Behavioural Study of Buildings with Vertical Irregularity

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***Abstract*— Symmetrical and regular structures are usually recommended for an effective design of earthquake-resistant structures; however, various irregularities in buildings are imposed by town bylaws and various occupational aspects. In the past, several major earthquakes have exposed the shortcomings in buildings, which had caused them to damage or collapse. It has been found that regular shaped buildings perform better during earthquakes. The irregularities cause non-uniform load distribution in various members of a building. A gap in effective transmission of forces results in failure of structure. In recent past, various studies have been carried out to evaluate the response of irregular buildings. In this paper, the various effects on structure due to Vertical Irregularities are found out using Response Spectrum analysis on ETABS software**

***Keywords*— Irregularities, Displacement, Time Period, Drift, Base shear, Response Spectrum Method**

I. INTRODUCTION

Now a day in cities due to limitation of space, different floors of buildings are used for different purposes like storing heavy mechanical appliances, car parking, for observatory towers at top etc. this results in variation of mass, strength and stiffness at different storeys. This may lead to building structures with irregularities along height of building. If such buildings are located in a high seismic zone, the structural engineer's role becomes more complicated. Therefore, the structural engineer needs to have a thorough understanding of the seismic response of irregular structures. A building is said to be a regular when the building configurations are almost symmetrical about the axis and it is said to be the irregular when it lacks symmetry and discontinuity in geometry, mass or load resisting elements.

During an earthquake, failure of structure starts at points of weakness and such weakness are formed due to irregularities in structure. Vertical irregularities are one of the major reasons of failures of structures during earthquakes. For example, structures with soft storey were the most notable structures which collapsed. Thus, the study of vertically irregularities in the seismic behaviour of structures becomes really important.

II. DEFINITION OF IRREGULAR BUILDINGS

A. Vertical Irregularities

1)Stiffness Irregularity
a) Soft Storey

A soft storey is one in which the lateral stiffness is less than 70 percent of that in the storey above or less than 80 percent of the average lateral stiffness of the three storeys above.

b) Extreme Soft Storey

An extreme soft storey is one in which the lateral stiffness is less than 60 percent of that in the storey above or less than 70 percent of the average stiffness of the three storeys above.

2) Mass Irregularity

Mass irregularity shall be considered to exist where the seismic weight of any storey is more than 200 percent of that of its adjacent storeys. The irregularity need not be considered in case of roofs. Irregularities of mass distribution in vertical and horizontal planes can result in irregular response and complex dynamics. The central force of gravity is shifted above the base in the case of heavy masses in upper floors resulting in large bending moments.

3) Vertical Geometric irregularity

Vertical geometric irregularity shall be considered to exist where the horizontal dimension of the lateral force resisting system in any storey is more than 150 percent of that in its adjacent storey. The general solution of a setback problem is the total seismic separation in plan through separation section, so that the portion of building is free to vibrate independently.

4) In-Plane Discontinuity in Vertical Elements Resisting Lateral Force

An in plane offset of the lateral force resisting elements greater than the length of those elements.

5) Discontinuity in Capacity - Weak Strorey

A weak storey is one in which the storey lateral strength is less than 80 percent of that in the storey above. The storey lateral strength is the total strength of all seismic force resisting elements sharing the storey shear in the considered direction.

III. PROBLEM FORMULATION

The problem considered for the study is taken from IS 1893-part 1: 2002. The different building frames are considered with stiffness and mass irregularities as taken from IS 1893-part1: 2002.

These five frames have been analysed using response spectrum method of IS 1893-part 1: 2002 while assuming seismic zone IV, and importance factor 1.5. Analysis has been carried out using CSI-ETABS program. Configuration of plan is shown in following figure.

