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Cyclic Behavior of Exterior Reinforced Beam-Column Joint with Cross-Inclined Column Bars

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Abstract : *The poor design practice of beam column joints is compounded by the high demand imposed by the adjoining flexural members (beams and columns) in the event of mobilizing their inelastic capacities to dissipate seismic energy. Unsafe design and detailing within the joint region jeopardizes the entire structure, even if other structural members conform to the design requirements. 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) modeled in Ansys Workbench showed high strength, and no appreciable deterioration even after reaching the maximum capacity. The load resisting capacity is increased as compared to that of seismic joint (IS: 13920-1993). A parametric study 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. The joint with M50 grade of concrete is discussed in this paper.*
Keywords: *Exterior Beam-Column Joint, Joint aspect Ratio, Joint Shear Strength*

I. INTRODUCTION

Past three decades extensive research[1] has been carried out on studying the behavior of joints under seismic conditions through experimental and analytical studies. Various international codes of practices have been undergoing periodic revisions to incorporate the research findings into practice. The paper is aimed at making designers aware of the theoretical background on the design of beam column joints highlighting important parameters affecting seismic behavior of joints .It is generally recognized that beam-column joints can be critical regions in reinforced concrete frames designed for inelastic response to severe seismic attack.

As a consequence of seismic moments in columns of opposite signs immediately above and below the joint, and similar beam moments reversal across the beam-column junction is subjected to horizontal and vertical shear forces whose magnitude is typically many times higher than in the adjacent beams and columns. Hence if not designed for the additional shear force generated in the joint, it will result in failure of joint.

The reversal in moment across the joint also necessitates the provision of beam reinforcement on both faces (Tension/Compression). In addition to high shear force generated, the high bond stresses required to sustain this force gradient across the joint may cause bond failure and corresponding degradation of moment capacity accompanied by excessive drift. 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, beam-column joints are generally classified with respect to geometrical configuration and identified as interior, exterior and corner joints. The basic requirement of design is that the joint must be stronger than the adjoining beam or column member. It is important to see that the joint size is adequate in the early design phase, otherwise the column or beam size will have to be suitably modified to satisfy the joint shear strength or anchorage requirements. The design of beam – column joint is predominantly focused on providing joint shear strength and adequate anchorage within the joint.A review of the behaviour and design of different types of beam-column joints in reinforced concrete moment resisting frames under seismic loading illustrates that design and detailing provisions for the joints in the current Indian seismic codes IS 13920:1993 and IS 1893:2002 are not adequate to ensure prevention of brittle failure due to large shear forces which develop in the joint during earthquake. Therefore, the current code needs to be upgraded to incorporate shear design provisions for beam-column joints.

Keeping the above discussion in view, the present research work has been undertaken with the objectives enlisted below.

i. To understand the different International Codal Provisions for the design of beam-column joint. (ACI-352-R, NZ-3505-1995, IS-13920-1993 and EURO- 8)
ii. To study the different loads and resulting forces acting on beam-column joint.
iii. To understand the behaviour of joint resisting mechanism: primarily concrete and truss mechanism and engineering design approach for calculation of joint shear
iv. To formulate Mathematical model for the combined concrete and truss mechanism.
v. Develop New External Reinforced Concrete joint (Type-2 as per ACI-352-R) configurations (crossed inclined bars in joint area)
vi. To study the influence of various key parameters: Compressive Strength of Concrete, Joint aspect ratio, No of Stirrups in joint Area (Stirrups Ratio), and different axial Loads, on the behaviour external beam- column joint for resisting the shear mechanism subjected to cyclic loading.
vii. To investigate the improvement / behaviour of crossed inclined bars in the external beam column joint subjected to monotonic [2] and cyclic loading.
viii. To develop regression models for predicting the shear strength of cyclically loaded exterior beam-column joint by considering all the key parameters.

1.1Beam Column Joints

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.

