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Research Paper

EFFECT OF KEY PARAMETERS OF REINFORCED CONCRETE BEAM-COLUMN JOINTS

[1]Prof. D. B. Sathavara, [2] Prof. F.Y. Parikh

Address for Correspondence

[1,2]Assistant Professor, Applied Mechanics Department /GEC, Modasa India

ABSTRACT:
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 shear failure is always brittle in nature which is not an acceptable structural performance especially in seismic conditions. A number of design code recommendations and analytical expressions are available for computing the beam-column joints shear strength under seismic loading. The paper present significant factors influencing the design of beam column joints are identified and the effect of variation of design parameters is compared. Understanding the joint behavior is essential in exercising proper judgment of design of joints. The paper discussed three cases by varying the column B/D ratios and concrete compressive strength and the amount of joint shear in three different locations viz. interior, exterior, and corner are compared.
KEY WORDS: Beam column joint, shear strength, Bond strength.

INTRODUCTION

Earthquakes are one of the most feared natural phenomena that are relatively unexpected and whose impact is sudden due to the almost instantaneous destruction that a major earthquake can produce. 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, the joint region is subjected to horizontal and vertical shear forces whose magnitude is typically many times higher than in the adjacent beams and columns. If not designed for, joint shear failure can take place. [1, 2]
The reversal in moment across the joint also means that the beam reinforcement is required to be in compression on one side of the joint and at tensile yield on the other side of the joint. The high bond stress required to sustain this force gradient across the joint may cause bond failure and corresponding degradation of moment capacity accompanied by excessive drift.
In the analysis of reinforced concrete moment resisting frames the joints are generally assumed as rigid. In Indian practice, the joint is usually neglected for specific design with attention being restricted to provision of sufficient anchorage for beam longitudinal reinforcement. This may be acceptable when the frame is not subjected to earthquake loads. There have been many catastrophic failures reported in the past earthquakes, in particular with Turkey and Taiwan earthquakes occurred in 1999, which have been attributed to beam-column joints. 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. [2, 3]. Since past three decades extensive research 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.

SHEAR STRENGTH

Internal forces transmitted from adjacent members to the joint as shown in fig1. Result in joint shear forces in both the horizontal and vertical directions. These shear forces lead to diagonal compression and tension stresses in the joint core. The latter will usually result in diagonal cracking of the concrete core. The mechanism of shear resistance at this stage changes drastically. [6]

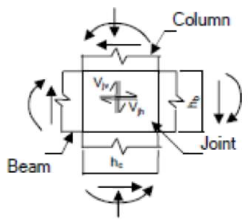

Fig. 1 shear force acting on the joint

Some of the internal forces, particularly those generated in the concrete, will combine to develop a diagonal strut. Other forces, transmitted to the joint core form beam and column by means of bond, necessitate a truss mechanism.
To prevent shear failure by diagonal tension, usually along a potential corner to corner failure plane. Both the horizontal and vertical shear reinforcement will be required. Such reinforcement will enable a diagonal compression field to be mobilized, which provides a feasible load path for both horizontal and vertical shear forces .The amount of horizontal joint shear reinforcement required, may be significantly more than would normally be provided in columns in the form of ties or hoops, particularly when axial compression on columns is small.
When the joint shear reinforcement is sufficient, yielding of the hoops will occur. Irrespective of the direction of diagonal cracking, horizontal shear reinforcement transmits tension forces only. The inelastic steel strains that may result are irreversible. Consequently, during subsequent loading, stirrup ties can make a significant contribution to shear resistance only if the tensile strains imposed are larger than those developed previously. This then leads to drastic loss of stiffness art low shear force levels, particularly immediately after a force or displacement reversal. [5]

BOND STRENGTH

At exterior column the difficulty in anchoring a beam bear of full strength can be overcome readily by providing a standard hook. At interior columns, however, this is impractical. Some codes require that beam bars at interior beam-column joints must pass continuously that bars may be anchored with equal if not greater efficiency using standard hooks within or immediately behind an interior joint.

