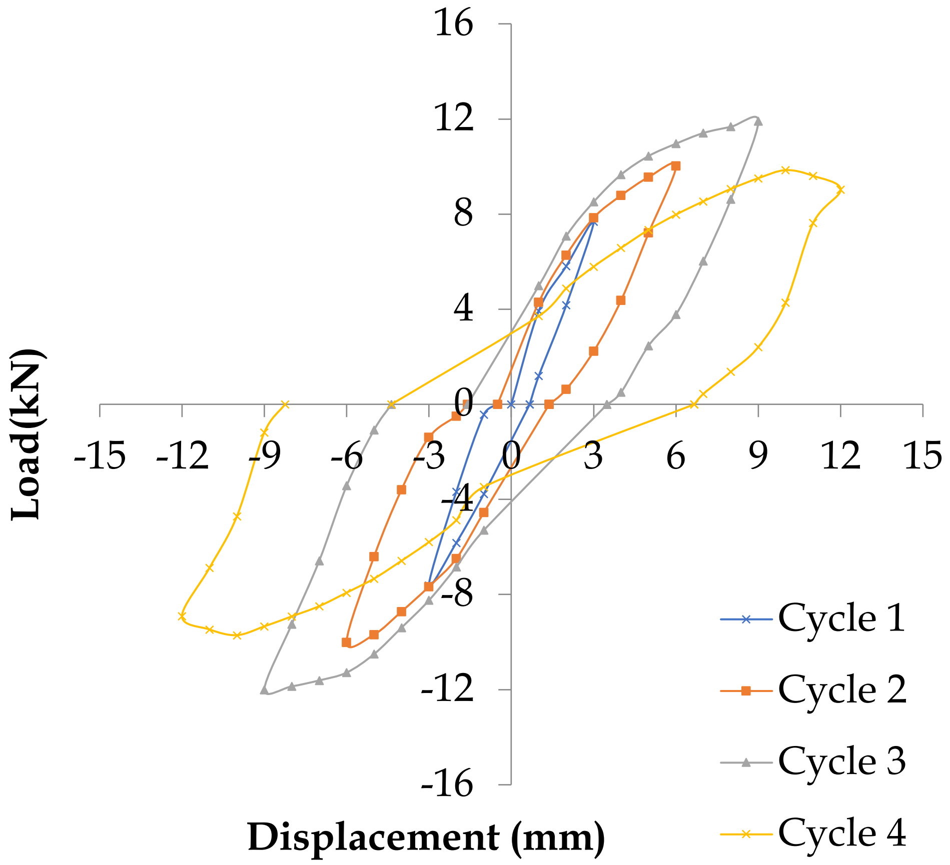


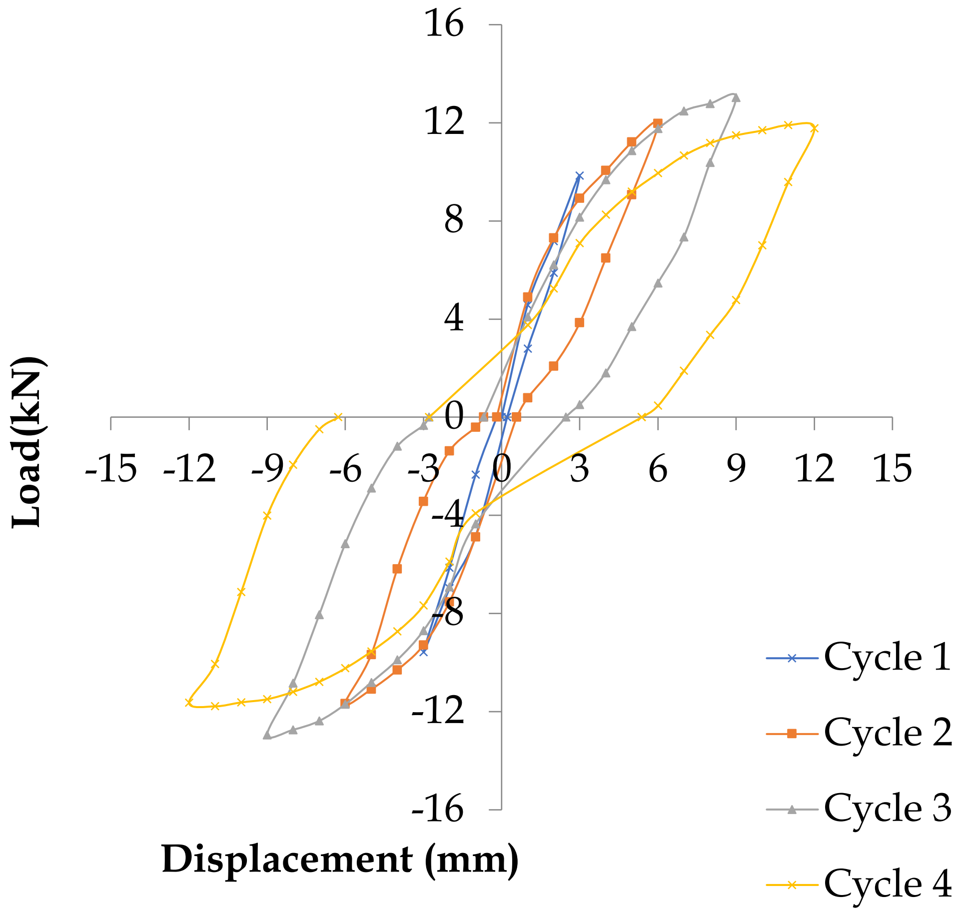
Fig. 6 - Loading regime

- Shape of hysteresis curves indicates energy dissipation
- Hysteresis curves of specimens J11, J12, J13 and J15
- Specimens J1 and J14
- Improved level of performance can be executed with headed bars
