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Evaluation of Advanced Reinforcement Pattern In Exterior RC Beam-Column Joint

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Abstract-Design philosophy permits moment-resisting frames subjected to seismic loading, apart from a few exceptions, to be induced into the inelastic range where the forces that develop in parts of the structure will exceed their design values. In this phase of inelastic intensity, the beam-column joints are obliged to resist high horizontal and vertical shear stresses coming from the adjacent beams and columns. This occurs during a large number of inelastic cycles, while the joints need to dissipate large energy.

Reinforced concrete beam-column joints are critical regions in reinforced concrete frames subjected to severe seismic attack. Beam moment reversals can produce high shear forces and bond breakdown into the joint resulting in cracking of the joint. The most important factors affecting the shear capacity of exterior RC beam-column joints are: the concrete compressive strength, the joint aspect ratio of the joints and number of lateral ties inside the joint. Advanced Reinforcement Pattern (ARP crossed inclined bars) is a feasible solution for increasing the shear capacity of the cyclically loaded exterior beam-column joints. The presence of inclined bars introduces an additional mechanism for shear transfer.

External beam-column joints with crossed inclined reinforcement (ARP) modelled in Ansys Workbench showed high strength, and no appreciable deterioration even after reaching the maximum capacity. Hysteresis loops are observed, with more energy dissipation capacity and it varies from 45 % to 65 % in ARP-2 pattern, which makes the joint relatively more ductile. The load resisting capacity is increased by 1.43 times the yield strength as compared to that of seismic joint (IS: 13920-1993). The pattern shifts the flexural hinges away from the joint thus failure occurs at the end of the beam near the column, absorbing more energy. It increases the joint shear capacity of external RC beam-column joint by 18%.

Key words- Critical Regions, Advanced Reinforcement Pattern, cyclically loaded, Joint shear

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1 INTRODUCTION

The functional requirement of a joint, which is the zone of intersection of beams and columns, is to enable the adjoining members to develop and sustain their ultimate capacity. The demand on this finite size element is always severe especially under seismic loading. The joints should have adequate strength and stiffness to resist the internal forces induced by the framing members.

The joint is defined as the portion of the column within the depth of the deepest beam that frames into the column. In a moment resisting frame, three types of joints can be identified viz. interior joint, exterior joint and corner joint (Fig.1.1).

Types of joints in frames

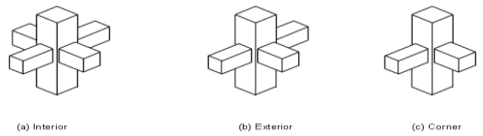
(a) Interior (b) Exterior (c) Corner

Fig 1 Types of Joints in frames

When four beams frame into the vertical faces of a column, the joint is called as an interior joint. When one beam frames into a vertical face of the column and two other beams frame from perpendicular directions into the joint, then the joint is called as an exterior joint. When a beam each frames into two adjacent vertical faces of a column, then the joint is called as a corner joint. The severity of forces and demands on the performance of these joints calls for greater understanding of their seismic behaviour. These

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forces develop complex mechanisms involving bond and shear within the joint. The objective of the paper is to review and discuss the well postulated theories for seismic behaviour of joints in reinforced concrete moment resisting frames.

1.2 *Performance Criteria*

The moment resisting frame is expected to obtain ductility and energy dissipating capacity from flexural yield mechanism at the plastic hinges. Beam-column joint behaviour is controlled by bond and shear failure mechanisms, which are weak sources for energy dissipation. The performance criteria for joints under seismic actions may be summarized as follows:

- The joint should have sufficient strength to enable the maximum capacities to be mobilized in the adjoining flexural members.
- The degradation of joints should be so limited such that the capacity of the column is not affected in carrying its design loads.
- The joint deformation should not result in increased storey drift.

1.3 *Joint Mechanisms*

In the strong column-weak beam design, beams are expected to form plastic hinges at their ends and develop flexural over strength beyond the design strength. The high internal forces developed at plastic hinges cause critical bond conditions in the longitudinal reinforcing bars passing through the joint and also impose high shear demand in the joint core.

The joint behavior exhibits a complex interaction between bond and shear. The bond performance of the bars anchored in a joint affects the shear resisting mechanism to a significant extent.

1.2 *Exterior Joint*

In exterior joints the beam longitudinal reinforcement that frames into the column terminates within the joint core. After a few cycles of inelastic loading, the bond deterioration initiated at the column face due to yield penetration and splitting cracks, progresses towards the joint core. Repeated loading will aggravate the situation and a complete loss of bond up to the beginning of the bent portion of the bar may take place.

