Beam Column Joint Analysis By Response Spectrum Method

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Abstract- *Beam-column connections are the common junction point of neighboring columns, beams, and slabs. The beam-column connection was one of the weakest links in the moment-resistant reinforced concrete (RC) framed constructions during the recent severe earthquake. Earthquakes are a worldwide phenomenon. Due to the frequency of earthquakes, they are no longer seen as divine occurrences, but rather as scientific phenomena that need investigation. The unpredictable horizontal and vertical ground movements that occur during an earthquake cause building to shake and create inertia forces. Analysis of earthquake-caused damage to moment-resisting RC-framed buildings reveals that failure may be attributable to insufficiently resistant concrete, soft storey, beam-column junction failure owing to poor reinforcements or inappropriate anchoring, and column failure triggering storey mechanism. Perform seismic analysis on an RCC building and validate the results using the StadPro programme. Using IS 1893:2002 and an analogous static approach, seismic analysis is performed. Design of Beam-column Joint in accordance with IS 13920:1993, ACI318-08. The performance of framed constructions is contingent upon both the structural parts and the joints. In seismic circumstances, the design and details of joints are crucial. This research demonstrates that there has been a sufficient modification in the codal provisions on beam-column joints and provides an assessment of the design and details of the structure's beam-column joints. And its purpose is to meet bonding and shear requirements inside the joints.*

Keywords- Beam Column Joint, Seismic Analysis, Staad Pro.

I. INTRODUCTION

General:

Beam-column connections are a common point of intersection of columns, beams, and slab adjacent to the joint. During the past devastating earthquake, the beam-column connection demonstrated as one of the weakest link in the moment-resisting reinforced concrete (RC) framed structures. Under seismic excitation, the beam-column joint region is subjected to horizontal and vertical shear forces whose magnitudes are many times higher than those within the adjacent beams and columns. Further, the exterior beam-column connections confined by only two or three framing beams and having lesser confinement level had suffered more in comparison to the interior ones. To achieve a better seismic performance of the RC frame, various building codes recommends the minimum amount of longitudinal and transverse reinforcement at the beam-column connections.

Earthquake is a global phenomenon. Due to frequent occurrence of earthquakes it is no more considered as an act of God rather a scientific happening that needs to be investigated. During earthquake, ground motions occur both horizontally and vertically in random fashions which cause structures to vibrate and induce inertia forces in them. Analysis of damages incurred in moment resisting RC framed structures subjected to past earthquake show that failure may be due to utilization of concrete not having sufficient resistance, soft storey, beam column joint failure for weak reinforcements or improper anchorage, column failure causing storey mechanism. Beam-column connection is considered to be one of the potentially weaker components when a structure is subjected to seismic loading. Designing beam-column joints are viewed as an unpredictable, complex and challenging task for structural engineers, and careful design of joints in reinforced concrete frame structures is vital to the security of the structure. Even though the size of the joint is constrained by the size of the casing individuals, joints are exposed to an alternate arrangement of loads from those utilized in designing beams and columns. It has been distinguished that the lack of joints is mainly caused because of deficient design to resist shear forces (horizontal and vertical). Therefore, insufficient transverse and vertical shear reinforcement and inadequate anchorage makes joint weaker.

The reinforcement details of such structures comply with the general construction code of practice may not adhere to the modern seismic provisions. The reinforced concrete joints are treated as rigid in the analysis of moment-resisting frames. The joint is normally ignored in Indian practice for explicit design and consideration is limited to the arrangement of adequate anchorage for beam longitudinal reinforcement and can be worthy when the frame isn't subjected to earthquake loads. A beam-column joint turns out to be less efficient when subjected to large lateral loads. By increasing the number of stirrups at the joint the joint shear limit can be increased. When the spacing of the stirrups at the joint becomes closer, the joint will become clogged and concrete will not be entered into the joint because of inadequate spacing and this is the handy trouble looking at the site while concreting the beam-column joints. Hence required compaction at the joint will not be attained.

1.1 BACKGROUND

Along with the development of many strength-based design procedures, currently used performance-based seismic design approach of building includes the capacity design philosophy proposed by Paulay and Priestley (1992) as an important tool for earthquake resistant design. In this process the design is based on both the stress resultants obtained from linear structural analysis subjected to code specified design lateral forces and equilibrium compatible stress resultants obtained from pre-determined collapse mechanism. The flexural capacities of members are determined on the basis of overall structural response of a structure to earthquake forces. For this purpose, within a structural system the objects which can be permitted to yield before failure otherwise known as ductile components and the objects which will remain elastic and will collapse immediately without warning known as brittle components are chosen.