- Corresponding hysteresis curves of force drift performance for individual specimen is shown in Fig. 7(a) – 7(f)



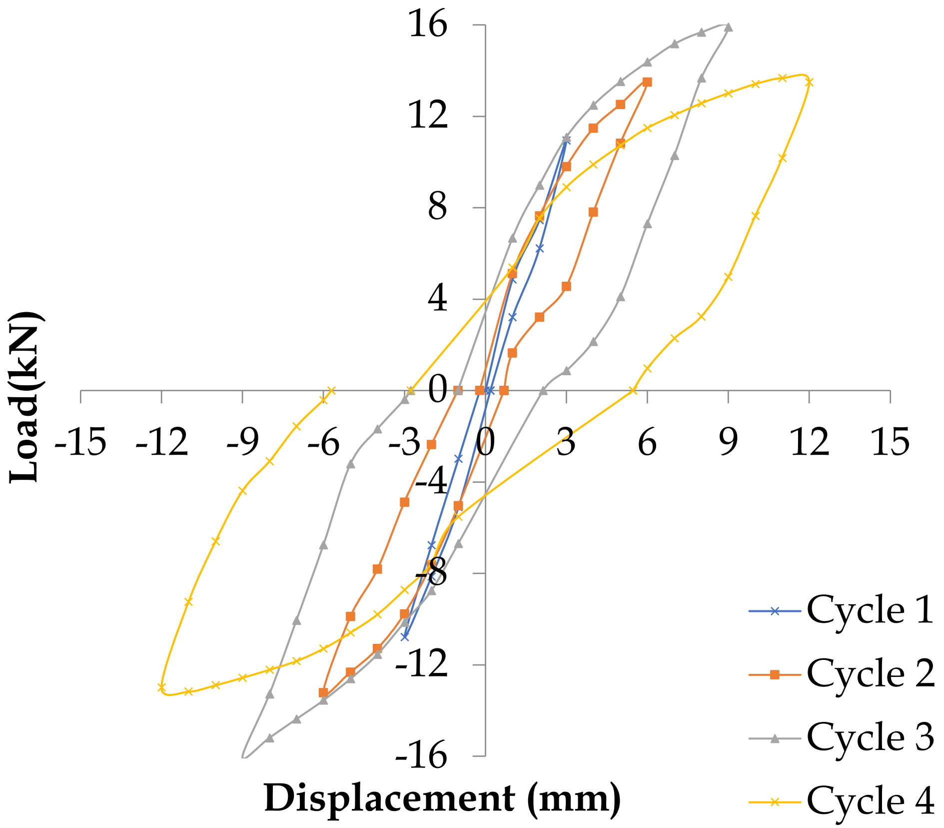
Load(kN)
16
12
8
4
0
-4
-8
-12
-16
-15
-12
-9
-6
-3
0
3
6
9
12
15
Displacement (mm)
Cycle 1
Cycle 2
Cycle 3
Cycle 4