1.1.1 Types of joints in frames[8]

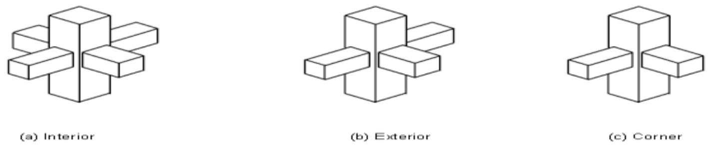


Fig 1.1 Types of Joints in frames

The joint is defined as the portion of the column within the depth of the deepest beam that frames into the column1. In a moment resisting frame, three types of joints can be identified viz.interior joint, exterior joint and corner joint (Fig.1.1). 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 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.

1.1.2 Forces acting on a beam column joint

The pattern of forces acting on a joint depends upon the configuration of the joint and the type of loads acting on it. The effects of loads on the three types of joints are discussed with reference to stresses and the associated crack patterns developed in them.

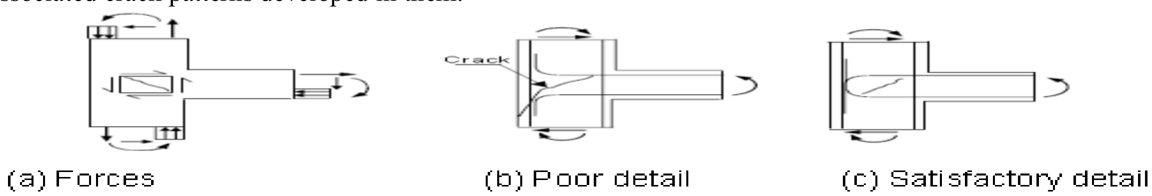


Fig 1.2 Forces acting on a Joint

The forces acting on an exterior joint can be idealized as shown in Fig.1.2. The shear force in the joint gives rise to diagonal cracks thus requiring reinforcement of the joint. The detailing patterns of longitudinal reinforcements significantly affect joint efficiency. Some of the detailing patterns for exterior joints are shown in Fig.1.2(b) and Fig.1.2(c). The bars bent away from the joint core (Fig.1.2(b)) result in efficiencies of 25-40 % while those passing through and anchored in the joint core show 85- 100% efficiency. However, the stirrups have to be provided to confine the concrete core within the joint.

1.2Joint 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 8. The bond performance of the bars anchored in a joint affects the shear resisting mechanism to a significant extent.

1.2.1 Exterior Joint[6]

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.

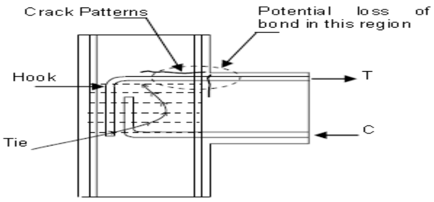


Fig 1.3 Hook in an Exterior Joint

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.

II. PROBLEM STATEMENT

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)[7]. 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 (CCIR)) [5]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.

2.1 Solution

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.

2.2 General data

Grade of concrete	: M20, M25, M40
Grade of steel considered	: Fe 250, Fe 415
Live load on roof	: 1.75 KN/m2 (Nil for earthquake)
Live load on floors	: 3.5 KN/m2 (50 % for earthquake)
Roof finish	: 1.0 KN/m2
Floor finish	: 1.0 KN/m2
Brick wall in longitudinal direction(BL)	: 250 mm thick
Brick wall in transverse direction(BT)	: 150 mm thick
Density of concrete	: 25 KN/m3
Density of brick wall including plaster	: 20 KN/m3