In ACI web sessions 1976, when the structure detailed in Fig. 1.4 was being tested for checking the type of joint failure an unexpected result obtained and the beam failed instead of the failure at joint. While investigating this issue the column to beam moment capacity ratio (refer Eq. 1) obtained was more than one.

$$\text{Moment capacity ratio (MCR)} = \frac{\sum M_{nc}}{\sum M_{nb}}$$

Where Mnc = flexural strength of columns framing into joint and Mnb = moment capacities of beams framing it.

1.3 RESPONSE SPECTRUM ANALYSIS

Response spectrum analysis is a method to estimate the structural response to short, nondeterministic, transient dynamic events. Examples of such events are earthquakes and shocks. Since the exact time history of the load is not known, it is difficult to perform a time-dependent analysis. Due to the short length of the event, it cannot be considered as an ergodic ("stationary") process, so a random response approach is not applicable either.

The response spectrum method is based on a special type of mode superposition. The idea is to provide an input that gives a limit to how much an eigenmode having a certain natural frequency and damping can be excited by an event of this type.

The text below is separated into three parts:

- The definition of a response spectrum
- Generation of a response spectrum from a given time history
- The use of a given response spectrum in a structural analysis

In most cases, the engineer performing a response spectrum analysis is presented with a given design response spectrum, in which case the two first parts can be considered as background material.

Definition of a Response Spectrum

A response spectrum is a function of frequency or period, showing the peak response of a simple harmonic oscillator that is subjected to a transient event. The response spectrum is a function of the natural frequency of the oscillator and of its damping. Thus, it is not a direct representation of the frequency content of the excitation (as in a Fourier transform), but rather of the effect that the signal has on a postulated system with a single degree of freedom (SDOF).

1.4 OBJECTIVES

The objectives of this study are specifically given as following.

1. To perform seismic analysis on RCC building and its validation in StaadPro software.
2. The analysis is carried out using STAAD-Pro. Software for a residential G+7 RC framed building.
3. Seismic analysis is carried out by response spectrum method using IS 1893:2002.
4. Design of Beam- column Joint by IS 13920:1993, ACI318-08.
5. Comparison of design parameters.

II. LITERATURE REVIEW

A Survey of work done in the research area and need for more research

2.1 Comingstarful Marthong, (2015).

An experimental study has been conducted on reduced-scale exterior RC beam-column connections to investigate its behavior due to the addition of Polyethylene terephthalate (PET) fiber-reinforced concrete, i.e., PFRC at the joint region. PET fiber (aspect ratio = 25) of 0.5% by weight of concrete used in the PFRC mix was obtained by hand cutting of post-consumer PET bottles. Three reference specimens were cast and subjected to reverse cyclic loading. Additionally, PFRC specimens were also cast and subjected to similar cyclic displacement. Comparing the results, PFRC specimens improved the damage tolerance, load resisting capacity, stiffness degradation, ductility, and energy dissipation of the specimens. The results obtained gave experimental evidence of the suitability of PET fibers as a discrete reinforcement in substitution of steel fiber for structural use. Beam-column connections are a common point of intersection of columns, beams, and slab adjacent to the joint. During the past devastating earthquake, the beam-column connection demonstrated as one of the weakest link in the moment-resisting reinforced concrete (RC) framed structures. Under seismic excitation, the beam-column joint region is subjected to horizontal and vertical shear forces whose magnitudes are many times higher than those within the adjacent beams and columns.

2.2 P. Rajaram, (2010).

Beam column joint is an important component of a reinforced concrete moment resisting frame and should be designed and detailed properly, especially when the frame is subjected to earthquake loading. Failure of beam column joints during earthquake is governed by bond and shear failure mechanism which are brittle in nature. Therefore, a current international code gives high importance to provide adequate anchorage to longitudinal bars and confinement of core concrete in resisting shear. Modern codes provide for reduction of seismic forces through provision of special ductility requirements. Details for achieving ductility in reinforced concrete structures are given in IS 13920. A two bay five storey reinforcement cement concrete moment resisting frame for a general building has been analyses and designed in STAAD Pro as per IS 18932002 code procedures and detailed as IS 139201993 recommendations. A beam column joint has been modeled to a scale of 1/5 th from the prototype and the model has been subjected to cyclic loading to find its behavior during earthquake. Nonlinear analysis is carried out in ANSYS software. The behavior of reinforced concrete moment resisting frame structures in recent earthquakes all over the world has highlighted the consequences of poor performance of beam column joints. Beam column joints in a reinforced concrete moment resisting frame are crucial zones for transfer of loads effectively between the connecting elements (i.e. beams and columns) in the structure. In the analysis of reinforced concrete moment resisting frames, the joints are generally assumed as rigid.

