International Journal of Scientific Research in Engineering and Management (IJSREM)
Volume: 04 Issue: 02 | Feb -2020 ISSN: 2582-3930

STUDY ON SEISMIC BEHAVIOR OF RC FRAMED VERTICALLY ASYMMETRICAL BUILDING

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ABSTRACT : The main objective of this study is to understand different irregularity and torsional response due to plan and vertical irregularity, and to analyze "T"-shaped building while earthquake forces acts and to calculate additional shear due to torsion in the columns. Additional shear due to torsional moments needs to be considered because; this increase in shear forces causes columns to collapse. So in design procedures this additional shear must be taken into account.

Irregularity [1]

Irregular buildings constitute a large portion of the modern urban infrastructure. The group of people involved in constructing the building facilities, including owner, architect, structural engineer, contractor and local authorities, contribute to the overall planning, selection of structural system, and to its configuration. This may lead to building structures with irregular distributions in their mass, stiffness and strength along the height of building. When such buildings are located in a high seismic zone, the structural engineer's role becomes more challenging. Therefore, the structural engineer needs to have a thorough understanding of the seismic response of irregular structures. In recent past, several studies have been carried out to evaluate the response of irregular buildings work that has been already done pertaining to the seismic response of vertically irregular building frames. Buildings with plan irregularities (e.g., those with re-entrant corners such as L-shape plans on corner plots) and those with elevation irregularities (e.g., large vertical setbacks in elevation such as a plaza-type configuration in commercial structures) are common in the affected area.

There are different types of irregularity is given in the code which are listed in Table-1. Major failures occurred due to irregularities like soft storey Failure, Mass Irregularity Failure, Plan Irregularity Failure, Shear Failure.

- Seismic Analysis of T-shaped building is done for torsional analysis manually. Center of mass and center of rigidity are calculated, then static eccentricity and design eccentricity is calculated. Torsional moments are calculated for seismic force at each floor. Additional shear along each column line is calculated.
- Same building is analyzed as regular building, building with soft storey and Modified building (with soft storey) as per IS 1893 (Part-I) : 2002. And comparison of different parameters like bending moments, storey drift, storey displacement is done by using software.

Table 1: Types of Irregularity

Plan irregularity	Vertical irregularity
Torsion irregularity	Stiffness Irregularity
Re-entrant Corners	Mass Irregularity
Diaphragm Discontinuity	Vertical Geometric Irregularity
Out of plane offsets	In Plane discontinuity in vertical elements resisting lateral force
Non parallel Systems	Discontinuity in capacity-weak story

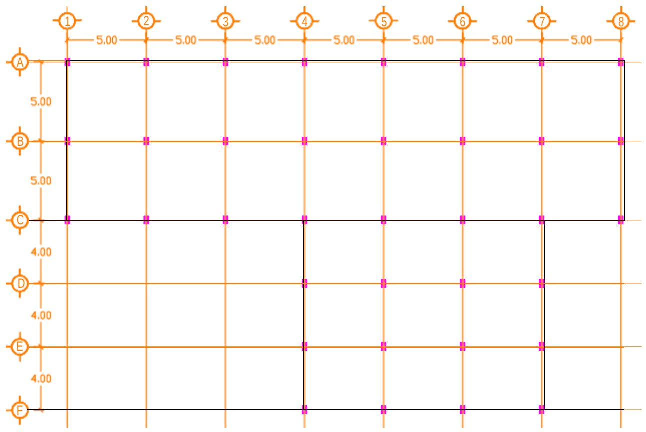

Figure 1: Building Plan

Architectural Features Affecting Seismic Performance of Buildings

Looking ahead, of course, one will continue to make buildings interesting rather than monotonous. However, this need not be done at the cost of poor behaviour and earthquake safety of buildings. Architectural features that are detrimental to earthquake response of buildings should be avoided. If not, they must be minimised. When irregular features are included in buildings, a considerably higher level of engineering effort is required in the structural design and yet the building may not be as good as one with simple architectural features.