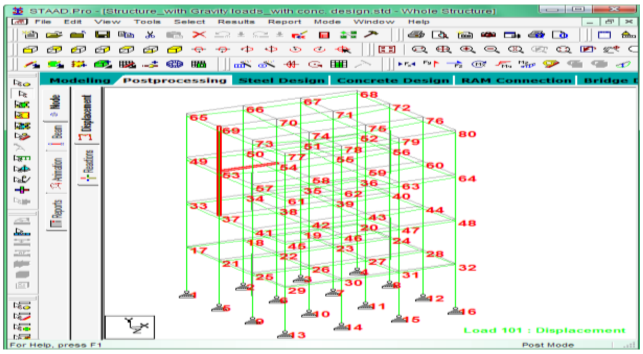


Fig 2.4 Exterior Beam Column Joint Depicted

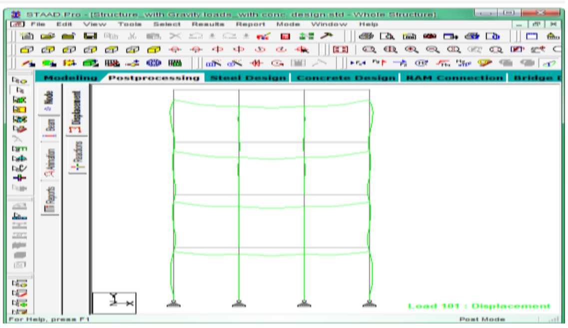


Fig 2.5 Exterior Beam Column Joint Displacements

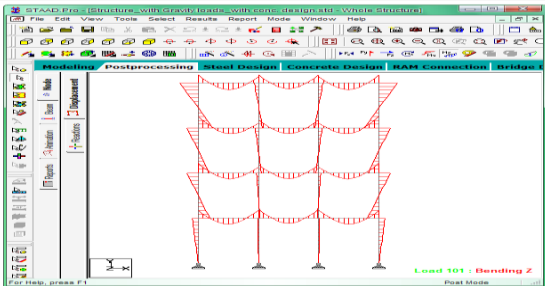


Fig 2.6 Exterior Beam Column Joint Bending Moments

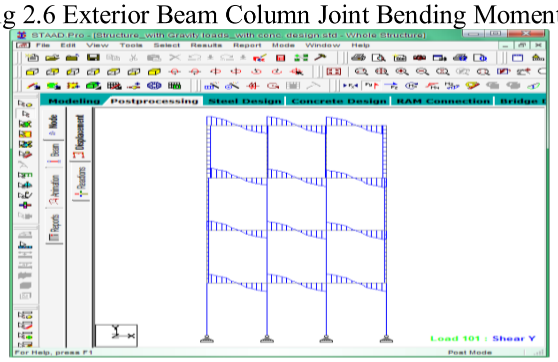


Fig.2.7 Exterior Beam Column Joint Shear Forces

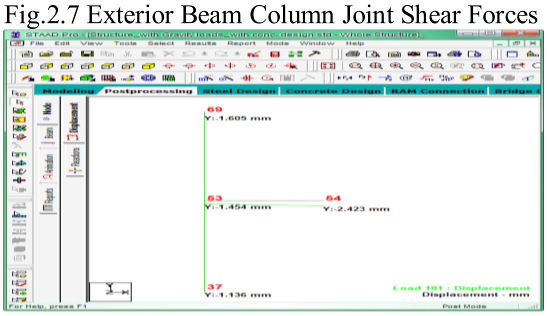


Fig 2.8 Load Displacement for the joint in Staadpro

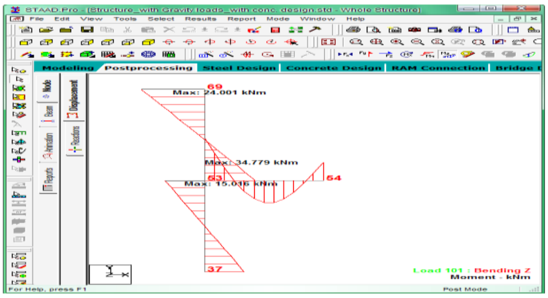


Fig 2.9 Moments at the joint in Staadpro

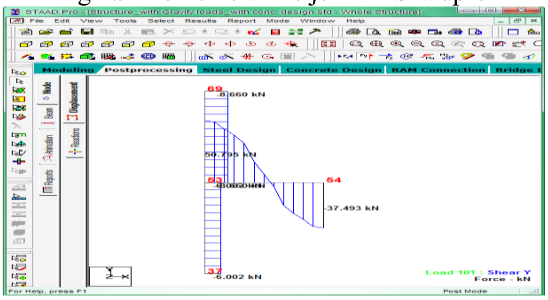


Fig 2.10 Shear forces at the joint in Staadpro

2.3 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.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.