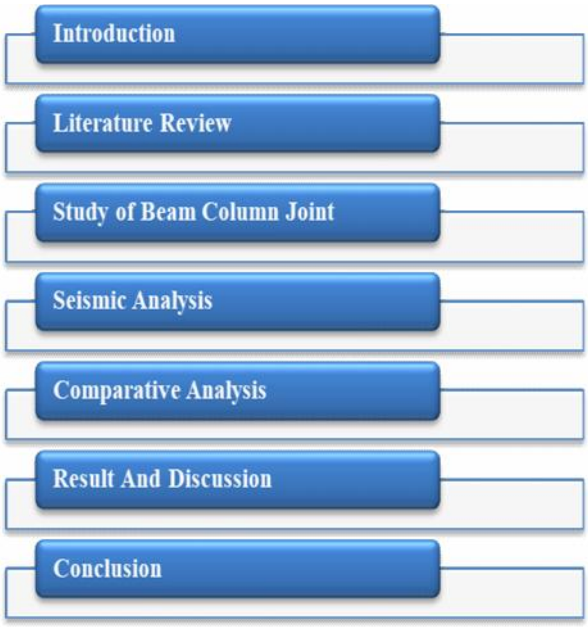
2.3 Mr. Anant S. Vishwakarma, (2017).

In reinforced concrete structures, portions of columns that are common to beams at their intersections are called Beam-Column Joint. Beam-column joint is an important part of reinforced concrete frames in terms of seismic lateral loading. The two major failure at joints are, joint shear failure and end anchorage failure. As we know that nature of shear failure is brittle so the structural performance cannot be accepted especially in seismic conditions. This study presents design as well as detailing of beam-column joint of the structure. From this paper we get a review on the behavior of joints under ACI 352R-02 and IS13920:1993 code. Design and detailing provisions on beam-column joints in IS13920:1993 do not adequately address prevention of anchorage and shear failure during severe earthquake shaking. A careful study and understanding of joint behaviour is essential to arrive at a proper judgement of the design of joints. This paper focus on the seismic action on various type of joints and even on the parameters which affect joints and all component parts will be check for strength and stability.

2.4 Pramod Verma, (2019).

In a multi-storied building, the beam-column joint is one of the most critical regions. Usually the beam-column joint was considered as rigid frames. Various researchers over the past years indicated that the joint is not rigid. Now it is also stated that instead of the failure in beam and column, failure can also occur in joint; hence joint must be considered as a structural member. The Indian standards define a joint as the portion of the column within the depth of the deepest beam that frames into the column. In framed structures the bending moment and shear forces are maximum at the junction area. So, beam column joint is one of the failure zones. Among the beam column joints, the exterior joint is more critical. The exterior beam column joint has been a study for about 30 years since now. Still there are many more to be understood. In the present work a building is designed in STAAD. Pro V8i and an exterior beam column joint is considered. This joint is modelled in NX CAD and imported to ANSYS to analyse it to derive the shear stress and the corresponding deformation.

III. METHODOLOGY



General:

Earthquakes are nature's greatest hazards to life on this planet. The hazards imposed by earthquakes are unique in many respects, and consequently planning to mitigate earthquake hazards requires a unique engineering approach. An important distinction of the earthquake problem is that the hazard to life is associated almost entirely with manmade structure expect for earthquake triggered landslides, the only earthquake effect that causes extensive loss of life are collapse of bridges, buildings, dams, and other works of man. This aspect of earthquake hazard can be countered only by designs and construction of earthquake resistant structure. The optimum engineering approach is to design the structure so as to avoid collapse in most possible earthquake, thus ensuring against loss of life but accepting the possibility of damage.

Various methods for determining seismic forces in structures fall into two distinct categories:

(i) Equivalent static force analysis (ii) Dynamic Analysis

(i) Equivalent static force analysis:

These are approximate methods which have been evolved because of the difficulties involved in carrying out realistic dynamic analysis. Codes of practice inevitable rely mainly on the simpler on the simpler static force approach, and incorporate varying degree of refinement in an attempt to simulate the real behaviour of structure. Basically they give total horizontal force (Base Shear) V, on a structure:

$$V = ma$$

Where,

m is mass of structure
V is applied to the structure by a simple rule describing its vertical distribution. In a building this generally consist of horizontal point loads at each concentration of mass, most typically at floor level. The seismic forces and moments in the structure are then determined by any suitable analysis and the results added to those for the normal gravity load cases. An important feature of equivalent static load requirement in most codes of practice is that calculated seismic forces are considerably less than those which would actually occur in the larger earthquakes likely in the area concerned.
V=F1+F2+F3