(a)

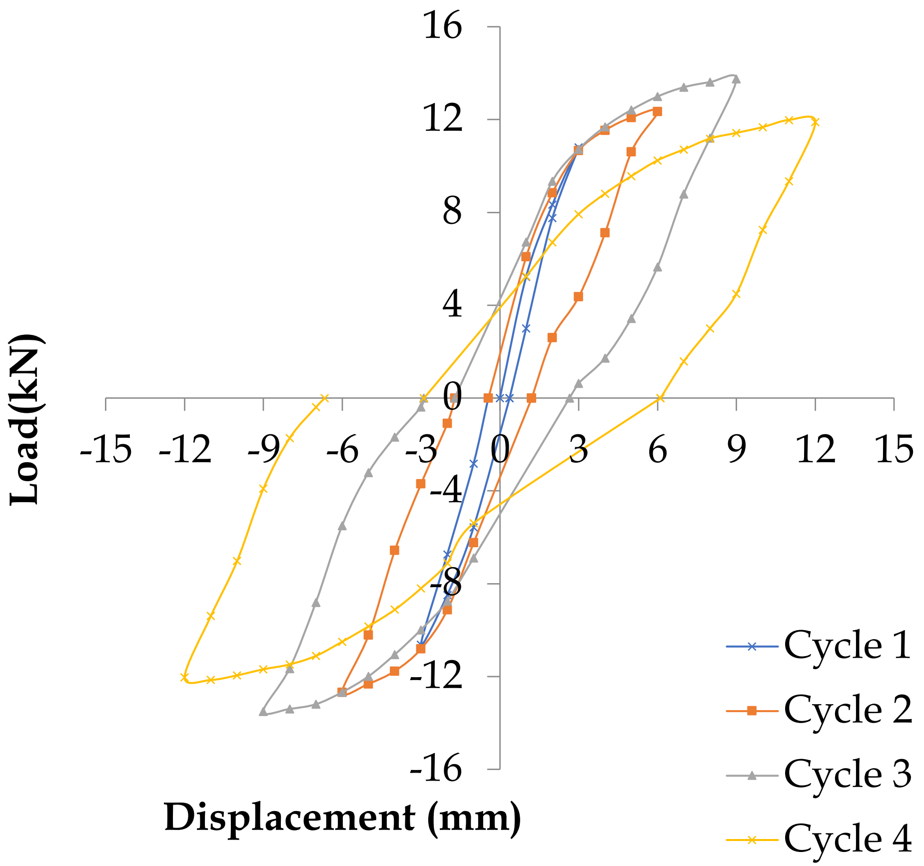


Load(kN)
16
12
8
4
0
-4
-8
-12
-16
-15
-12
-9
-6
-3
0
3
6
9
12
15
Displacement (mm)
Cycle 1
Cycle 2
Cycle 3
Cycle 4

(b)


16
12
8
4
0
-4
-8
-12
-16
-15
-12
-9
-6
-3
0
3
6
9
12
15
Load(kN)
Displacement (mm)
Cycle 1
Cycle 2
Cycle 3
Cycle 4

(c)


