Feasibility of Reinforced Concrete Monolothic Beam Column Joints in Different Seismic Zones

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Abstract

The present paper emphasizes the design of R.C. monolithic beam-column joints for strength criteria and to find out feasibility of the structure designed for Zone 2 and Zone 5 as per IS1893(Part1):2002, incorporating ductility provisions of IS13920:1993. For this research a moment resisting RCC frame is modeled and analyzed for above mentioned seismic zones. After analyzing, resultant frames are then designed as per IS 456. An Internal Beam Column Joint form first, third, and top floor is selected and designed manually for nominal shear strength so as to compare it with shear developed in the same joints provided by the software. The software of choice for this paper is ETABS.

Keywords : **Beam column joints, ETABS, Frame structure, Joint shear, Moment resisting frame, R.C.C. design**

I. INTRODUCTION

Monolithic beam-column joints in frames are open to extensive forces under severe ground motions and the way joints behave significantly influences the response of the structure [10]. Hence, it proves to be a critical zone in Moment Resisting Frame. The general assumption of joints being rigid does not comprise the effects of high shear forces developed within. The shear failure due to which it is always brittle is not acceptable, especially in seismic conditions. Joints are also to ensure the continuity of a structure by transferring forces that are present at the ends of the members into and through the joint. In short, monolithic beam-column joints are defined as that portion of the column within the depth of the beam(s) that frame into the column.

The performance criteria implicit in IS: 1893 [8] [9] requires that a structure be able to :

- Resist minor intensity earthquake without damage;
- Resist moderate intensity earthquake with minor structural and non-structural damage; and
- Resist major earthquakes without collapse.

Based on loading conditions and an anticipated deformation, structural joints can be classified as:

- **Type 1 :** It is a joint in a continuous moment-resisting structure designed for strength avoiding special ductility requirements [6].
- **Type 2** : It is a joint that connects members, which are required to dissipate energy through reversals of deformation into the inelastic range.

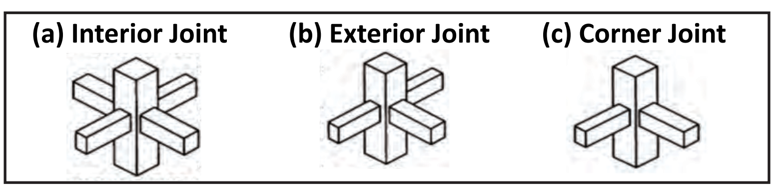

Fig. 1. Types of Joints

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Functional Requirements of Beam-Column Joints [3]:

- A joint should exhibit a service load performance equal in quality to that of the members it joins.
- A joint should possess a strength that corresponds at least with the most adverse load combinations that the adjoining members could possibly sustain, several times if necessary.
- The strength of the joint should not normally govern the strength of the structure, and its behavior should not impede the development of the full strength of the adjoining member.
- Ease of construction and access for depositing and compacting concrete are other prominent issues of joint designs.

Forces Acting on a Different Type of Beam-Column Joints

The figure depicts the forces acting on an interior joint exposed only to gravity loads. The compression and tension exerted from the beam ends and axial loads from the columns can be transmitted directly through the joint [1]. When it comes to lateral loading, the equilibrating forces from columns and from beams develops diagonal compressive and tensile stresses within the joint. Cracks develop at joint faces and in the joint. The tensions ties and the compression struts are shown by solid and dashed lines respectively. To resist diagonal tensile forces, transverse reinforcement across the plane of failure is to be provided.