(ii) Dynamic analysis

For large or complex structure static methods of seismic analysis are not accurate enough. Various methods of differing complexity have been developed for the dynamic seismic analysis of structures. They all have in common the solution of the equation of motion as well as the usual static relationship of equilibrium and stiffness. The three main techniques currently used for dynamics analysis are:

(i) Direct integration of the equation of motion by step by step procedure
(ii) Normal Mode Analysis
(iii) Response spectrum Technique

Direct integration provides the most powerful and informative analysis for any given earthquake motion. A time dependent forcing function (earthquake accelerogram) is applied and the corresponding response history of the structure during the earthquake force is computed. The moment and force diagram at each of series of prescribed interval throughout the applied motion can be found. Three dimensional nonlinear analysis have been devised which can take three orthogonal accelerogram components from a given earthquake, and apply them simultaneously to the structure. This is the most complete dynamic analysis technique and is unfortunately expensive to carry out.

Normal mode analysis depends on artificially separating the normal modes of vibration and combining the force and displacement associated with a chosen number of them by superposition. As with direct integration techniques, actual earthquake accelerograms can be applied to the structure and a stress-history determined, but because of the use of superposition the techniques is limited to linear material behaviour. Although modal analysis can provide any desired order of accuracy for linear behaviour by incorporation all the modal responses, some approximation is usually made by using only the few modes to save computation time. Problems are encountered in dealing with system where the mode coupling occurs.

Seismic Analysis using IS 1893 (Part1):2002

In this approach the earthquake force is applied on the structure using seismic coefficient method. In this method the design horizontal seismic coefficient Abfor the structure is given as

$$A_h = \frac{Z}{2} \cdot \frac{I_m}{R} \cdot \frac{S_a}{g}$$

Where,

Ah is seismic horizontal acceleration (Generally in the range of 0.05g to 0.2g) Z is zone factor as per different zones, IS 1893 (Part1):2002 has classified India in to four zones II to V. In zone II seismic intensity is low and very severe for zone v, I= importance factor, depending upon the functional use of the structures, R= Response reduction factor, depending on the perceived seismic damage performance of the structure, characterized by ductile or brittle deformations. However, the ratio I/R shall not be greater than 1.0 and Sa/g = Average response acceleration coefficient for rock or soil sites. This ratio depends upon the time period and site condition.

IV. MODELING AND PROBLEM STATEMENT

Problem Statement

The building considered is regular G+7 normal RC building of dimension of plan with 11.42mX14.10m, the building is considered to be located in Zone IV as pre IS 1893-2002.The Table 1 shows structural data of the building.

I)Material Data	
Grade of concrete	M30
Grade of Steel	Fe500
Unit weight of RCC	25kN/m2
II) Structural Data	
Type of structure	SMRF
Type of soil	Medium soil
Size of beam	230mm X450mm
Size of column	300mmX700mm
	300X450mm
Depth of slab	200mm
III) Architectural Data	
Number of stories	G+7
Floor height	3m
Dimension of plan	11.42mX14.10m
IV)Seismic Data	
Seismic Zone	IV
Response reduction factor	5
Importance factor	1
Damping ratio	5%
V) Loads	
Live load	2kN/m2
Floor finish	4.75kN/m2
Wall load on exterior frame	12kN/m
Wall load on interior frame	6kN/m