TABLE I
SPECIFICATIONS OF FRAMES

	FRAME 1	FRAME 2	FRAME 3	FRAME 4	FRAME 5
Nature of Building	Regular	Irregular (Similar to Frame 1)	Regular	Irregular (Similar to Frame 3)	Irregular (Similar to Frame 3)
Bays in X	4 @ 5 m	4 @ 5 m	4 @ 4 m	4 @ 4 m	4 @ 4 m
Bays in Y	4 @ 4 m	4 @ 4 m	3 @ 5 m	3 @ 5 m	3 @ 5 m
Storeys	9 (G+8)	9 (G+8)	10 (G+9)	10 (G+9)	10 (G+9)
Typical Storey Height	3m	3m	3.5m	3.5m	3.5m
Column size	500 X 500mm	500 X 500mm	500 X 500mm	500 X 500mm	500 X 500mm
Beam Size	350 X 450mm	350 X 450mm	350 X 450mm	350 X 450mm	350 X 450mm
Slab thickness	200 mm	200 mm	200 mm	200 mm	200 mm
Nature of Irregularity	-	Ground floor height is 4m remaining are 3m	-	Mass at 3rd floor increased by 200%	Mass at 8th floor increased by 200%

OTHER PROPERTIES
Imposed Load: 5.0KN/m2
Floor Finish: 1.0 KN/m2
Waterproofing Finish: 2.0 KN/m2
Grade of Concrete: M30 for all floors
Specific Weight of RCC: 25 KN/m3
Type of Soil: II as per IS 1893 (Part-1) 2002
Response Spectra: As per IS 1893 (Part-1) 2002
Damping: 5%
Response reduction Factor: 5.0

A special situation arises when buildings are perfectly symmetric in mass and stiffness distribution in both plan and elevation (building is in square in plan). Some fundamental or early modes of oscillation are along the diagonal direction and not along the sides of the building. Generally, in such cases, the torsional mode is also an early mode of oscillation. In such buildings, columns undergo bending about axes oriented along their diagonal. To avoid such kind of situation in frames for analysis rectangular frames are selected.

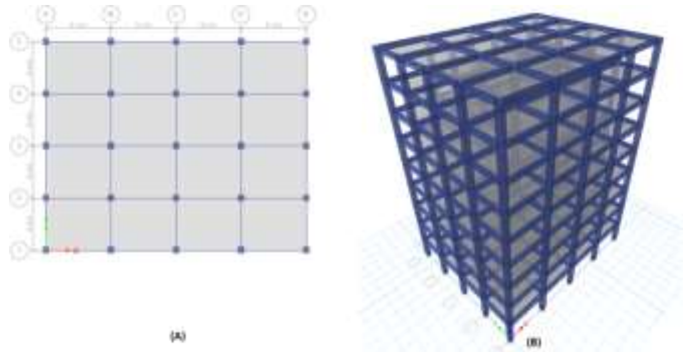

Figure 1 (A) Plan and (B) 3D Elevation of Frame 1& 2

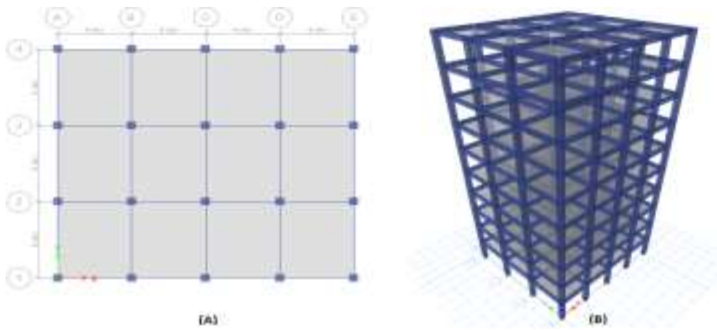

Figure 2 (A) Plan and (B) 3D Elevation of Frame 3,4&5

IV. ANALYSIS RESULT

The five frames have been analysed and their lateral storey-displacements, time period and base shears have been computed to study the effects of irregularities on the frames. The results are presented and discussed hereafter.

A) Storey displacement

The displacement from Response spectrum analysis in X and Y direction is taken for analysis purpose.