The longitudinal reinforcement bar, if terminating straight, will get pulled out due to progressive loss of bond. The pull out failure of the longitudinal bars of the beam results in complete loss of flexural strength. This kind of failure is unacceptable at any stage. Hence, proper anchorage of the beam longitudinal reinforcement bars in the joint core is of utmost importance.

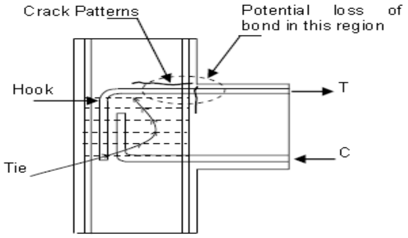


Fig 2 Hook in an Exterior Joint

The pull out failure of bars in exterior joints can be prevented by the provision of hooks or by some positive anchorage. Hooks, as shown in Fig. 1.3 are helpful in providing adequate anchorage when furnished with sufficient horizontal development length and a tail extension. Because of the likelihood of yield penetration into the joint core, the development length is to be considered effective from the critical section beyond the zone of yield penetration. Thus, the size of the member should accommodate the development length considering the possibility of yield penetration.

When the reinforcement is subjected to compression, the tail end of hooks is not generally helpful to cater to the requirements of development length in compression. However, the horizontal ties in the form of transverse reinforcement in the joint provide effective restraints against the hook when the beam bar is in compression.

Literature Review shows that a number of papers have been published on the research work done on exterior reinforced beam column joint with different innovative reinforcement patterns. Cross bars in the beam, Inclined bars in column etc., (Tsonos AG et al). Here a gap in this research has been taken up for study and a column new reinforcement pattern is being proposed. Advanced Reinforcement Pattern(ARP) (Cross inclined bars in the column) is proposed and a study is carried out.

A parametric study of this joint with cross inclined bars at the joint will be studied with different parameters like grade of concrete, tie ratio, joint aspect ratio, energy dissipation, yield ratio etc. A number of models in ANSYS 13.0 workbench and mechanical APDL are developed for different cyclic loads and boundary conditions.

Modeling of Building Frame: A G+3 storey building having panel aspect ratio 1.00 for all bays is analyzed and designed for seismic forces in Zones III as SMRF respectively using STAADPRO 2007.The plan and sectional elevation of the building.

Finite Element Modeling of External Beam-Column Joint

ANSYS 13.0, APDL and WORKBENCH a nonlinear finite element analysis package is used to develop a 3D model of

External beam-column joint.

Modeling – The beam-column joint geometry is modeled using link 8 and solid 65 elements which represent steel and concrete respectively. The mesh is generated using a preprocessor.

Mesh Refinement - Refinement is done in the limited areas of the specimen although regular meshing is performed over the entire area. Mesh refinement is done in compression zones where the concrete is expected to crush at failure.

Reinforcing Bar Anchorage - To study the effect of individual reinforcing bars on joint behavior, discrete bars are specified for all of the reinforcements within the model. The anchorage of the beam tension bar is one of the main contributors to joint behavior. The anchorage behavior is significantly affected by the material model of the element in which the bar is embedded, and the presence of any additional reinforcing bars within the elements

Boundary Condition - Modeling of the boundary conditions is the most critical aspect in achieving sensible and reliable data from a finite element model. Column connection is modeled as fixed supports to match the displacement response of the model.
Mesh Arrangement - A single mesh is developed for use with both the new reinforcement bar anchorages within the joints.

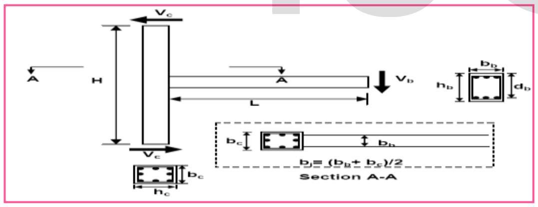


Fig 3 Joint Notations

The finite element analysis is an assembly of finite elements which are interconnected at a finite number of nodal points. The main objective is to simulate the behavior of the beam-column joint under cyclic load on the beam by constraining the columns.

Finite element modeling of exterior beam-column joints

During strong earthquake, beam-column connections are subjected to severe reversed cyclic loading. If they are not designed and detailed properly, their performance can significantly affect the overall response of a ductile moment-resisting frame building. The performance of beam-column joints subjected to seismic forces may be improved only if the major design considerations are satisfied. Though there is no explicit Indian Code for design of beam-column joints for seismic forces, where as severe importance is given in many international codes for design and detailing of joints.