MODEL DETAILS

MODEL 1	RC structure with IS 13920 - 1993
MODEL 2	RC structure with ACI318-08

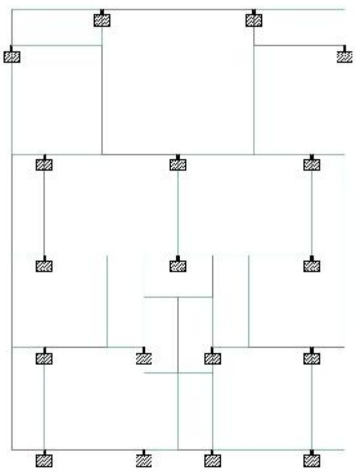


Figure. 1 Plan View

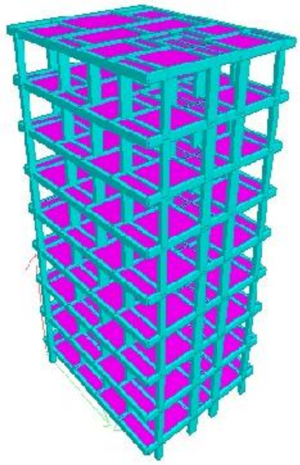


Figure. 3 3D Rendered View

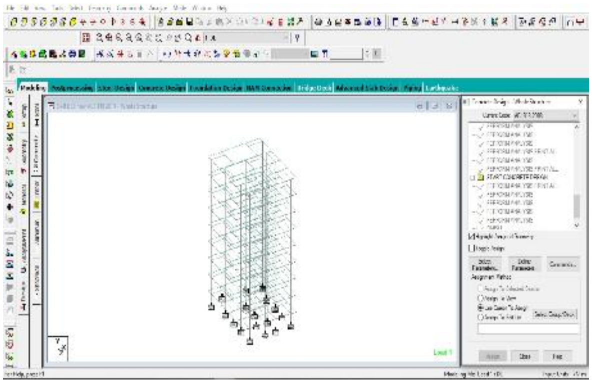


Figure. 4 Concrete Design as per ACI 318-08

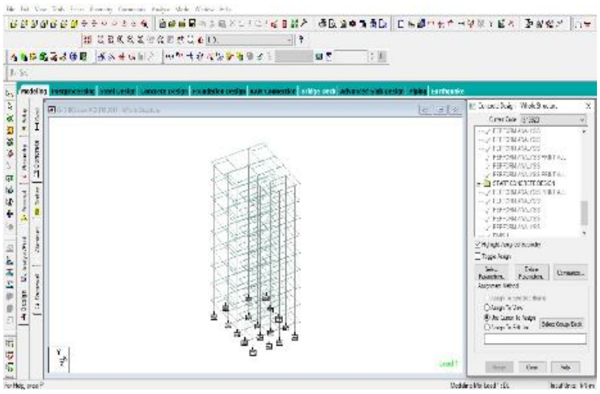


Figure. 5 Concrete Design as per IS 13920

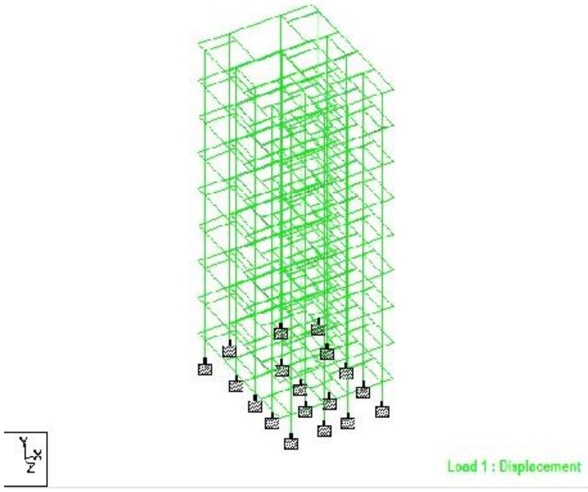


Figure. 6 Displacement

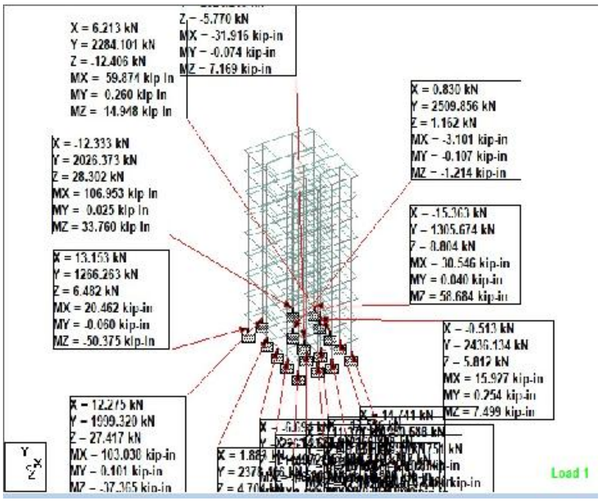


Figure. 7 Reactions

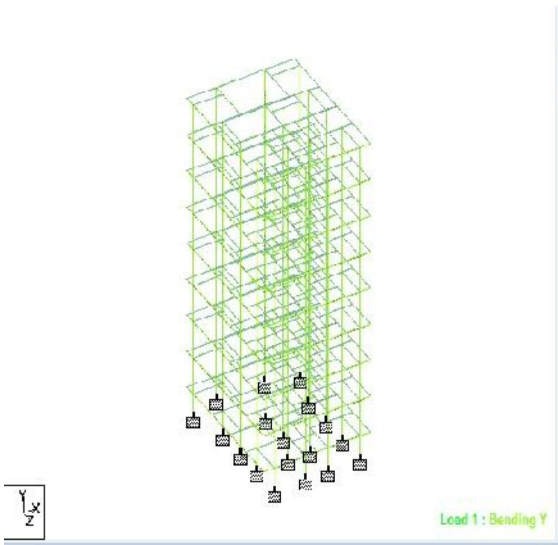


Figure. 8 Bending Y direction

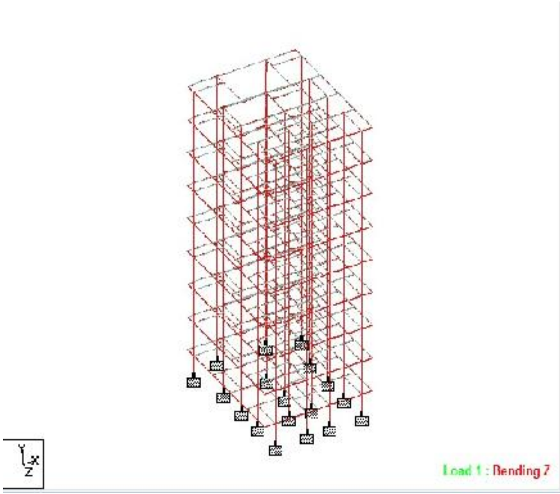


Figure. 9 Bending Z direction

V. RESULT AND DISCUSSION

The comparison of different parameters for a beam column shown in below tables and graphs:

Results for exterior column:

Table: 6.5 Displacement in X direction in mm

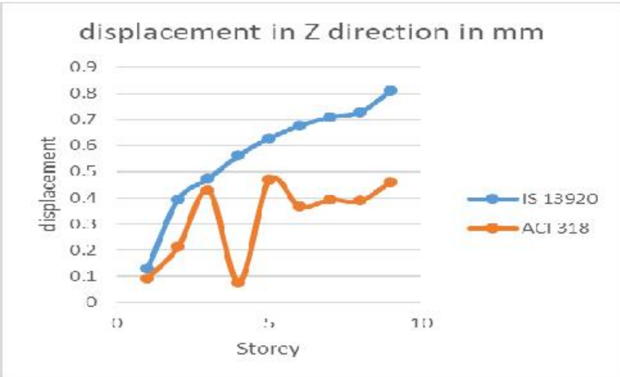
displacement in X direction in mm		
Storey	IS 13920	ACI 318
GL	0.005	0.085
1	0.061	0.228
2	0.09	0.356
3	0.12	0.369
4	0.137	0.569
5	0.146	0.539
6	0.154	0.57
7	0.159	0.562
8	0.232	0.785

Graph 6.5: Displacement in x direction in mm