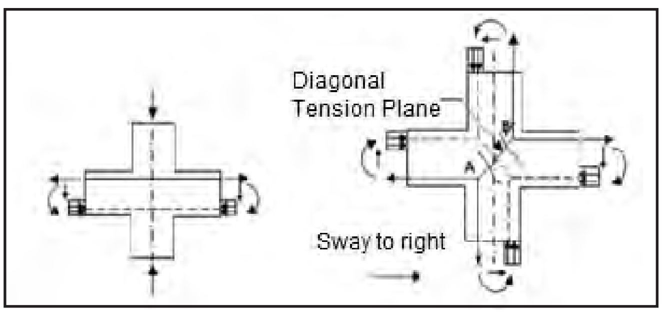

Fig. 2. Forces Acting on an Interior Joint

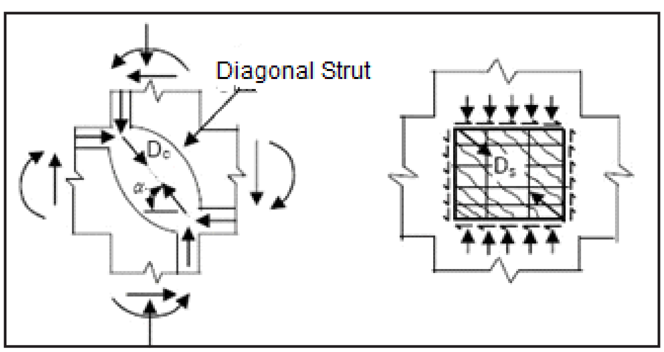

Fig. 3. Shear Resisting Mechanism

Force Transfer in Beam-Column Joints

Force transfer in beam-column joints is discussed in [4]. The horizontal shear forces in a joint can be transferred through the joint by a combination of two mechanisms as shown in Fig. 2. The first is a large strut formed between the opposite corners of the joint in compression, and the second is a panel truss mechanism formed by intermediate joint ties acting as tension members and smaller inclined strut acting in compression. Both of these represent two extremes of behavior. In practice, the behavior of the joint probably falls somewhere between these two extremes [2].

Joint Mechanisms

Beams are supposed to form plastic hinges at ends in strong columns – weak beams concept, so as to develop flexural over strength beyond the design strength. High shear demand develops in the joint core due to high internal forces developed at plastic hinges and cause critical bond conditions in bars passing through joints. 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 significantly.

Bond Requirement

Tension and compression forces develop in the longitudinal bars passing through the joints due to flexure in beams and columns. Large tensile forces transfer through bonds during the formation of plastic hinges. When the longitudinal bars at the joint face are stressed beyond yield, splitting cracks are initiated along the bar at the joint face which is referred to as 'yield penetration'. Sizes of the beams and columns forming a joint need to accommodate bond requirements so as to ensure adequate development length of longitudinal reinforcement to overcome yield penetration.

In an interior joint, the force in a bar passing continuously through the joint changes from compression to tension. This causes a push-pull effect which imposes severe demand on bond strength and necessitates adequate development length within the joint. The development length has to satisfy the requirements for compression and for tension forces in the same bar.

Factors Affecting Bond Strength

The significant parameters that influence bond performance of the reinforcing bar are confinement, clear distance between the bars, and nature of the surface of the bar. Confinement of the embedded bar is very essential to improving bond performance in order to transfer the tensile forces.

Shear Requirements of Joint

Generally, the shear load that a joint has to resist, V_j, comes from the beams and columns framing into it. From Fig. 4 it can be seen that T, T_1, and T_2 are found by multiplying the beam tension steel area, A_{st} by the steel yield stress, f_y. The column shear force, V_{col}, is found from external equilibrium of the forces imposed on the frame in consideration.

In order to prevent failure of the joint, its shear strength must at least V_j.

In established methods of joint design, shear strength is assumed to come essentially from concrete strength, column axial compressive load and link strength.

Generally, in ensuring the effectiveness of joint to resist the forces, the strength of column is an important view which needs to be considered. In design view, one of the important criteria is to ensure that the designed element would not fail in any condition, no matter whether caused by bending or shear forces. Thus, it is very common for designer to always have the column with higher strength than beam.

Strength Requirement of Column at Joint

To ensure the joint would not fail at any condition, two criteria need to be taken into account:

For exterior joints	For interior joints
$V_j = T - V_{col} = C - V_{col}$	$V_j = T_1 + C_2 - V_{col} = T_2 + C_1 - V_{col} = T_1 + T_2 - V_{col}$
T : Tension Force	V_j : Shear stress joint has to resist
$T1$: Tension in beam while hogging	V_{col} : Column shear
$T2$: Tension in beam while sagging	C : Compression force
A_{st} : Area of steel reinforcement	C_1 : Compression in beam while hogging
f_y : Yield strength of steel	C_2 : Compression in beam while sagging