In the present study, discrete modeling approach is used to model the behaviour of Steel reinforced beam-column joints using ANSYS software[3]. In this approach, concrete column and beam elements are modeled by Solid65 elements while the reinforcement (steel) is modeled by Link8 elements. The nonlinearity is derived from the nonlinear relationships in material models and the effect of geometric nonlinearity is not considered. The parameters to be considered for Solid65 element are material number, volume ratio and orientation angles (in X and Y direction). Since there is no rebar data (smeared reinforcement), the real constants (volume ratio and orientation angle) are set to zero.

The parameters to be considered for Link8 element are cross sectional area and initial strain. The values entered for Link8 element are given in the Table 1. The material properties defined in the model are given in Table 1. Material model number 1 and 2 refer to the Link8 element and 3 refers to Solid65 element respectively. EX is the modulus of elasticity of the material and PRXY is the Poisson's ratio.

Table 1 : Material Properties

Material Model No	Element Type	Material Properties
1	Link Spar 8 Steel	Linear Isotropic
Ex		2.1×10^{11} N/m^2
Prxy		0.3
Bilinear Kinematic		
Yield Stress		498×10^6 N/m^2
Tangent Modulus		847×10^6 N/m^2
2	Solid-Concrete 65	Linear Isotropic
Ex-M20		28794×10^6 N/m^2
Ex-M25		32527×10^6 N/m^2
Ex-M30		34517×10^6 N/m^2
Ex-M40		36577×10^6 N/m^2
Prxy		0.15
Concrete		
Shear Transfer Coefficients For An Open Crack		0.2
Shear Transfer Coefficients For An Closed Crack		0.9
Uniaxial Tensile Cracking Stress		3.71×10^6 N/m^2
Uniaxial Crushing Stress		35.376×10^6 N/m^2

2.4 Column Cross Inclined Reinforcement

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 2 Reinforcement Details

Specimen	fck (MPa)	Reinforcement					
		Beam bars		Stirrups	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
CCIR	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

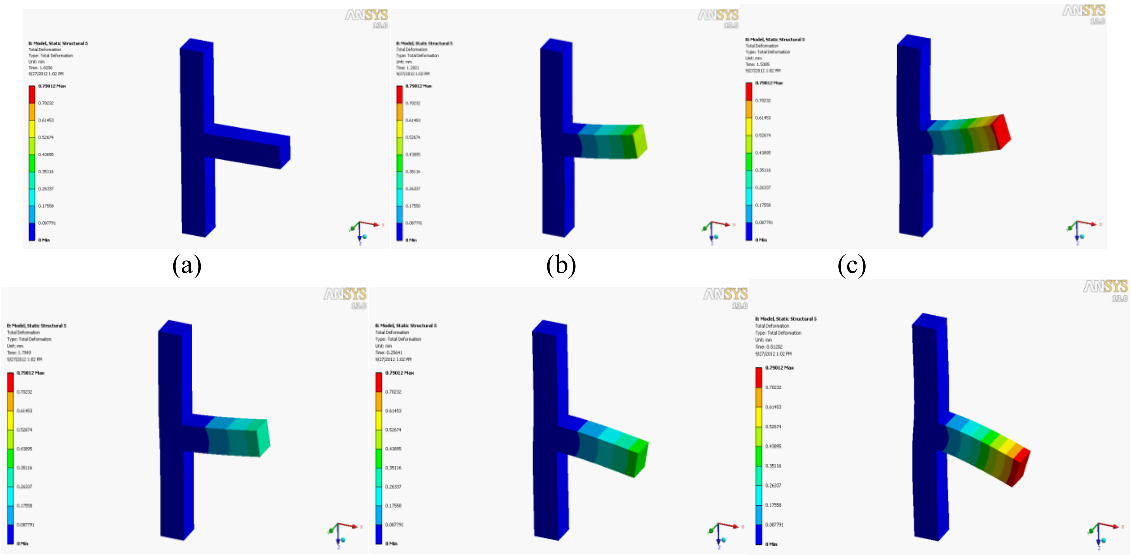
Table 3: Geometry Details

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

2.5Results and Discussion

To understand the complex mechanism and safe behavior of joint, a non conventional way of reinforcement such as the use of the crossed inclined bars (CCIR) are used in the joint area. In this study, to improve the joint behavior and joint capacity following tasks are taken into consideration[4].