Above graph shows for Displacement in x direction in mm for IS 13920 and ACI 318 as we can see that ACI 318 is maximum Displacement is 0.785 and minimum Displacement is 0.232.

Table 6.6: Displacement in z direction in mm

displacement in Z direction in mm		
Storey	IS 13920	ACI 318
GL	0.132	0.093
1	0.395	0.213
2	0.474	0.429
3	0.564	0.077
4	0.629	0.47
5	0.677	0.367
6	0.71	0.393
7	0.729	0.389
8	0.811	0.462



Graph 6.6: Displacement in z direction in mm

Above graph shows for Displacement in z direction in mm for IS 13920 and ACI 318 as we can see that IS 13920 is maximum displacement is 0.811 and minimum Displacement is 0.462.

Table 6.7: Bending moment in X direction

Bending moment in X direction		
Storey	IS 13920	ACI 318
1	29.55197	18.75672
2	53.35809	35.50706
3	70.02346	42.55753
4	84.15447	32.23671
5	95.09942	55.77438
6	103.2729	57.7297
7	108.9892	60.04306
8	115.0029	63.01287

Graph 6.7: Bending moment in X direction

Above graph shows Bending moment in X direction IS 13920 and ACI 318 as we can see that IS 13920 is maximum Bending moment is 115.0029 and ACI 318 is minimum Bending moment is 63.01287,