16
12
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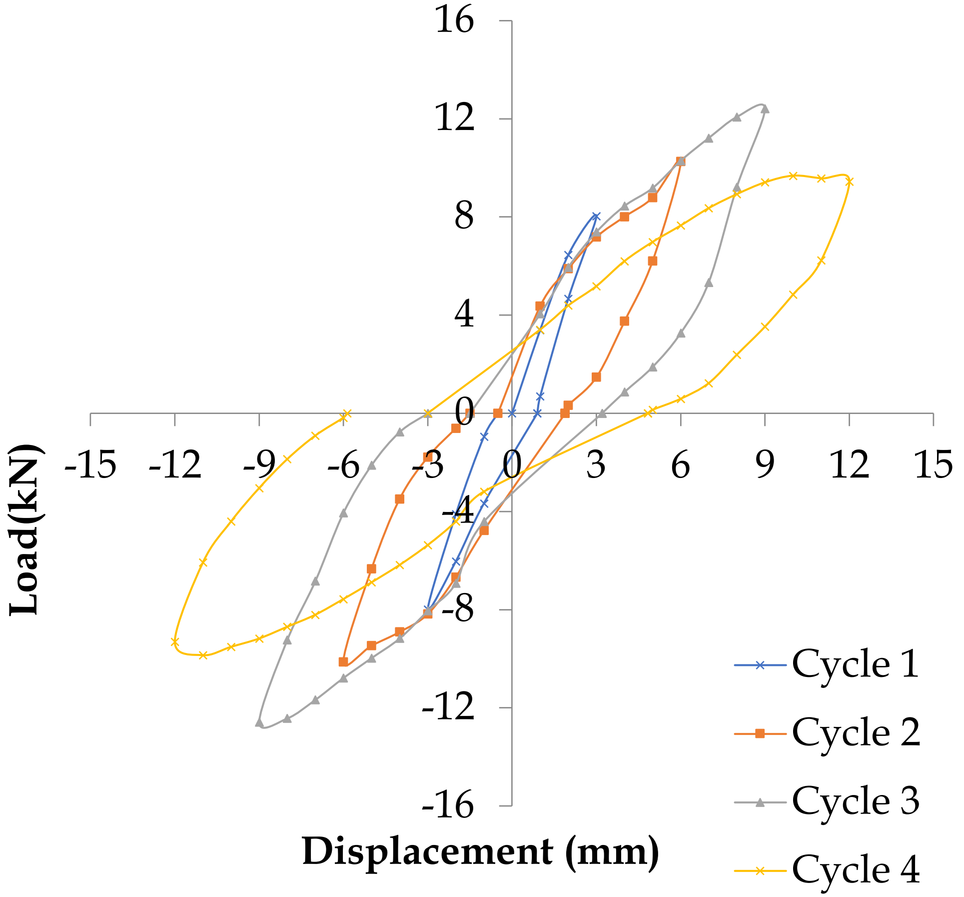
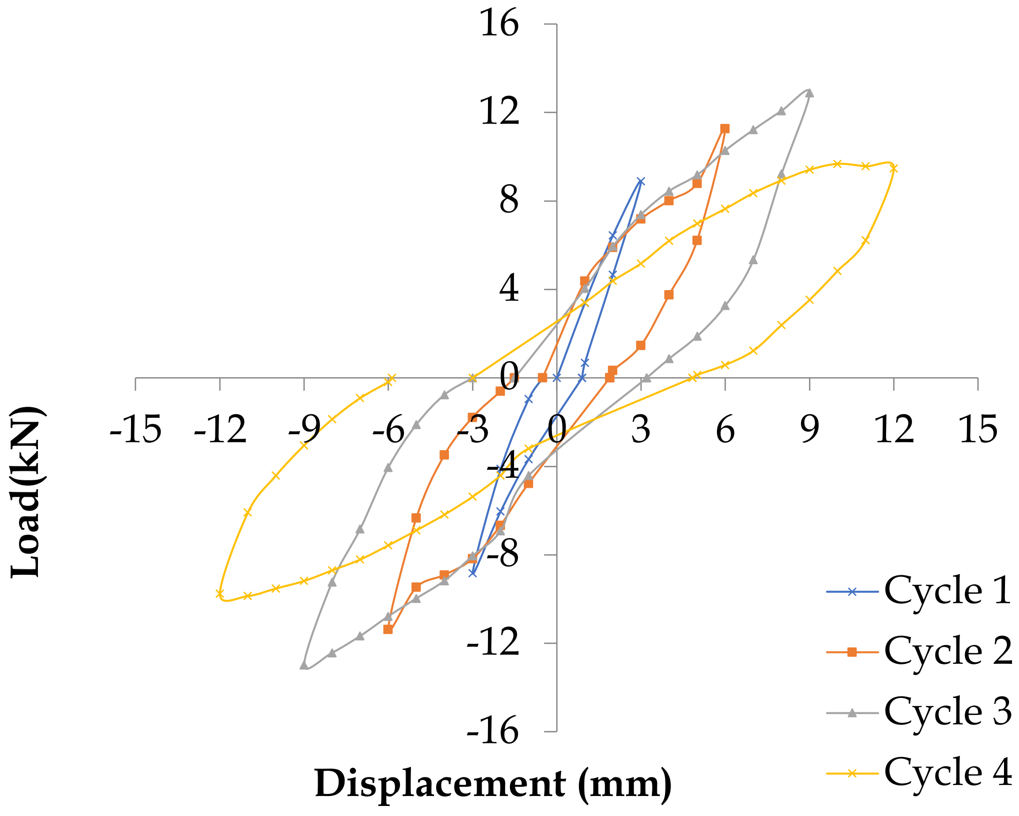
4
0
-4
-8
-12
-16
-15
-12
-9
-6
-3
0
3
6
9
12
15
Load(kN)
Displacement (mm)
Cycle 1
Cycle 2
Cycle 3
Cycle 4