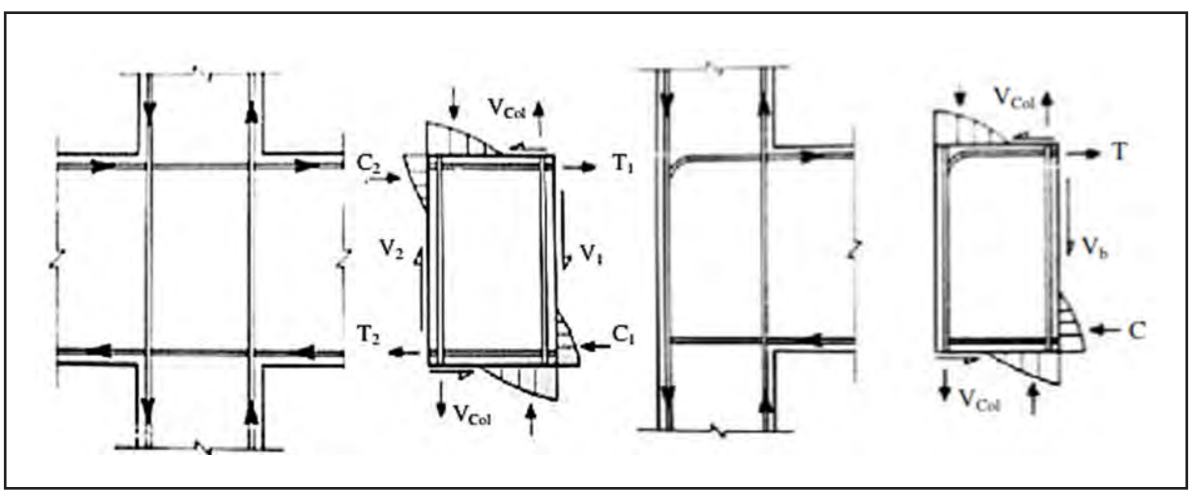

Fig. 4. Shear Requirements of Joints

(i) Moments produced by surrounding beam or slab system must able to be resisted by supported column, where:

$$M_{u(col)} = M_{bL} + M_{bR} \quad (1)$$

Where :

$M_{u(col)}$ = Moment must able to be resisted by column.

M_{bL} = Moment produced by left side beam.
M_{bR} = Moment produced by right side beam.

(ii) Column must be able to resist the ultimate shear value which is produced by interaction of moment, where:
Ultimate shear resistance of column

$$= \quad (M_{bL} + M_{bR}) / \text{Height of each floor} \quad (2)$$

II. PROBLEM FORMULIZATION

Structure is 18m x 18m RCC moment resisting frame with a height of 16m. It is composed of 5 storeys, each 3.2m high. Each floor area is divided into 9 bays with each bay spanning 6m x 6m. The structure consists of an assembly of cast-in-place concrete beams and columns. Floors and roof framings consist of cast-in-place concrete slabs and concrete beams. The lateral forces are resisted by concrete slabs and concrete beams that developed their stiffness through the monolithic beam-column connections. All the frames of the structure are considered to resist the lateral forces developed due to the earthquake ground motion.

As per Fig. 5 to 8 it is clear that the structure is composed of beams BM1 and BM2, columns COL1 and COL2 and a slab SL. Table I shows the dimensions of all the structural elements composing the structure.

The base supports of the structure were assigned as fixed. In this study a semi-rigid diaphragm D2 is applied to all the floors, so as to facilitate the transfer of lateral loads from the slabs to the beams.