Seismic Analysis of T-Shaped Building

Building Details

The structural analysis of a five story reinforced concrete building is done. The building is assumed as commercial complex. Geometry of building is "T" in shape consisting of parking area at the ground floor and 4 typical floors above them, so total 5 floors are there. Linear Static analysis has been done. Regular Grid Plan of the structure is shown in Fig 1 and 3-D model has been shown in Fig 2. The structure is assumed to be located in seismic zone IV on a site with medium soil. Building contains different irregularity like Plan irregularity and Re-entrant corner irregularity. Building is studied for two cases as mentioned below:-

- Torsional Moments: Seismic Analysis of building is done for torsional analysis manually. Center of mass and center of rigidity are calculated, static eccentricity and design eccentricity is calculated. Torsional moments are calculated for seismic force at each floor. Additional shear due to torsional moments along each column line is then calculated.
- Stiffness Irregularity: Soft Storey is considered in building at the ground floor and is analyzed by using software Staad Pro. The building is then modified as per the provisions of the code IS 1893 (Part 1): 2002 and results have been compared with regular building. And comparison of different parameters like bending moments, storey drift, storey displacement etc is placed in the form of tables, curves and charts.

Structural Data

Table 2: Structural Data

Length	=	35.00 m
Width	=	22.00 m
No. of Storey	=	5.00
Storey Height	=	3.60
Total No. of Column	=	36.00
Slab thickness	=	150.00 mm
Periphery wall	=	200.00 mm
Concrete grade	=	M-20.00
Steel grade	=	Fe-415.00
Density of Conc.	=	25.00 kN/m^3
Density of Wall	=	20.00 kN/m^3
Earthquake Data:-		
Zone	=	V
Importance Factor	=	1.00
Response Reduction Factor	=	5.00
Type of soil	=	2.00
Damping	=	5.00%

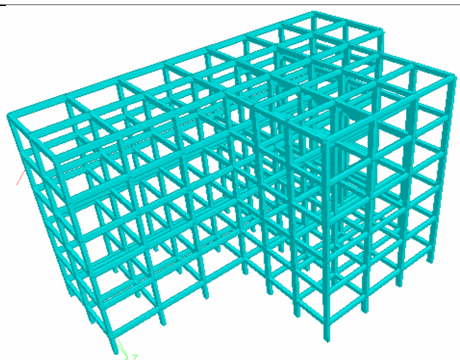

Figure 2: Isometric view showing beam and column frame

Storey Shear

Table 3: Dimensions in mm

Slab thickness= 150mm		
	b	d
Beam 1	300.00	500.00
Beam 2	300.00	400.00
Column	300.00	500.00

Table 4: Dead Load

Total wt. of slab in a storey	1987.50 kN
Total wt. of beam in a storey	643.13 kN
Total wt. of columns in a storey	486.00 kN
Total wt. of walls in a storey	1641.60 kN

Table 5: Live Load

	A	B	C	Total LL
Roof	0.00	0.00	0.00	0.00
4th floor	750.00	200.00	135.00	1085.00
3rd floor	187.50	200.00	135.00	522.50
2nd floor	600.00	150.00	135.00	885.00
1st floor	600.00	150.00	135.00	885.00
Gd. floor	0.00	0 .00	0 .00	0.00

Table 6: Total weight lumped at each of floor level

Roof	3694.43 kN
4th floor	5843.23 kN
3rd floor	5280.74 kN
2nd floor	5643.25 kN
1st floor	5643.25 kN
Gd. floor	4758.23 kN
total weight of building	30863.05 kN

Vertical Distribution of Base Shear to Different Floor Level

Table 7: Total Lateral Force And Storey Shear

Storey	Wi (kN)	hi (m)	$Wi*hi^2$	Qi (kN)	Vi (kN)
Roof	3694.43	20	1477772	596.42	596.42
4th floor	5843.23	16.4	1571595	634.29	1230.71
3rd floor	5280.73	12.8	865195	349.19	1579.90
2nd floor	5643.23	9.2	477643	192.77	1772.68
1st floor	5643.23	5.6	176972	71.43	1844.10
Gd. floor	4758.23	2	19033	7.68	1851.78
Total			4588210		