The fact that bars passing through interior joints are being "pulled" as well "pushed" by the adjacent beams, to transmit forces corresponding to steel stresses up to the strain hardening range in tension, has not as a rule, been take into account code specifications until recently. In most practical situations bond stresses required to transmit bar forces to the concrete of the joint core consistent with plastic hinge development at both sides of the joint, would be very large and well beyond limits considered by codes for bar strength development. [7] Even at moderate ductility demands, a slip of beam bars through the joint can occur. A breakdown of bond within interior joints does not necessarily result in sudden loss of strength. [8]

BUILDING DETAIL

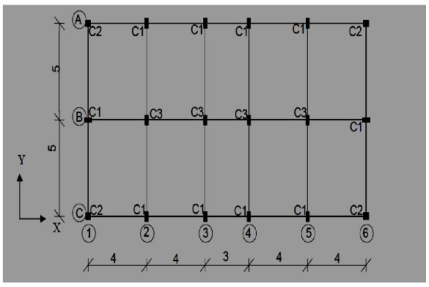

Fig 1: plan of building (all dimension in meter)

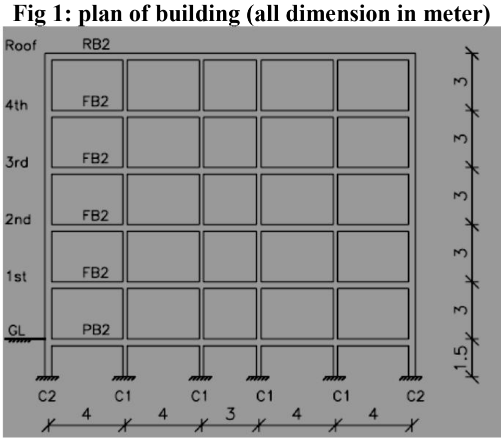

Fig 2: elevation of frame A, B and C.

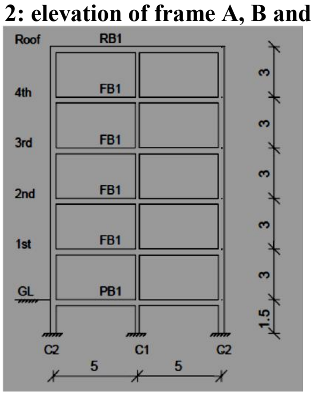

Fig 2: elevation of transverse frame 1 to 6

GENERAL DETA

Grade of concrete: M20, M25, M30

Grade of steel: Fe 415

Live load on roof = 1.5 kN/m^2 (nil for earthquake)

Live load on floors = 3 kN/m^2 (25% for earthquake)

Roof finish = 1 kN/m^2

Floor finish = 1 kN/m^2

Brick wall on peripheral beams = 230 mm thick

Brick wall on internal beams = 150 mm thick

Density of concrete = 25 kN/m^3

Density of brick wall including plaster = 20 kN/m^3

Shear reinforcement in beams is obtained for design shear force at supports and at centre. For detailing main reinforcement in beams, the available diameters of steel ranging from 12 to 20 mm has been used and a set of arrangement is provided that is closest to theoretical area of steel required. If two members are on either side of a column and are continuous in alignment, the same reinforcement is provided on both sides of the column by picking up the higher steel area. The minimum and maximum reinforcement requirements are also checked.

In addition to detailing of beams as in above, in the design of beams in SMRF it is also ensured that the positive steel at support is at least half the negative steel provided at that support or joint. The steel provided at each of the top and bottom face of the member at any section along its length is more than one fourth of the maximum negative moment steel provided at the face of either joint. All other requirements are checked as per clauses given in IS: 13920-1993.

Table 1: Schedule of member sizes (Case-1)

Note: all dimensions in mm.