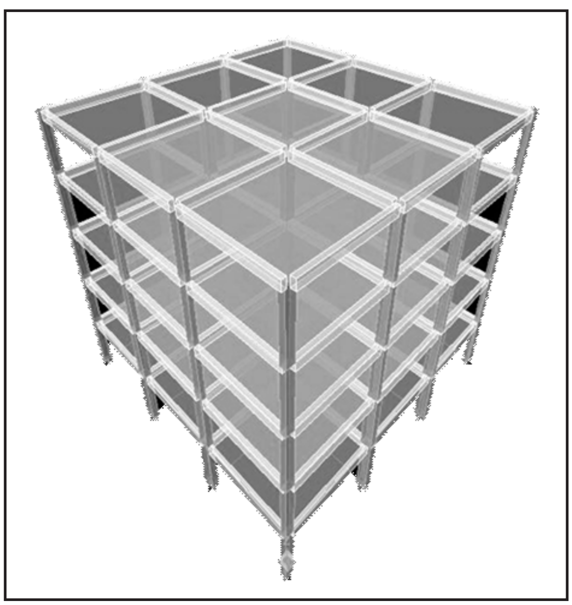

Fig. 5. 3D Model

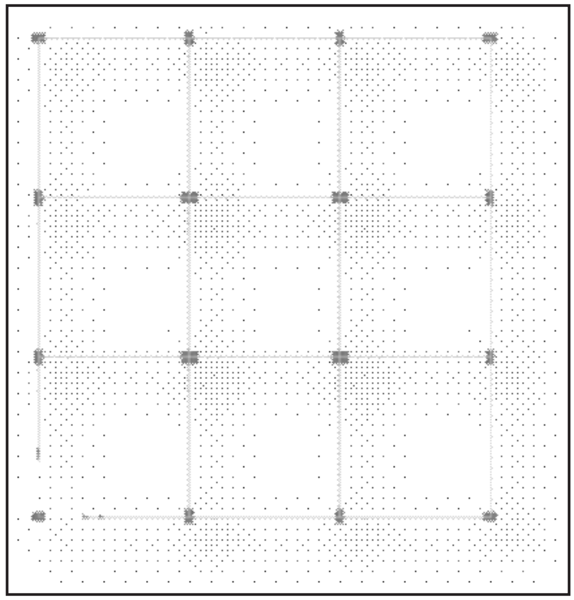

Fig. 6. Plan

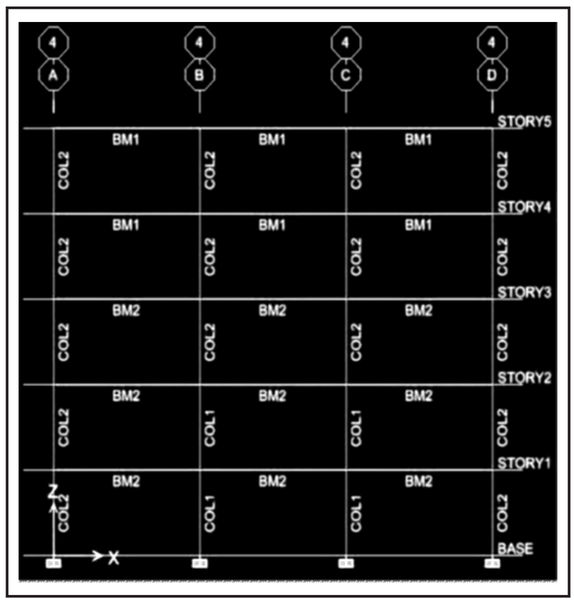

Fig. 7. Outer frames in X-Z Plane

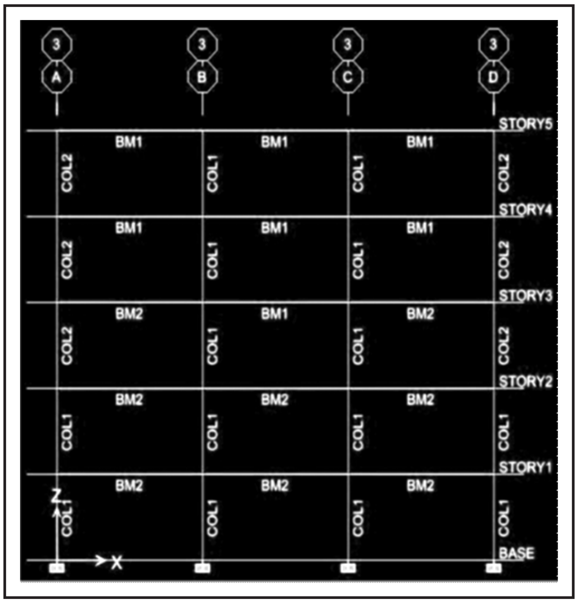

Fig. 8. Intermediate frames in X-Z Plane

TABLE I.
PARAMETERS OF STRUCTURAL ELEMENTS

S.No.	ELEMENT	LENGTH m	WIDTH m	DEPTH m
1	Slab			
1.a	SL	–	–	0.150
2	Beams			
2.a	BM1	6	0.250	0.450
2.b	BM2	6	0.250	0.500
3	Columns			
3.a	COL1	3.2	0.400	0.600
3.b	COL2	3.2	0.300	0.500

TABLE II.
LOADS ACTING ON THE STRUCTURE

Dead Load	Automatically calculated by the software
Live Load	Live load considered on each floor is 2.5kN/m^2 and on the terrace level it is considered to be 1.5 kN/m^2.
Floor finish	1.1 kN/m^2
Load of walls	12 kN/m on beams of all the floors except the roof
Load of Parapet	5 kN/m on the peripheral beams of the roof

NOTE: All the frames of the structure have been identified as seismically active structural elements.