Table 3 Reinforcement Details

Specimen	fck (MPa)	Reinforcement					
		Beam bars		Stir-rups	Column bars	Hoops	Fy
		Top	Bottom				
Seismic (13920)	40	2 No 12 mm ϕ	2 No 12 mm ϕ	8mm ϕ @125 c/c	4 No 12 mm ϕ	8mm ϕ @ 75 c/c	415
ARP	40	2 No 12 mm ϕ	2 No 12 mm ϕ	8mm ϕ @125 c/c	4 No 12 mm ϕ	8mm ϕ @ 75 c/c	415

Table 4: Geometry Details

Types of Joints	H (mm)	L (mm)	hc (mm)	bc (mm)	hb (mm)	bb (mm)
Seismic (13920)	1800	1640	200	300	300	200

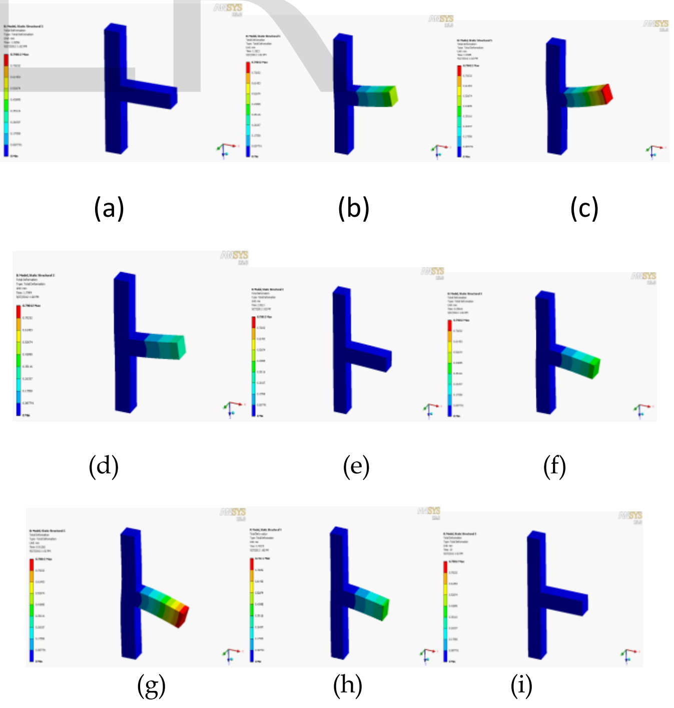

(a) (b) (c)
(d) (e) (f)
(g) (h) (i)

Fig 4 Ansys workbench models (a),(b),(c),(d),(e) depicting load cycle in reverse direction and (f), (g),(h),(i) showing the cyclic behavior in downward direction.

Study of Advanced Reinforcement Pattern

Terminology

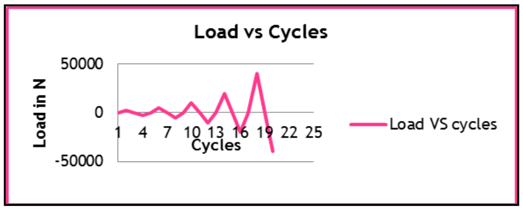
- Drift ratio: It is the ratio of total maximum displacement of beam during each cycle to the length of beam (Δ/Lb)
- Average yield ratio: It is the ratio of the average maximum ratio applied during each cycle to the yield load of the specimen (P/Py)
- Displacement ductility (μ): It is the ratio of the total displacement of beam during each cycle to the yield displacement of beam. (Δ/ Δy)
- Joint aspect ratio (hb/hc): It is the ratio of depth of the beam to the depth of the column.

Table 5 Seismic Joint as per IS 13920 Grade of Concrete – M 40

Load Cycle	Load in kN	Displace place-ment in mm	Stiffness kN/mm	Drift in mm	Avg Yield Ratio	Dis-place-ment Ductil-ity	Joint Shear in kN	Joint shear Stress in kN/mm2
1	2.5	2.163	1.156	0.132	0.111	0.078	110.400	1.840
2	5	4.513	1.108	0.275	0.222	0.163	211.800	3.530
3	10	9.470	1.056	0.577	0.444	0.342	285.600	4.760
4	15	14.881	1.008	0.907	0.667	0.537	319.800	5.330
5	20	20.921	0.956	1.276	0.889	0.755	393.000	6.550
6	25	27.503	0.909	1.677	1.111	0.993	433.800	7.230
7	30	35.047	0.856	2.137	1.333	1.265	471.600	7.860
8	35	43.263	0.809	2.638	1.556	1.562	520.800	8.680
9	40	52.910	0.756	3.226	1.778	1.910	532.800	8.880
10	35	63.559	0.708	3.876	1.556	2.295	534.600	8.910