Column		Beam	
C1	300*500	RB1 , FB1	300*600
C2	400*400	RB2 , FB2	300*600
C3	400*500	PB1	300*400
		PB 2	300*350
Slab thickness = 125 mm			

Table 2: Schedule of member sizes (Case-2)

Note: all dimensions in mm

Column		Beam	
C1	500*500	RB1 , FB1	300*600
C2	500*500	RB2 , FB2	300*600
C3	500*600	PB1	300*400
		PB 2	300*350
Slab thickness = 125 mm			

Table 3: Schedule of member sizes (Case-3)

Note: all dimensions in mm

Column		Beam	
C1	500*500	RB1 , FB1	300*600
C2	400*500	RB2 , FB2	300*600
C3	600*600	PB1	300*400
		PB 2	300*350
Slab thickness = 125 mm			

Table 4: Joint shear details at Roof level for case-1 (Zone-V)

f_y	415 N/mm^2	Beam x dir	300 mm
zone	V	Beam y dir	300 mm

Case 1

joint	f_{ck}	location	direction	Joint shear strength kN
interior				
1	20	Roof	Y dir	1073
			X dir	894
2	25	Roof	Y dir	1200
			X dir	1000
3	30	Roof	Y dir	1314
			X dir	1095
exterior				
1	20	Roof	Y dir	671
			X dir	604
2	25	Roof	Y dir	750
			X dir	675
3	30	Roof	Y dir	822
			X dir	739
corner				
1	20	Roof	Y dir	715
			X dir	715
2	25	Roof	Y dir	800
			X dir	800
3	30	Roof	Y dir	876
			X dir	876

columns	B(mm)	D(mm)
interior	400	500
exterior	300	500
corner	400	400

Case 1

joint	Joint shear calculated kN	result	Strong column weak beam condition	Confining links
interior				
1	493	safe	satisfied	10#100mm c/c
	441	safe	satisfied	10#100mm c/c
2	465	safe	satisfied	10#80mm c/c
	424	safe	satisfied	10#80mm c/c
3	503	safe	satisfied	10#75mm c/c
	462	safe	satisfied	10#75mm c/c
exterior				
1	284	safe	satisfied	10#80mm c/c
	469	safe	not satisfied	10#80mm c/c
2	281	safe	satisfied	10#75mm c/c
	468	safe	not satisfied	10#75mm c/c
3	222	safe	satisfied	10#75mm c/c
	468	safe	not satisfied	10#75mm c/c
corner				
1	198	safe	satisfied	10#100mm c/c
	186	safe	satisfied	10#100mm c/c
2	202	safe	satisfied	10#85mm c/c
	185	safe	satisfied	10#85mm c/c
3	234	safe	satisfied	10#75mm c/c
	230	safe	satisfied	10#75mm c/c

Table 5: Joint shear details at Second floor level for case-1 (Zone-V)

f_y	415 N/mm^2	Beam x dir	300 mm
zone	V	Beam y dir	300 mm

Case 1

joint	f_{ck}	location	direction	Joint shear strength kN
		interior		
1	**20**	**floor**	**Y dir**	**2078**
			X dir	**1732**
2	**25**	**floor**	**Y dir**	**2078**
			X dir	**1732**
3	**30**	**floor**	**Y dir**	**2008**
			X dir	**1673**
		exterior		
1	**20**	**floor**	**Y dir**	**1209**
			X dir	**1088**
2	**25**	**floor**	**Y dir**	**1209**
			X dir	**1088**
3	**30**	**floor**	**Y dir**	**1209**
			X dir	**1073**
		corner		
1	**20**	**floor**	**Y dir**	**1012**
			X dir	**1012**
2	**25**	**floor**	**Y dir**	**1012**
			X dir	**1012**
3	**30**	**floor**	**Y dir**	**1073**
			X dir	**1073**

columns	B(mm)	D(mm)
interior	400	500
exterior	300	500
corner	400	400

Table 6: Joint shear details at Second floor level for case-2 (Zone-V)