TABLE III.
MATERIAL PROPERTIES OF CONCRETE MIX

1.	Grade of Concrete Mix	M25
2.	Grade of Steel	Fe415
3.	Mass per unit volume	25 kN/m^3
4.	Modulus of Elasticity	2,50,000 N/mm^2
5.	Poisson's Ratio	0.2

TABLE IV.
VALUES TO DEFINE RESPONSE SPECTRUM FUNCTIONS FOR SEISMIC ZONES

Zone	Seismic Zone Factor	Response Reduction Factor	Importance Factor	Soil Type
	Z	*R*	I	
II	0.10	5	1	i
V	0.36	5	1	i

As mentioned earlier the structure is being analyzed for Zone 2 and Zone 5. In order to analyze the structure for earthquake lateral loads, dynamic analysis is to be implemented in order to obtain accurate results. In this

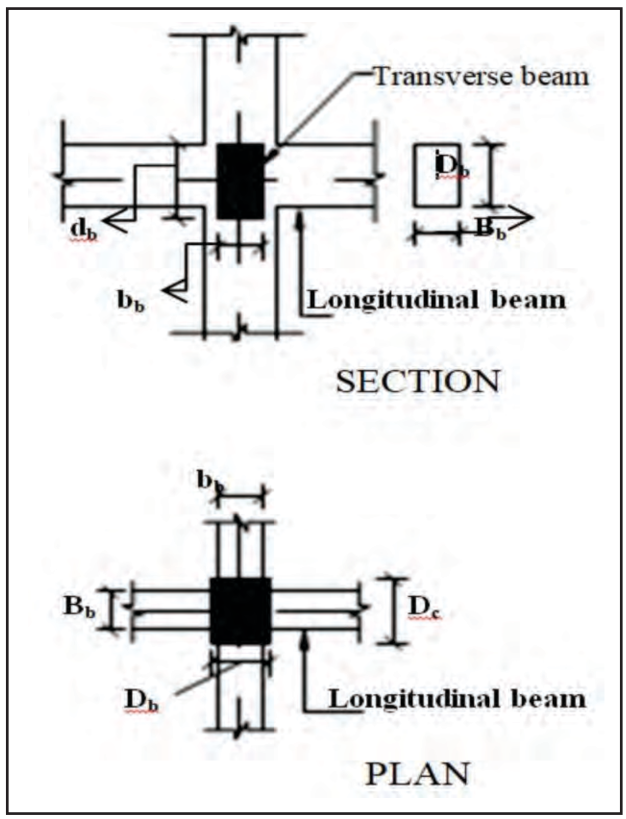

Fig. 9. Section and Plan of an Interior Beam-Column joint

study, the structure undergoes Response Spectrum Analysis. Bare frame analysis was pursued which neglects the effect of the in-fill walls on the structural response.

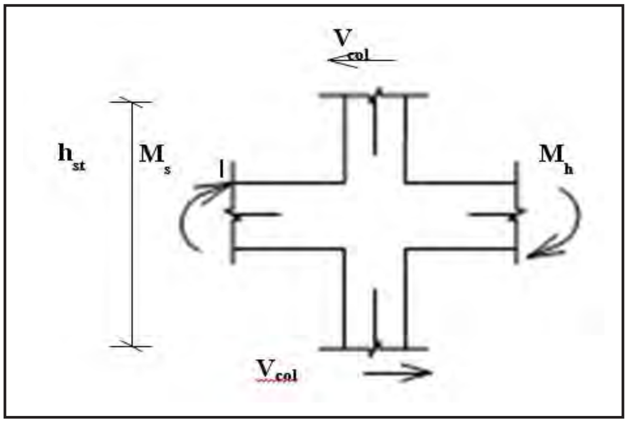

Fig. 10. Column With Sway to Left

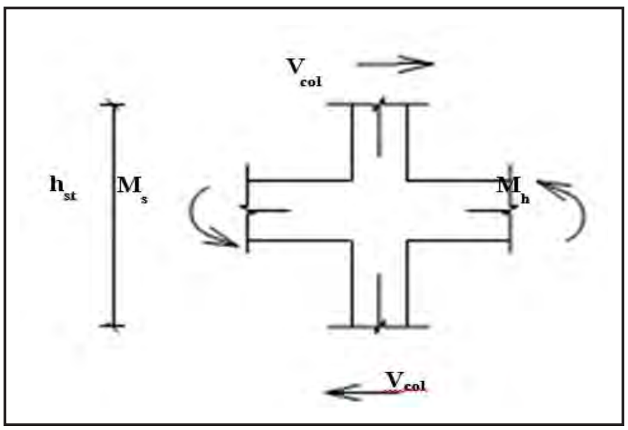

Fig. 11. Column With Sway to Right

$$V_{col} = 1.4 \left[\frac{M_h + M_s}{h_{st}} \right]$$

Design of Interior Beam-Column Joint Column Shear

The column shear [5] is as explained in Fig. 10 to Fig. 11.