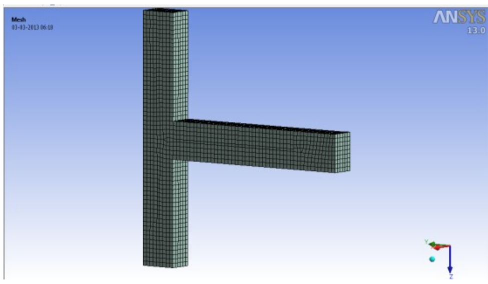
a) The influence of the Column Cross Inclined Bars on the shear strength of the cyclically loaded exterior RC beam column joint.
b) The influence of the High Strength Concrete on the shear strength of the cyclically loaded exterior RC beam column joint.
c) To examine the effectiveness of exterior beam-column joints designed as per IS 1893: (part 1) 2002 and detailed as per IS 13920: 1993.



(a) (b) (c)

(d) (e) (f)

Fig 4.2. Ansys workbench models (a),(b),(c),(d),(e) depicting load cycle in reverse direction and (f) showing the cyclic behavior in downward direction.



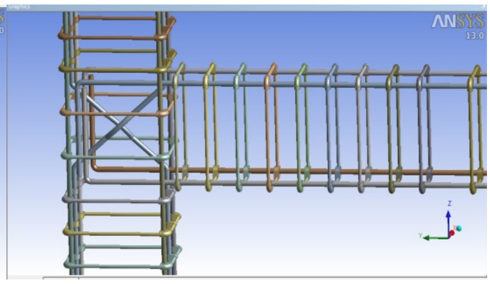
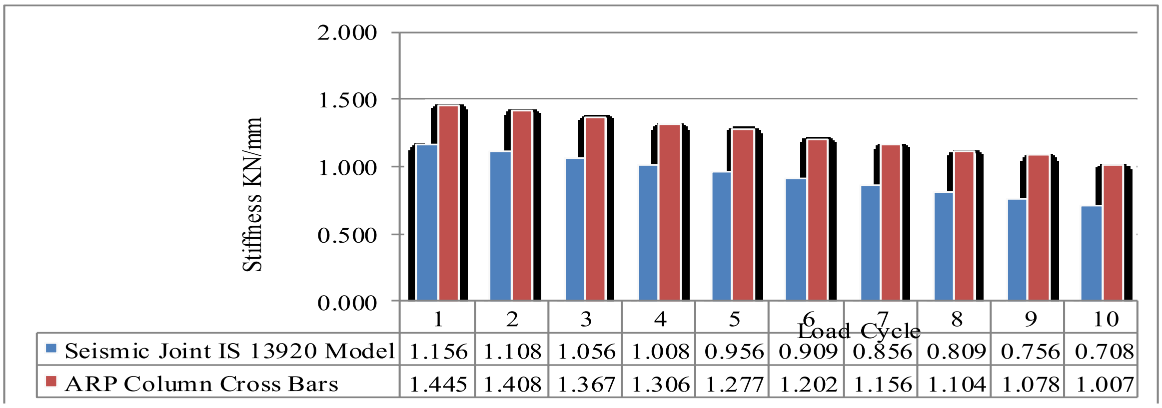


Table 4ARP I Seismic Joint as per IS 13920 Grade of Concrete – M 30

Load Cycle	Load in kN	Displacement in mm	Stiffness kN/mm	Drift in mm	Avg Yield Ratio	Displacement Ductility	Joint Shear in kN	Joint shear Stress in kN/mm²
1	2.500	2.163	1.156	0.132	0.111	0.078	110.400	1.840
2	5.000	4.513	1.108	0.275	0.222	0.163	211.800	3.530
3	10.000	9.470	1.056	0.577	0.444	0.342	285.600	4.760
4	15.000	14.881	1.008	0.907	0.667	0.537	319.800	5.330
5	20.000	20.921	0.956	1.276	0.889	0.755	393.000	6.550
6	25.000	27.503	0.909	1.677	1.111	0.993	433.800	7.230
7	30.000	35.047	0.856	2.137	1.333	1.265	471.600	7.860
8	35.000	43.263	0.809	2.638	1.556	1.562	520.800	8.640
9	40.000	52.910	0.756	3.226	1.778	1.910	532.800	8.660
10	35.000	63.559	0.708	3.876	1.556	2.295	534.600	8.690