(d)



(e)



(f)

Fig. 7 - Comparison of force-drift responses of specimens (a) J1, (b) J11, (c) J12, (d) J13, (e) J14, (f) J15

Stiffness

- ➢ Comparable pattern of stiffness degradation with higher displacement cycle.
- ➢ Deviations are remarkable for all the specimens

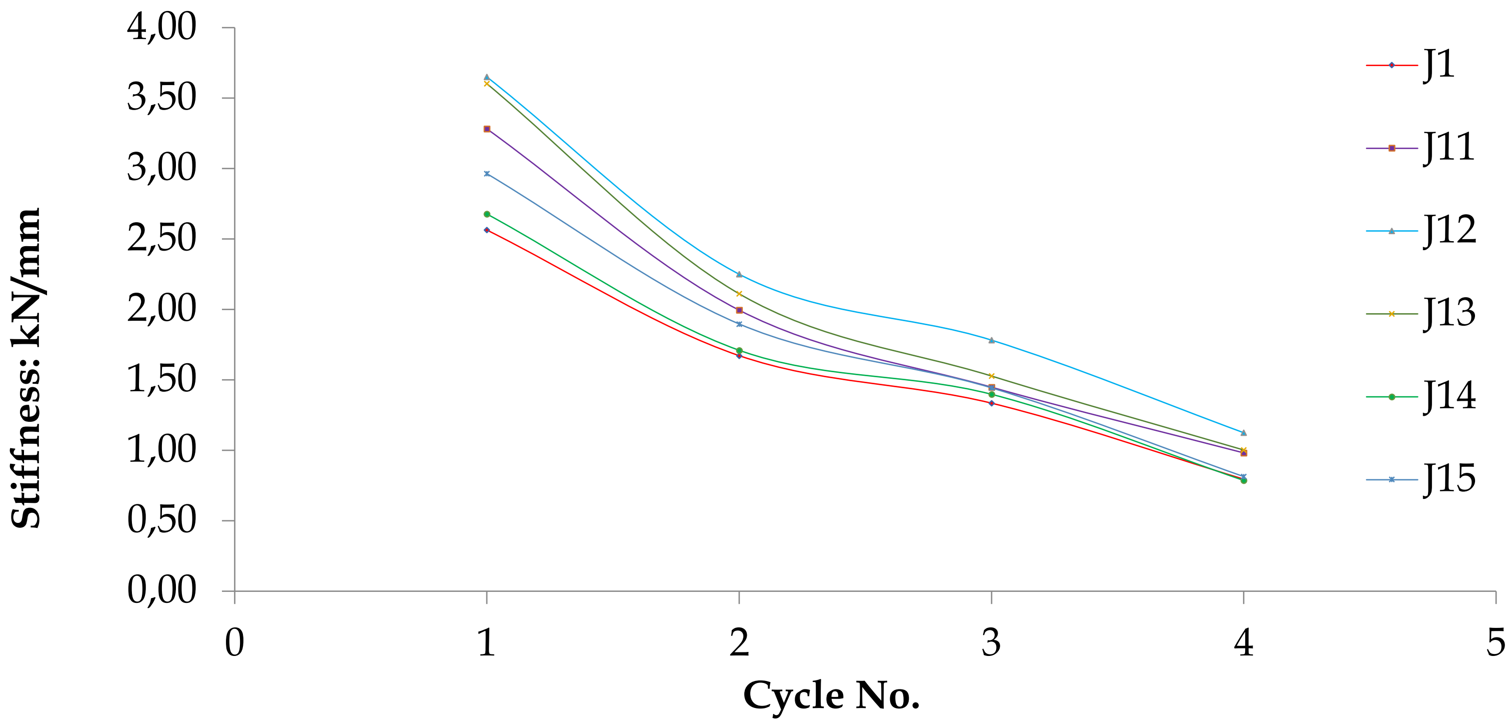


Fig. 8 - Stiffness degradation of test specimens

- Gradual degradation of stiffness
- Specimen J1 had the lowest initial as well as final stiffness
- The hoop confinement resulted higher stiffness compared to control specimen.