Force Developed in Beam Reinforcement

Fig.13 shows the development of forces in the joint due to beam reinforcement for sway to right and left, respectively.

Force developed in the top bars.

$T_1 = A_{st}$ x 1.25x$f_y = C_1$ Force developed in the bottom bars. (3)

$T_2 = A_{st}$ x 1.25 x$f_y = C_2$ (4)

The factor 1.25 is to account for the actual ultimate strength being higher than the actual yield strength [1] [7]. [Draft revision of IS 13920]

Joint Shear

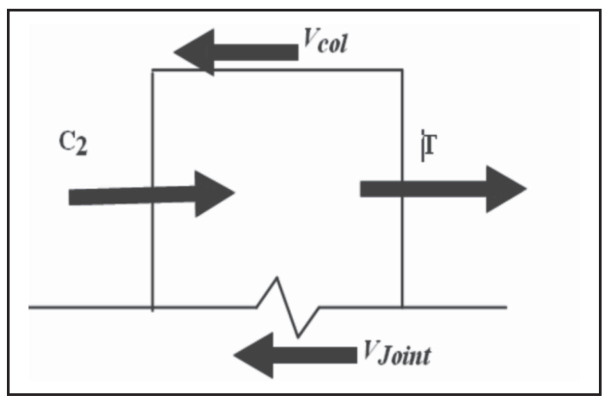

Fig. 12. Joint Shear Equlibrium

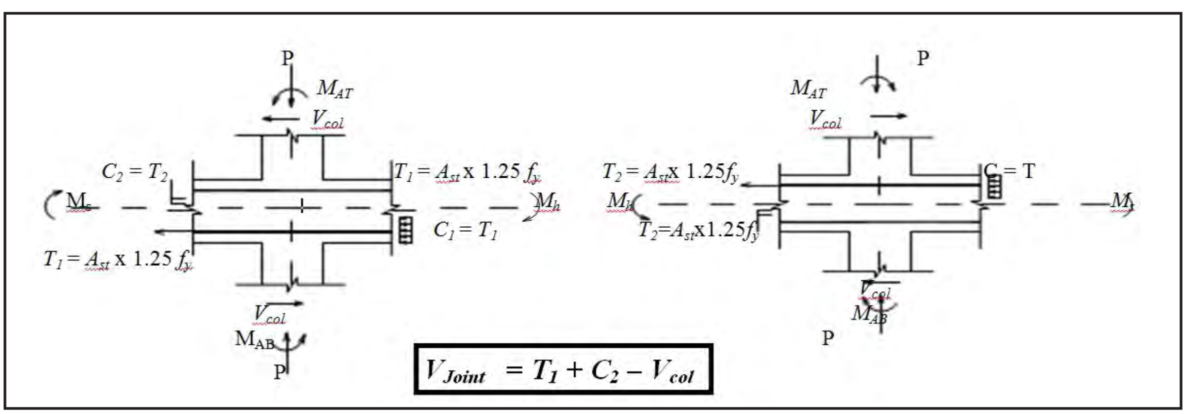

Fig. 13. Free Body Diagram of the Joint [5]

Nominal Shear Strength of Joint

As per Committee 352, the permissible shear stress of concrete in a joint is:

$$\zeta_{cj} = 0.083\, r \sqrt{f_{c'}}\, Mp_a \qquad (5)$$

here, $f_{c'}$ is cylinder compressive strength of concrete, and r is a shear strength factor.

TABLE V.
VALUE OF 'r' FOR BEAM TO COLUMN CONNECTIONS

Type of Joint	Discontinuous Columns	Continuous Columns
Interior Joint	15	20
Exterior Joint	12	15
Corner Joint	8	12

The nominal shear strength of the Joint $= \zeta_{cj}\, b_j\, h_c$ (6)

i.e., $\boxed{V_{nj} = 0.083\, r \sqrt{f_{c'}}\, b_j\, h_c}$ (7)

TABLE VI.
ZONE AND INTERIOR JOINT

Zone	Roof Interior Joint	3rd Floor Interior Joint	Interior Joint 1st Floor
2nd	2-R-IJ	2-3-IJ	2-1-IJ
5th	5-R-IJ	5-3-IJ	5-1-IJ