Soft Storey Analysis for T-Shaped Building

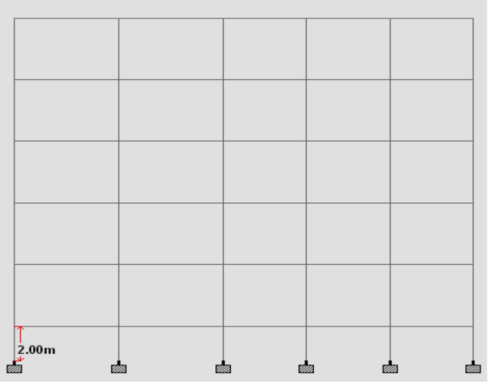

Figure 3: Regular building

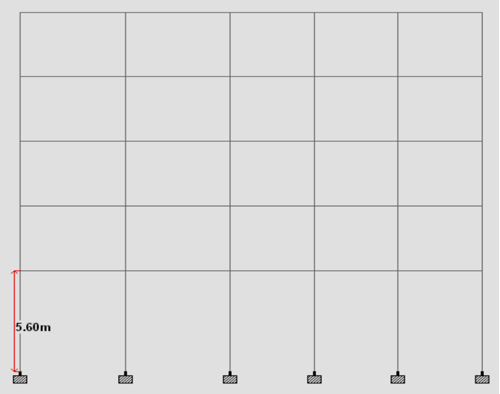

Figure 4: Building with soft storey

Modeling and analysis of five storey framed structure, using Staad-pro is presented in this chapter. The main purpose of taking this type of building is to understand basic behaviour of soft storey structure.

As per IS 1893 (Part 1):2002 Clause 7.10 Buildings with Soft Storey

In case of buildings with a flexible storey, such as the ground storey consisting of open spaces for parking that is Stilt buildings, special arrangement needs to be made to increase the lateral strength and stiffness of the soft/open storey.

The following design criteria are to be adopted after carrying out the earthquake analysis, neglecting the effect of infill walls in other storeys. The columns and beams of the soft storey are to be designed for times the storey shears and moments calculated under seismic loads specified in the other relevant clauses.

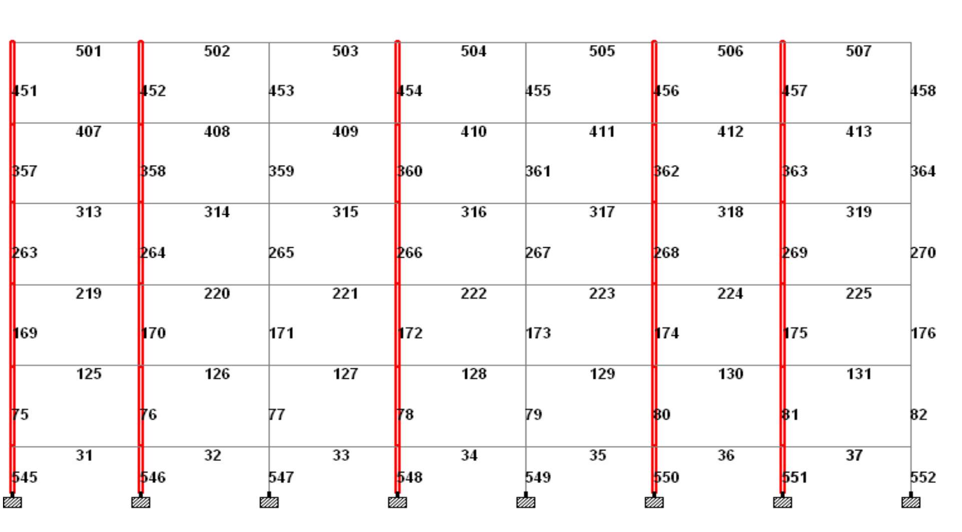

Figure 5: Columns highlighted for the results

Comparison of moments for various Columns

Table 8 Bending Moments in Corner Column C_1

Storey	Column C_1					
	Column No.	Moments M (kN-m)				
		Building A	Building B	% variation in moments	Building C	% variation in moments
Roof	451	44.02	42.32	-4.02	48.43	9.11
4th floor	357	71.17	67.61	-5.27	80.91	12.04
3rd floor	263	80.83	76.54	-5.60	93.00	13.09
2nd floor	169	86.06	80.42	-7.01	100.70	14.54
1st floor	75	80.99	119.00	31.94	206.90	60.86

Building A-Regular Building,Building B- Building With Soft Storey
Building C- Building with Soft Storey modified As per IS 1893 (Part 1):2002