Table 6 ARP Joint - Grade of Concrete – M 40

Load Cycle	Load in kN	Displace-ment in mm	Stiffness kN/mm	Drift in mm	Avg Yield Ratio	Displace-ment Ductility	Joint Shear in kN	Joint shear Stress in kN/mm2
1	5	1.730	1.445	0.105	0.2	0.095	139.2	2.320
2	10	3.551	1.408	0.217	0.4	0.194	193.8	3.230
3	15	7.315	1.367	0.446	0.6	0.400	247.2	4.120
4	20	11.485	1.306	0.700	0.8	0.628	280.2	4.670
5	25	15.662	1.277	0.955	1.0	0.856	313.2	5.220
6	30	20.799	1.202	1.268	1.2	1.137	346.8	5.780
7	35	25.952	1.156	1.582	1.4	1.418	400.2	6.670
8	40	31.703	1.104	1.933	1.6	1.732	459.0	7.650
9	45	37.106	1.078	2.263	1.8	2.028	513.0	8.550
10	40	44.687	1.007	2.725	1.6	2.442	533.4	8.890



Results and Discussions

Effect of Compressive Strength of Concrete on Joint Shear of Seismic Joints-SJ & ARP

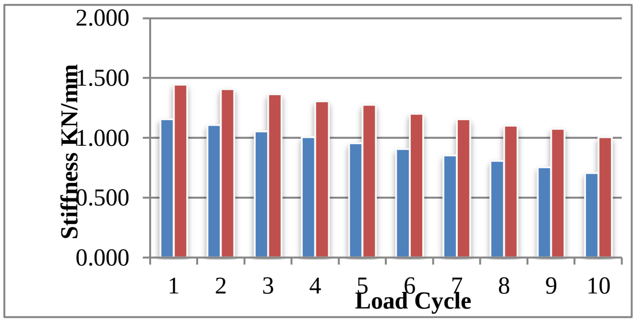
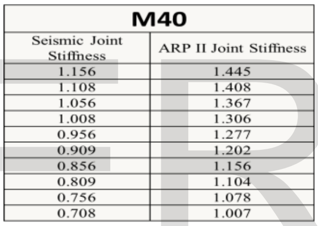


Fig 6 Stiffness vs. Load cycle for Grade of Concrete M40

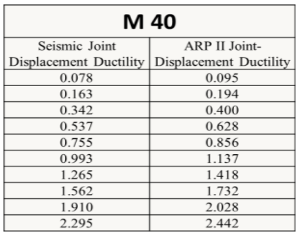
Fig 5 Load Vs Cycles

Table 7



M40	
Seismic Joint Stiffness	ARP II Joint Stiffness
1.156	1.445
1.108	1.408
1.056	1.367
1.008	1.306
0.956	1.277
0.909	1.202
0.856	1.156
0.809	1.104
0.756	1.078
0.708	1.007

Table 8



M 40	
Seismic Joint Displacement Ductility	ARP II Joint-Displacement Ductility
0.078	0.095
0.163	0.194
0.342	0.400
0.537	0.628
0.755	0.856
0.993	1.137
1.265	1.418
1.562	1.732
1.910	2.028
2.295	2.442

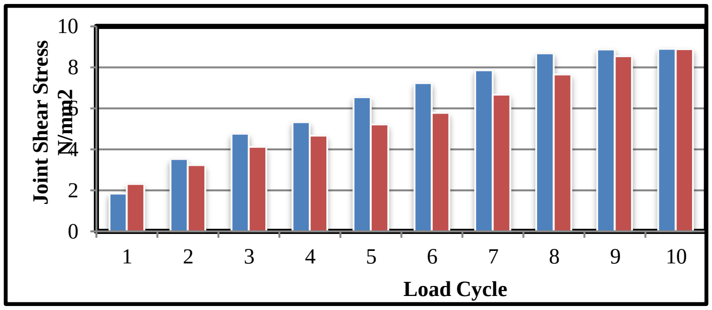


Fig 7 Joint Shear stress Vs. Load Cycle in Seismic Joints as per IS 13920 and ARP for Grade of Concrete M 40

Table 9 Joint Shear Stress

Joint Shear Stress N/mm^2 for Seismic Joint	Joint Shear Stress N/mm^2 for ARP Joint
2.320	1.840
3.230	3.530
4.120	4.760
4.670	5.330
5.220	6.550
5.780	7.230
6.670	7.860
7.650	8.680
8.550	8.880
8.890	8.910

Conclusions

1. Stiffness increases up to second cycle, and there after it decreases rapidly as the intensity of cycle increases 30 % more in ARP as compared to seismic joint (IS13920)

2. At last cycle (displacement ductility 2.442) it is found that stiffness of ARP it is 29.9 % more than IS Seismic 13920).

3. Stiffness of specimen decrease as the intensity of cycle loading increases and after third cycle (13.1 % drift of ARP) rate of strength deteoriation is very fast.

4. Joint shear stress developed in ARP is less than SJ (13920) by 2%

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