Case 1

joint	Joint shear calculated kN	result	Strong column weak beam condition	Confining links
interior				
1	1865	Not safe	satisfied	10#75mm c/c
	1710	Not safe	satisfied	10#75mm c/c
2	1861	Not safe	satisfied	10#75mm c/c
	1688	Not safe	satisfied	10#75mm c/c
3	1891	Not safe	satisfied	10#75mm c/c
	1665	Not safe	satisfied	10#75mm c/c
exterior				
1	1197	Not safe	satisfied	10#75mm c/c
	1059	Not safe	not satisfied	10#75mm c/c
2	1199	Not safe	satisfied	10#75mm c/c
	1012	Not safe	not satisfied	10#75mm c/c
3	1201	Not safe	satisfied	10#75mm c/c
	1010	Not safe	not satisfied	10#75mm c/c
corner				
1	982	Not safe	satisfied	10#100mm c/c
	968	Not safe	Not satisfied	10#100mm c/c
2	983	Not safe	satisfied	10#85mm c/c
	971	Not safe	Not satisfied	10#85mm c/c
3	930	Not safe	satisfied	10#75mm c/c
	1024	Not safe	Not satisfied	10#75mm c/c

f_y	415 N/mm^2	Beam x dir	300 mm
zone	V	Beam y dir	300 mm

Case2

joint	f_{ck}	location	direction	Joint shear strength kN
		interior		
1	20	floor	Y dir	1775
			X dir	1627
2	25	floor	Y dir	1775
			X dir	1627
3	30	floor	Y dir	1775
			X dir	1627
		exterior		
1	20	floor	Y dir	1369
			X dir	1369
2	25	floor	Y dir	1250
			X dir	1250
3	30	floor	Y dir	1369
			X dir	1369
		corner		
1	20	floor	Y dir	1118
			X dir	1118
2	25	floor	Y dir	1250
			X dir	1250
3	30	floor	Y dir	1369
			X dir	1369

columns	B(mm)	D(mm)
interior	500	600
exterior	500	600
corner	500	500

joint	Joint shear calculated kN	result	Strong column weak beam condition	Confining links
interior				
1	1865	safe	satisfied	10#75mm c/c
	1710	safe	satisfied	10#75mm c/c
2	1861	safe	satisfied	10#75mm c/c
	1688	safe	satisfied	10#75mm c/c
3	1891	safe	satisfied	10#75mm c/c
	1665	safe	satisfied	10#75mm c/c
exterior				
1	1197	safe	satisfied	10#100mm c/c
	1059	safe	satisfied	10#100mm c/c
2	1199	safe	satisfied	10#90mm c/c
	1012	safe	satisfied	10#90mm c/c
3	1201	safe	satisfied	10#75mm c/c
	1010	safe	satisfied	10#75mm c/c
corner				
1	982	safe	satisfied	10#100mm c/c
	968	safe	satisfied	10#100mm c/c
2	983	safe	satisfied	10#90mm c/c
	971	safe	satisfied	10#90mm c/c
3	930	safe	satisfied	10#75mm c/c
	1024	safe	satisfied	10#75mm c/c

Table 7: Joint shear details at Second floor level for case-3(Zone-V)

f_y	415 N/mm^2	Beam x dir	300 mm
zone	V	Beam y dir	300 mm

Case3

joint	f_{ck}	location	direction	Joint shear strength kN
		interior		
1	20	floor	Y dir	1972
			X dir	1972
2	25	floor	Y dir	1800
			X dir	1800
3	30	floor	Y dir	1775
			X dir	1775
		exterior		
1	20	floor	Y dir	1095
			X dir	1095
2	25	floor	Y dir	1095
			X dir	1095
3	30	floor	Y dir	1095
			X dir	1095
		corner		
1	20	floor	Y dir	1118
			X dir	1118
2	25	floor	Y dir	1250
			X dir	1250
3	30	floor	Y dir	1369
			X dir	1369

columns	B(mm)	D(mm)
interior	600	600
exterior	400	500
corner	500	500

joint	Joint shear calculated kN	result	Strong column weak beam condition	Confining links
interior				
1	1865	safe	satisfied	10#80mm c/c
	1608	safe	satisfied	10#80mm c/c
2	1785	safe	satisfied	10#95mm c/c
	1538	safe	satisfied	10#95mm c/c
3	1760	safe	satisfied	10#80mm c/c
	1516	safe	satisfied	10#80mm c/c
exterior				
1	1041	safe	satisfied	10#100mm c/c
	1052	safe	satisfied	10#100mm c/c
2	1018	safe	satisfied	10#80mm c/c
	969	safe	satisfied	10#80mm c/c
3	1061	safe	satisfied	10#75mm c/c
	983	safe	satisfied	10#75mm c/c
corner				
1	992	safe	satisfied	10#100mm c/c
	881	safe	satisfied	10#100mm c/c
2	1009	safe	satisfied	10#90mm c/c
	894	safe	satisfied	10#90mm c/c
3	992	safe	satisfied	10#75mm c/c
	824	safe	satisfied	10#75mm c/c