1st Floor Interor Joint

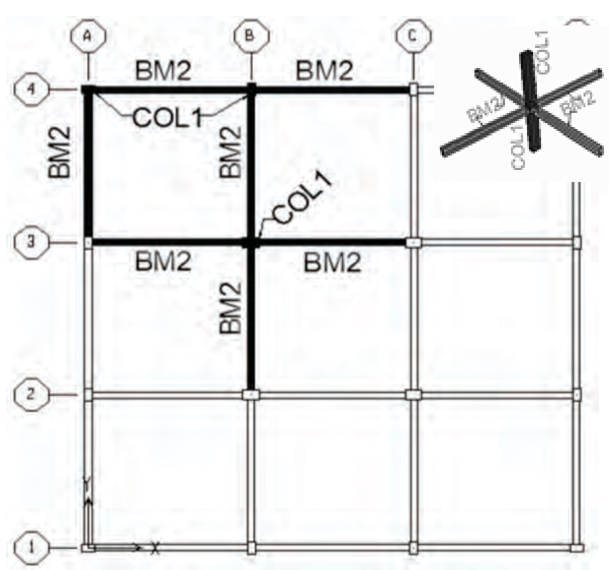

Fig. 14. 1st Floor Plan

3rd Floor Interior JointsRoof Interior Joint

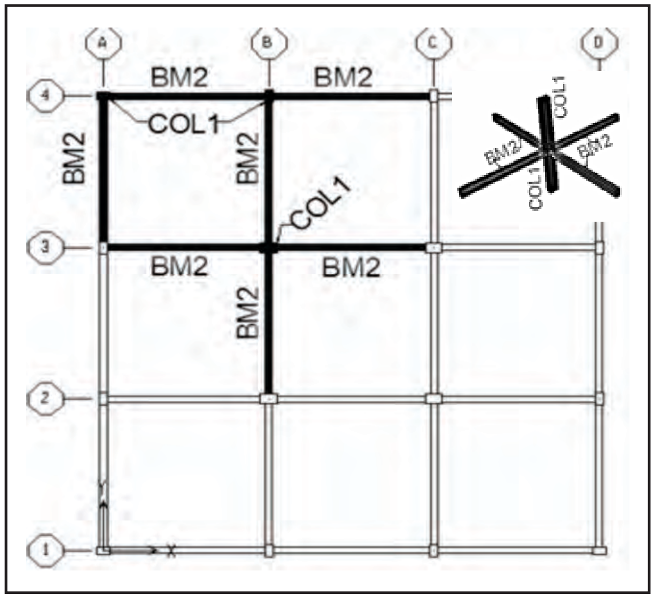

Fig. 15. 3rd Floor Plan

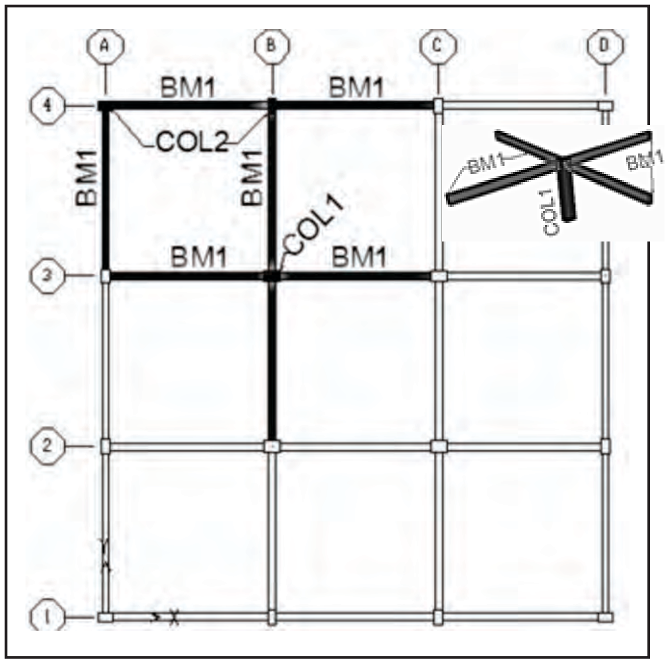

Fig. 16. Top Floor Plan

Where, h_c is the depth of concrete in the Joint in plan, h_c being measured perpendicular to b_j.

For safety, $V_{joint} \leq V_{nj}$ (8)

TABLE VII.