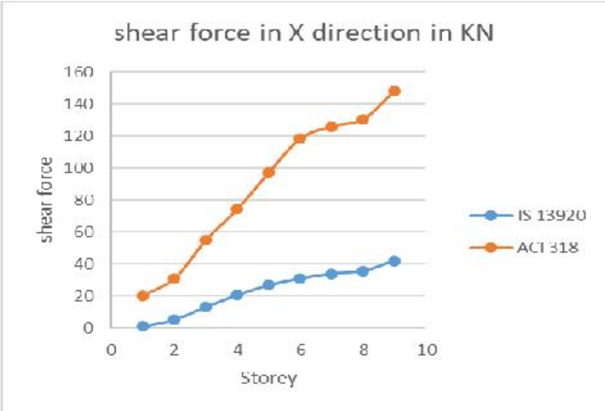
Graph 6.8: Bending moment in z direction

bending moment in Z direction		
Storey	IS 13920	ACI 318
1	5.729685	40.76446
2	17.95747	75.35126
3	28.97269	108.1829
4	38.76158	136.5193
5	45.51288	175.0214
6	50.17101	186.5703
7	53.57638	194.8749
8	59.68456	212.9164

Above graph shows Bending moment in z direction storey IS 13920 and ACI 318 as we can see that ACI 318 is maximum Bending moment is 212.9164 and IS 13920 is minimum Bending moment is 59.68456.

Table 6.9: Shear force in X direction in KN

Shear force in X direction in KN		
Storey	IS 13920	ACI 318
GL	1.075	20.305
1	5.324	30.941
2	13.286	54.978
3	20.584	74.174
4	26.758	97.064
5	30.886	118.063
6	34.009	125.703
7	35.785	130.178
8	41.88	147.987



Graph 6. 9: Shear force in X direction in KN

Above graph shows Shear force in X direction in KN for IS 13920 and ACI 318 as we can see that ACI 318 is maximum Shear force is 147.987 and IS 13920 is minimum Shear force is 41.88.

Table 6.10: Shear force in Z direction in KN

shear force in Z direction in KN		
Storey	IS 13920	ACI 318
GL	13.793	9.856
1	22.779	13.884
2	37.555	26.672
3	48.42	24.693
4	57.462	25.417
5	64.426	37.341
6	69.591	38.843
7	73.129	40.103
8	77.799	42.888

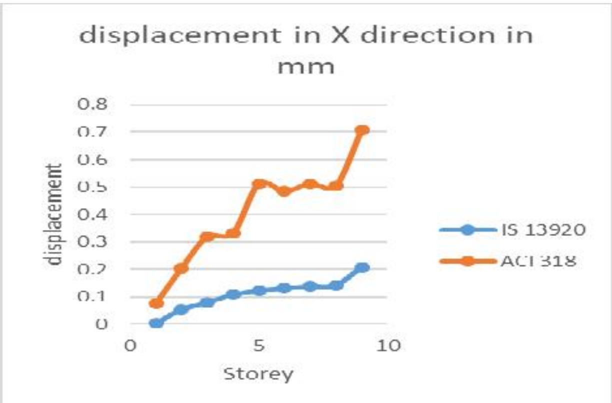
Graph 6.10: Shear force in Z direction in KN

Above graph shows Shear force in Z direction in KN for IS 13920 and ACI 318 as we can see that IS 13920 is maximum Shear force is 77.799 and ACI 318 is minimum Shear force is 42.888.

Results for interior column:

Table 6.11 displacement in X direction in mm

displacement in X direction in mm		
Storey	IS 13920	ACI 318
GL	0.0045	0.0765
1	0.0549	0.2052
2	0.081	0.3204
3	0.108	0.3321
4	0.1233	0.5121
5	0.1314	0.4851
6	0.1386	0.513
7	0.1431	0.5058
8	0.2088	0.7065

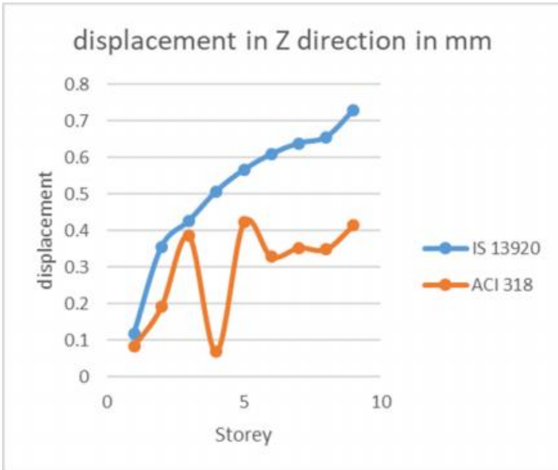


Graph 6.11: displacement in X direction in mm

Above graph shows for displacement in X direction in mm for IS 13920 and ACI 318 as we can see that ACI 318 is maximum displacement is 0.7065 and IS 13920 is minimum displacement is 0.2088.