CONCLUSIONS

- For non-seismic loads column shear alone is acting as the joint shear, whereas in seismic conditions contribution of beam forces developed by seismic loads is also considered in the joint shear calculation.
- The joint shear strength can be increased with increase in concrete compressive strength, and column B/D ratio. However, there is no increase in joint shear strength observed, while changing the beam B/D ratio.
- In seismic zones V, minimum grade of concrete is M30. M25, which can be used for beams and columns with rich mix concrete in joint regions.
- In all cases roof joint are safe against joint shear but the column reinforcement should be provided in the roof column to satisfy the strong column weak beam condition.
- In an exterior joint and a corner joint the depth of the column should be provided to satisfy the anchorage requirements of the beam longitudinal bar.
- Joint shear in floor joints is 3 to 5 times more than the roof joints.

REFERENCES

1. Paulay, T. and Priestley, M. J. N. (1992), Seismic Design of Reinforced Concrete and Masonry Buildings, John Wiley and Sons.
2. Subramanian, N. and Prakash Rao, D. S., 2003, "Seismic Design of Joints in RC Structures," The Indian Concrete Journal, 77(2), pp 883-892.
3. Ichinose, T., 1991, "Interaction between bond at beam bars and shear reinforcement in RC interior joints", Design of Beam-Column Joints for Seismic Resistance, SP-123, American Concrete Institute, Farmington Hills, Mich., pp 379-400.
4. French, C.W. and Moehle, J. P., 1991, "Effect of floor slab on behavior of slab-beam-column connections," Design of Beam-Column Joints for Seismic Resistance, SP-123, American Concrete Institute, Farmington Hills, Mich., pp 225-258.
5. Leon, R.T., 1990, "Shear Strength and Hysteretic Behavior of Beam-Column Joints," ACI Structural Journal, 87(1), pp 3-11.
6. Uma, S. R., "Seismic Behaviour of Beam Column Joints in Moment Resisting Reinforced Concrete Frame Structures," submitted to Indian Concrete Journal, October 2004.
7. Wakabayashi, M., Minami, K., Nishimura, Y. and Imanaka, N., 1983, "Anchorage of bent bar in reinforced concrete exterior joints," Transactions of the Japan Concrete Institute, 5, pp 317-324.
8. Paulay, T., Park, R. and Priestley, M. J. N. (1978), "Reinforced Concrete Beam-Column Joints under Seismic Actions," Journal of ACI, 75(11), 585-593
9. Park, R. and Hopkins, D. C., 1989, "United States/New Zealand/Japan/China Collaborative Research Project on the Seismic Design of Reinforced Concrete Beam-Column-Slab Joints," Bulletin of the New Zealand National Society for Earthquake Engineering, 22(2), pp 122-126.
10. ACI 352R-02, 2002, "Recommendations for design of beam-column-joints in monolithic reinforced concrete structures," American Concrete Institute, ACIASCE, Committee 352, Detroit
11. ENV 1998-1:2003, "General Rules-Specific Rules for Various Materials and Elements," Eurocode 8:
12. IS: 456-2000, "Indian Standard code of practice for plain and reinforced concrete," Bureau of Indian Standards, New Delhi.
13. IS: 13920-1993, "Indian Standard code of practice for ductile detailing of concrete structures subjected
14. IS: 13920-Draft, "Indian Standard code of practice for ductile detailing of concrete structures subjected to seismic forces, Bureau of Indian Standards, New Delhi, 1993.
15. SP: 34 (S&T)- 1987, "Handbook on concrete reinforcement detailing,", Bureau of Indian Standards, New Delhi.