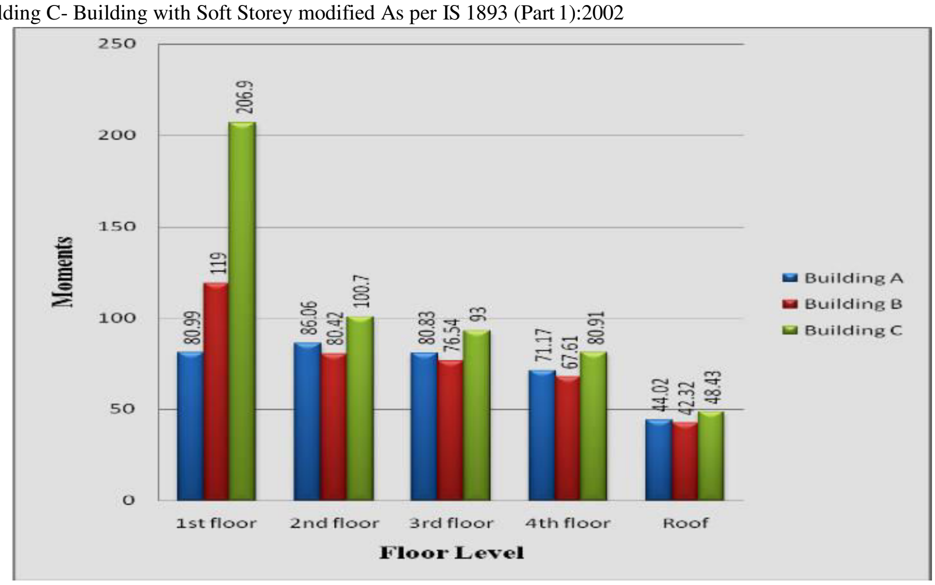

Figure 6: Bending Moments in Corner Column C_1

Table 9: Bending Moments in Intermediate Column C_2

Storey	Column C_2					
	Column No.	Moments M (kN-m)				
		Building A	Building B	% variation in moments	Building C	% variation in moments
Roof	452	30.90	28.49	-8.56	38.76	20.28
4^{th} floor	358	61.81	56.95	-8.53	78.42	21.18
3^{rd} floor	264	79.99	73.41	-8.96	99.01	19.21
2^{nd} floor	170	90.44	85.52	-5.75	124.83	27.55
1^{st} floor	76	91.84	121.82	24.61	216.89	57.66