Table 6.12 displacement in Z direction in mm

displacement in Z direction in mm		
Storey	IS 13920	ACI 318
GL	0.1188	0.0837
1	0.3555	0.1917
2	0.4266	0.3861
3	0.5076	0.0693
4	0.5661	0.423
5	0.6093	0.3303
6	0.639	0.3537
7	0.6561	0.3501
8	0.7299	0.4158



Graph :6.12 displacement in Z direction in mm

Above graph shows for displacement in Z direction in mm for IS 13920 and ACI 318 as we can see that IS 13920 is maximum displacement is 0.7299 and ACI 318 is minimum displacement is 0.4158

Table: 6.13 Bending moment in X direction

Bending moment in X direction		
Storey	IS 13920	ACI 318
1	29.55197	16.88105
2	53.35809	31.95635
3	70.02346	38.30178
4	84.15447	29.01304
5	95.09942	50.19694
6	103.2729	51.95673
7	108.9892	54.03875
8	115.0029	56.71158

Graph: 6.13 Bending moment in X direction

Above graph shows Bending moment in X direction IS 13920 and ACI 318 as we can see that IS 13920 is maximum Bending moment is 115.0029 and ACI 318 is minimum Bending moment is 56.71158.

Table: 6.14 bending moment in Z direction

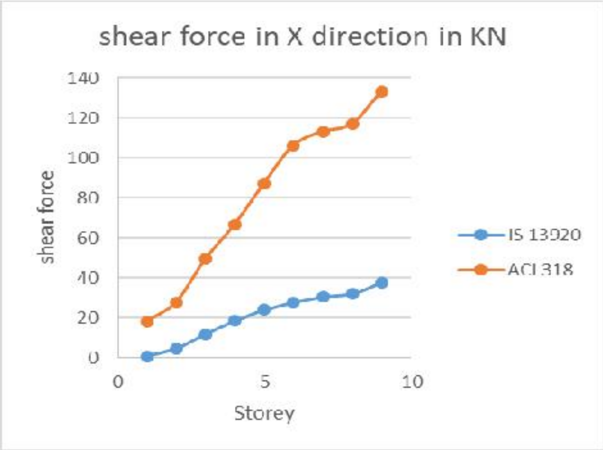
bending moment in Z direction		
Storey	IS 13920	ACI 318
1	5.156717	36.68802
2	16.16172	67.81613
3	26.07542	97.36465
4	34.88542	122.8674
5	40.96159	157.5192
6	45.15391	167.9133
7	48.21874	175.3874
8	53.7161	191.6247

Graph :6.14 bending moment in Z direction

Above graph shows Bending moment in z direction storey IS 13920 and ACI 318 as we can see that ACI 318 is maximum Bending moment is 191.6247 and IS 13920 is minimum Bending moment is 53.7161

Table: 6.15 shear in X direction in KN

shear in X direction in KN		
Storey	IS 13920	ACI 318
GL	0.9675	18.2745
1	4.7916	27.8469
2	11.9574	49.4802
3	18.5256	66.7566
4	24.0822	87.3576
5	27.7974	106.2567
6	30.6081	113.1327
7	32.2065	117.1602
8	37.692	133.1883



Graph :6.15 shear force in X direction in KN

Above graph shows Shear force in X direction in KN for IS 13920 and ACI 318 as we can see that ACI 318 is maximum Shear force is 133.1883 and IS 13920 is minimum Shear force is 37.692

Table: 6.16 shear force in Z direction in KN

shear force in Z direction in KN		
Storey	IS 13920	ACI 318
GL	12.4137	8.8704
1	20.5011	12.4956
2	33.7995	24.0048
3	43.578	22.2237
4	51.7158	22.8753
5	57.9834	33.6069
6	62.6319	34.9587
7	65.8161	36.0927
8	70.0191	38.5992

Graph :6.16 shear force in Z direction in KN

Above graph shows Shear force in Z direction in KN for IS 13920 and ACI 318 as we can see that IS 13920 is maximum Shear force is 70.0191 and ACI 318 is minimum Shear force is 38.5992

VII. CONCLUSION

If the joints are incapable of withstanding the forces and deformations caused by the transfer of forces between the elements meeting at the joint, the structural behaviour will deviate from what was expected during analysis and design. Specifically, the opening of joints must be carefully studied, as it will result in diagonal joint cracking. The offered material relates to seismic forces, but is of a generic character and may be applied to constructions susceptible to lateral forces. The following findings are drawn from the analysis of the problem

- Two codes find that the sizes of columns and beams at two joints are almost identical.
- The ACI 318 code has a higher joint shear strength than the other code.
- The ACI 318 code discovers that the shear strength at the joint is more than what the other code find.

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