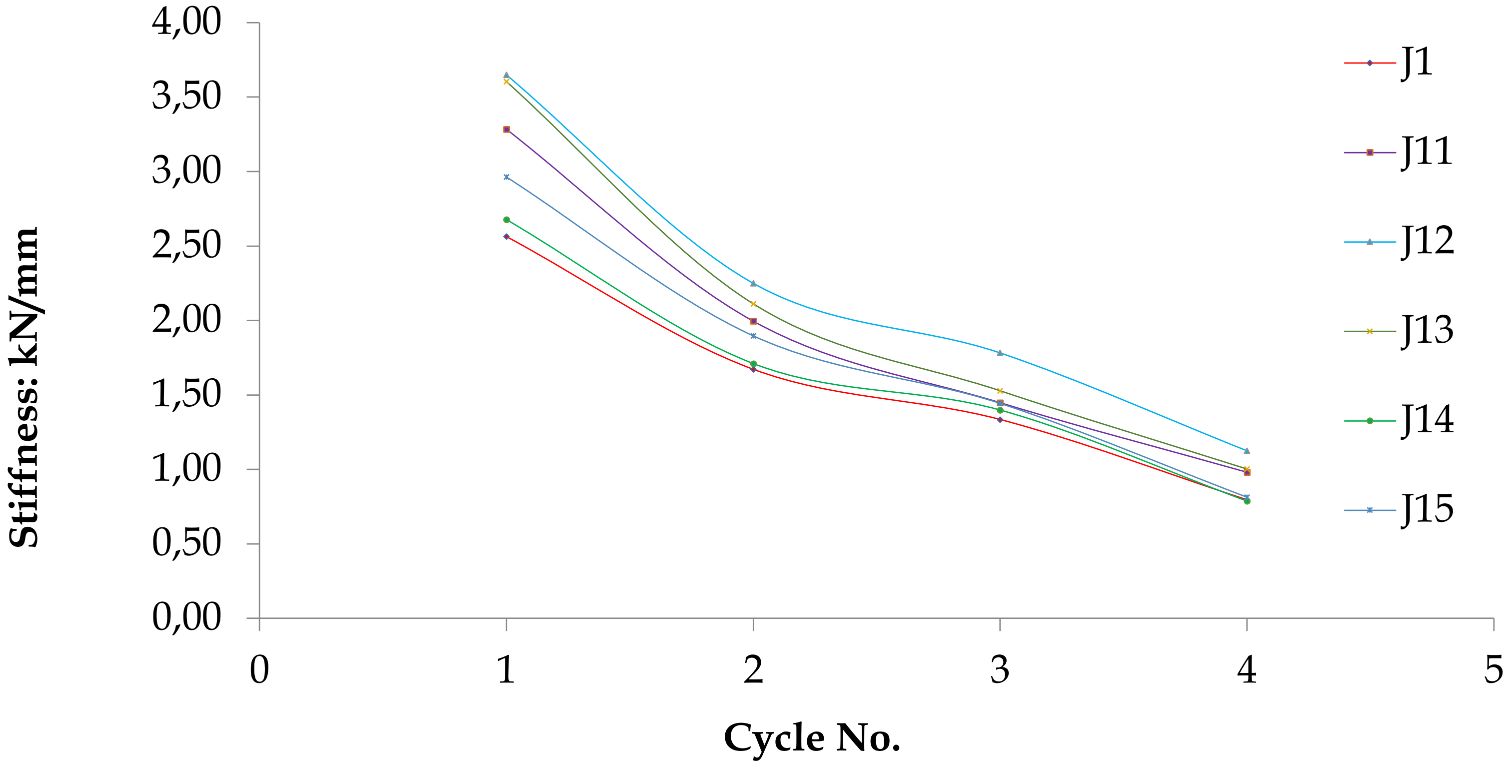


Fig. 8 - Stiffness degradation of test specimens

Shear strength

- **The joint shear strength Vjh,test is calculated using Eq. (3) and Eq. (4),**

$$V_{jh,test} = T_{max} - V_{col} \quad (3)$$

$$= P_{max} \{(L_b/jd) - (L_b + 0.5h_c)/L_c\} \quad (4)$$

- **The specimen J1 possesses least value of joint shear strength as compared to other specimens and the maximum shear strength is revealed by the specimen J12.**

- **Joint shear strength increases with increase in confinement**

- **All joint specimens perform better by an amount of 8.30%, 17.51%, 44.65%, 23.99%, 13.46% and 17.44% more than the estimated value of shear strength i.e 46.43 kN.**
- **Specimen J11, J12, J13, J14 and J15 exhibited more value of actual shear force than control specimen J1 by an amount of 8.49%, 33.54%, 14.48%, 4.75% and 8.15% respectively.**

Specimen	P_{max} (kN)	Nominal Flexural Strength, M_n (kNm)	Yielding Displacement in mm (d_y)	$V_{jh,test}$ (kN)	Displacement Ductility Factor, $\mu = (d_u/d_y)$	Stiffness (Initial) kN/mm	Stiffness (Final) kN/mm
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J_{15}	12.99	4.74	2.21	54.39	5.44	5.89	1.12

Conclusions

Research on six exterior beam-column joint specimens with differing joint hoops in quality (orientation) and quantity

The following conclusions are drawn from the tests.

- ✓ **The measure of joint hoops impacts the global response of the beam-column joint**
- ✓**Without joint hoop reinforcement experience remarkable dislodging with extensive cracks**

- ✓Confinement enhances extreme load-carrying capacity, displacement ductility, joint shear quality and stiffness of the specimen.
- ✓ Increase in the confinement of joint by using ties generally increases the ductility of the joint, shear strength and initial stiffness of joint. However, the shear strength increases with increase in the confinement using extra ties up to two, but it decreases with further increase in confinement.
- ✓ Increase in the confinement of joint by using stirrups invariably increases the shear strength; but reduction observed in ductility and initial stiffness of joint.

- ✓Confinement of joint using extra single tie or stirrup gives equal stiffness at final stage but it is more at initial stage in case of horizontal hoop.
- ✓ Increasing ties for joint confinement resulted in enhancing the shear strength, displacement ductility and initial stiffness of joint. However, increase in stirrups for confinement also increases shear strength but there is a reduction in ductility and initial stiffness
- ✓ Specimen J12 shows overall better performance amongst all the other specimens. i.e confinement of joint using two additional ties enhanced the general seismic performance of joint when compared with others.

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