Column C_2

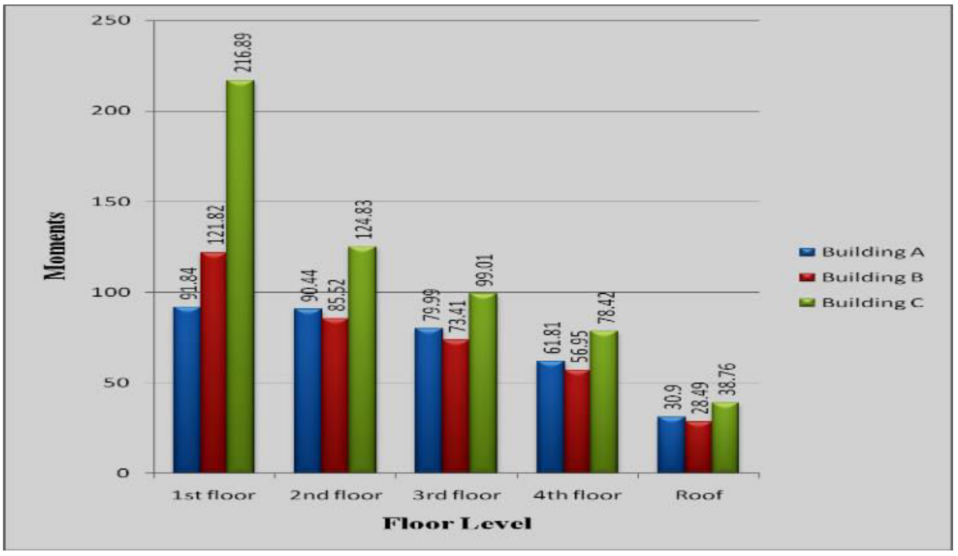

Figure 7: Bending Moments in Intermediate Column C_2

Table 10: Bending Moments in Intermediate Column C_4

Storey	Column C_4					
	Column No.	Moments M (kN-m)				
		Building A	Building B	% variation in moments	Building C	% variation in moments
Roof	454	35.82	33.42	-7.18	43.09	16.87
4^{th} floor	360	61.59	56.85	-8.34	76.58	19.57
3^{rd} floor	266	76.16	71.71	-6.21	96.27	20.89
2^{nd} floor	172	86.09	81.2	-6.02	120.46	28.53
1^{st} floor	78	88.63	120.16	26.24	216.34	59.03

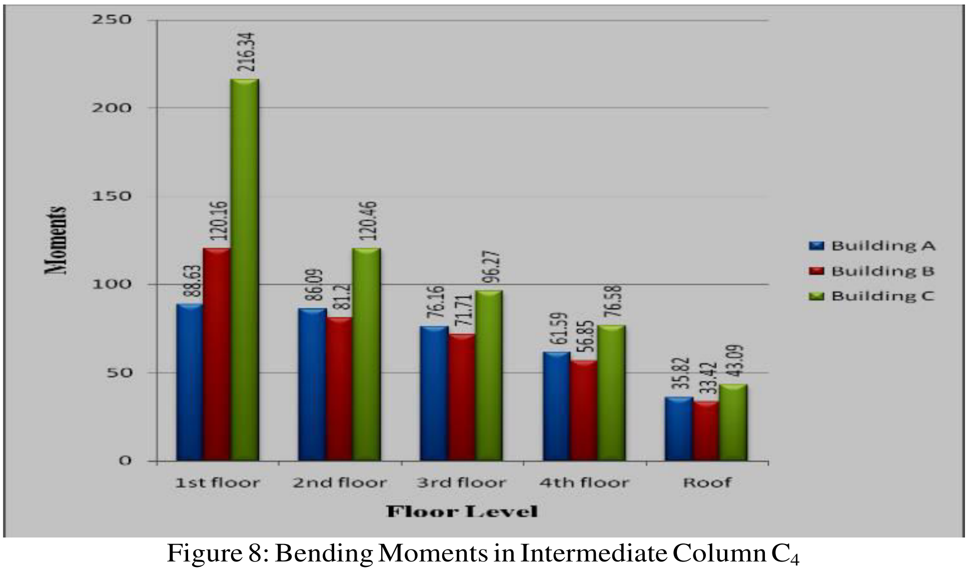

Figure 8: Bending Moments in Intermediate Column C_4

Conclusion

- In this paper, it is proposed that buildings with irregularities are prone to earthquake damage, as observed in many earthquake occurrences. Since current codes fall short of providing simplified analytical tools for irregular structures. It is necessary to develop a simple analytical procedure based on rigorous computations and experiments on the seismic response of irregular structures.
- A three dimensional analysis of a building using general purpose analysis computer programs is able to take care of the eccentricity "e" but without displaying its magnitude. However, there is no general purpose computer programme which is able to account for the design eccentricity, because there is no direct method to compute the center of Rigidity or Shear center at each floor/storey of a building. This is the main reason as to why most designers adopt approximate methods for the torsional analysis of buildings. Some designers consider a torsional analysis to be a secondary analysis. However, this may be an inaccurate assessment. Several studies of structural damages during the past wind storms and earthquakes reveal that torsion is the most critical factor leading to major damage or complete collapse of buildings. It is, therefore, necessary that irregular buildings should be carefully analyzed for torsion.
- Soft storey-For all new RC frame buildings, the best option is to avoid such sudden and large decrease in stiffness and/or strength in any storey; it would be ideal to build walls (either masonry or RC walls) in the ground storey also. Designers can avoid dangerous effects of flexible and weak ground storeys by ensuring that too many walls are not discontinued in the ground storey, i.e., the drop in stiffness and strength in the ground storey level is not abrupt due to the absence of infill walls. The existing open ground storey buildings need to be strengthened suitably so as to prevent them from collapsing during strong earthquake shaking. The owners should seek the services of qualified structural engineers who are able to suggest appropriate solutions to increase seismic safety of these buildings.

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