Table 5 ARP II Two Column Crossed - Grade of Concrete – M 30

Load Cycle	Load in kN	Displacement in mm	Stiffness kN/mm	Drift in mm	Avg Yield Ratio	Displacement Ductility	Joint Shear in kN	Joint shear Stress in kN/mm²
1	5.000	1.730	1.445	0.105	0.200	0.095	139.200	2.320
2	10.000	3.551	1.408	0.217	0.400	0.194	193.800	3.230
3	15.000	7.315	1.367	0.446	0.600	0.400	247.200	4.120
4	20.000	11.485	1.306	0.700	0.800	0.628	280.200	4.670
5	25.000	15.662	1.277	0.955	1.000	0.856	313.200	5.220
6	30.000	20.799	1.202	1.268	1.200	1.137	346.800	5.780
7	35.000	25.952	1.156	1.582	1.400	1.418	400.200	6.670
8	40.000	31.703	1.104	1.933	1.600	1.732	459.000	7.650
9	45.000	37.106	1.078	2.263	1.800	2.028	513.000	8.550
10	40.000	44.687	1.007	2.725	1.600	2.442	533.400	8.590



Stiffness vs. Load cycle for Grade of Concrete M 30

Table 6 Stiffness and Displacement Ductility

M30	
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

M 30	
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

- ➢ Stiffness increases up to second cycle, and there after it decreases rapidly as the intensity of cycle increases 21.3 % more in ARP 2 as compared to seismic joint (IS13920)
- ➢ At last cycle (displacement ductility 2.442) it is found that stiffness of ARP 2 it is 29.69 % more than IS Seismic (13920).
- ➢ Stiffness of specimen decrease as the intensity of cycle loading increases and after third cycle (13.1 % drift of ARP 2) rate of strength deteoriation is very fast.

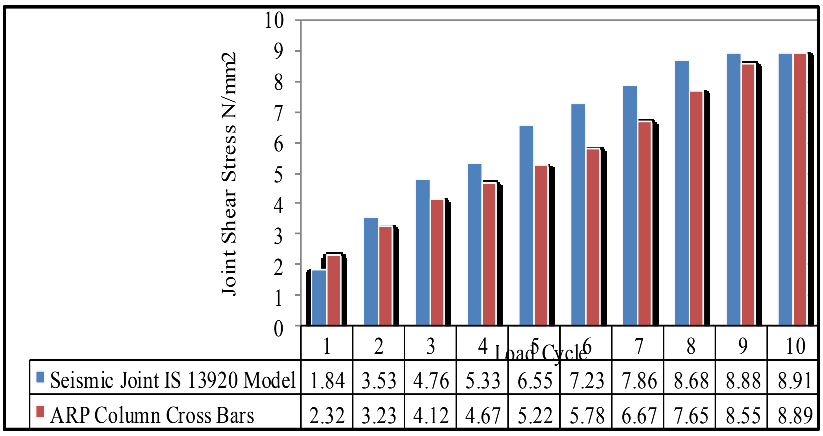


Fig Joint Shear stress Vs. Load Cycle Joints as per IS 13920 and ARP II for Grade of Concrete M 30

Table 7 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

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

III. Conclusions

The most important factors affecting the shear capacity of exterior RC beam-column joints are: the concrete compressive strength, No. of lateral ties in the joint,the joint aspect ratio of the joints, Column axial load, Bar diameter of column longitudinal bars

- ➢ ARP-2 (2-column crossed inclined bars), M30 gives a feasible solution for increasing the shear capacity of the cyclically loaded beam-column joints.

- The presence of inclined bars introduces an additional mechanism of shear transfer. The greater the joint aspect ratio (h_b/h_c) less will be the contribution of the crossed inclined bars to the joint shear capacity.
- External beam-column joints with crossed inclined reinforcement (ARP-2) showed high strength, and no appreciable deterioration even after reaching the maximum capacity.

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