VALUES OF V_{nj}

JOINT TYPE	DIRECTION	b_j mm	h_c mm	r	$\sqrt{f_{c'}}$ MPa	V_{nj} kN
	1st FLOOR					
Internal Joint	Transverse	425	400	20	20	1262
	Longitudnal	325	600	20	20	1448
	3rd FLOOR					
Internal Joint	Transvere	425	400	20	20	1262
	Longitudnal	325	600	20	20	1448
	ROOF					
Internal Joint	Transverse	425	400	15	20	947
	Longitudnal	325	600	15	20	1086

TABLE VIII.

RESULTS FOR ZONE *V*

DIRECTION	Ast_1 mm²	Ast_2 mm²	f_y N/mm²	h_{st} m	M_h kN-m	M_s kN-m	V_{Col} kN	T_1 kN	C_2 kN	V_J kN	V_{nj} kN	RESULT
JOINT	**5-1-IJ**											
Transverse	2571	1294	415	3.2	359	175	234	1334	671	1771	1262	FAIL
Longitudinal	2644	1386	415	3.2	365	181	239	1372	719	1852	1448	FAIL
JOINT	**5-3-IJ**											
Transverse	2752	1443	415	3.2	380	192	250	1428	749	1926	1262	FAIL
Longitudinal	2882	1577	415	3.2	395	210	265	1495	818	2048	1448	FAIL
JOINT	**5-R-IJ**											
Transverse	1154	577	415	1.6	135	75	184	599	299	714	947	PASS
Longitudinal	1330	665	415	1.6	150	86	207	690	345	828	1086	PASS

TABLE IX.

RESULTS FOR ZONE II

DIRECTION	Ast_1 mm²	Ast_2 mm²	f_y N/mm²	h_{st} mtrs.	M_h kN-m	M_s kN-m	V_{Col} kN	T_1 kN	C_2 kN	V_J kN	V_{nj} kN	RESULT
JOINT	**2-1-IJ**											
Transverse	1387	694	415	3.2	181	101	123	720	360	956	1262	PASS
Longitudinal	1415	726	415	3.2	191	105	130	753	377	1000	1448	PASS
JOINT	**2-3-IJ**											
Transverse	1443	722	415	3.2	191	105	130	749	375	994	1262	PASS
Longitudinal	1514	757	415	3.2	200	109	135	785	393	1043	1448	PASS
JOINT	**2-R-IJ**											
Transverse	574	361	415	1.6	75	49	109	298	187	377	947	PASS
Longitudinal	712	356	415	1.6	91	48	122	369	185	432	1086	PASS

Value of Nominal Shear Strenth of Joints (V_{nj})

Values of V_{nj} remains same for the joints in all four structures. The Design shear strengh of joints has to be compared with (V_{nj}) in order to find out if the joint can withstand shear stresses or not.

III. RESULT INTERPRETATION

It is clear that the structure becomes more and more vulnerable as we move from Zone 2 to Zone 5. Structure possess adequate strength in Zone 2 where the value of Z is 0.10 but it failed when we move to Zone 5 with value of Z as 0.36.

As stated earlier that ductility provisions described in IS 13920:1993 are taken into account while designing these structures, still the joints are lacking the strength to withstand the actual shear developed in it due to seismic motions.

IV. CONCLUSION

Buildings are severely impacted by lateral movements, that is, earthquake which disturbs the stability of buildings and can result in their collapse [11]. According to the latest seismic zone map of India, about 59% of India's land area is vulnerable to moderate or severe seismic hazard [12]. In the recent past, most Indian cities have witnessed excessive rise in high rise structures. The rapid expansion of the built environment in moderate or high risk cities make it imperative to incorporate seismic risk reduction strategies in various aspects of urban planning and construction of new structures. In Indian design practices, beam-column joint gets less attention than it actually deserves. The behavior and expected performance of flexural members of reinforced concrete moment resisting frames can be realized only when the joints are strong enough to sustain the severe forces set up under lateral loads [6].

This paper contributes on the need to be aware of the fundamental theory of joint seismic behavior by design engineers [1].

AUTHOR'S CONTRIBUTION

Er. Aqeel A S Wagla Wala conceived the idea to study details of the mechanism of monolithic reinforced concrete beam column joints. Comparison of joint shear under different seismic zones for different joints was carried out by Aqeel A. S. Wagla Wala and he wrote the manuscript.

CONFLICT OF INTEREST

The author certifies that he has no affiliations with or involvement in any organization or entity with any financial interest, or non-financial interest in the subject matter, or materials discussed in this manuscript.

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