TABLE III
DYNAMIC DISPLACEMENT OF FRAME 1 AND 2 IN X AND Y DIRECTION

	FRAME 1	FRAME 2	
Storey	**UX**	**UX**	**%increase**
Storey 9	17.2	18.2	5.81
Storey 8	16.6	17.6	6.02
Storey 7	15.6	16.6	6.41
Storey 6	814	15.2	8.57
Storey 5	12.1	13.4	10.74
Storey 4	9.9	11.3	14.14
Storey 3	7.3	8.9	21.91
Storey2	4.5	6.2	37.77
Storey 1	1.8	3.3	83.33
Base	0	0	

TABLE IIIII

DYNAMIC DISPLACEMENT OF FRAME 1 AND 2 IN Y DIRECTION

	Frame 1	Frame 2	
Storey	UY	UY	%increase
Storey 9	15.6	16.6	6.410
Storey 8	15	16	6.667
Storey 7	14	15.1	7.857
Storey 6	12.6	13.8	9.524
Storey 5	10.9	12.1	11.009
Storey 4	8.9	10.2	14.607
Storey 3	6.6	8	21.212
Storey 2	4.1	5.7	39.024
Storey 1	1.6	3.1	93.750
Base	0	0	

TABLE IVV

DYNAMIC DISPLACEMENT OF FRAME 3,4 AND 5 IN X DIRECTION

	FRAME 3	FRAME 4		FRAME 5	
Storey	UX	UX	%increase	UX	%increase
Storey 10	22.4	23.2	3.57	30.3	35.27
Storey 9	21.6	22.5	4.17	29.4	36.11
Storey 8	20.4	21.2	3.92	27.8	36.27
Storey 7	18.7	19.5	4.28	25.4	35.83
Storey 6	16.7	17.4	4.19	22.4	34.13
Storey 5	14.3	15	4.90	19.1	33.57
Storey 4	11.6	12.3	6.03	15.4	32.76
Storey 3	8.6	9.2	6.98	11.4	32.56
Storey 2	5.4	5.8	7.41	7.2	33.33
Storey 1	2.2	2.3	4.55	2.9	31.82
Base	0	0	0.00	0	0.00

TABLE V

DYNAMIC DISPLACEMENT OF FRAME 3,4 AND 5 IN Y DIRECTION

	FRAME 3	FRAME 4		FRAME 5	
Storey	UY	UY	% increase	UY	% increase
Storey 10	25.5	26.5	3.92	34.8	36.47
Storey 9	24.7	25.6	3.64	33.7	36.44
Storey 8	23.3	24.2	3.86	31.9	36.91
Storey 7	21.4	22.2	3.74	29.2	36.45
Storey 6	19.1	19.8	3.66	25.8	35.08
Storey 5	16.3	17.1	4.91	22	34.97
Storey 4	13.2	14	6.06	17.8	34.85
Storey 3	9.8	10.5	7.14	13.1	33.67
Storey 2	6.1	6.6	8.20	8.1	32.79
Storey 1	2.4	2.6	8.33	3.2	33.33
Base	0	0	0.00	0	0.00

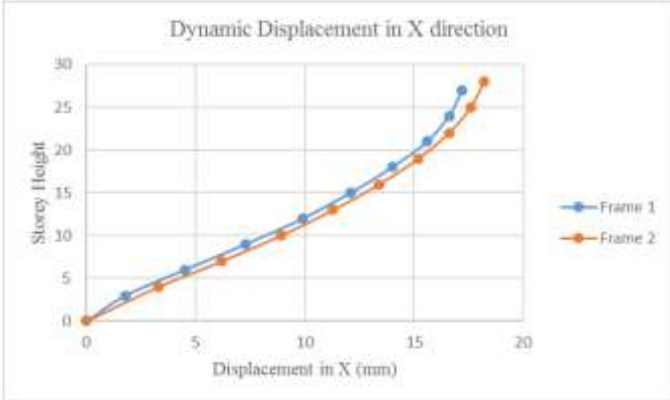

Figure 3 Comparison of Frame 1 and Frame 2 in X direction displacement

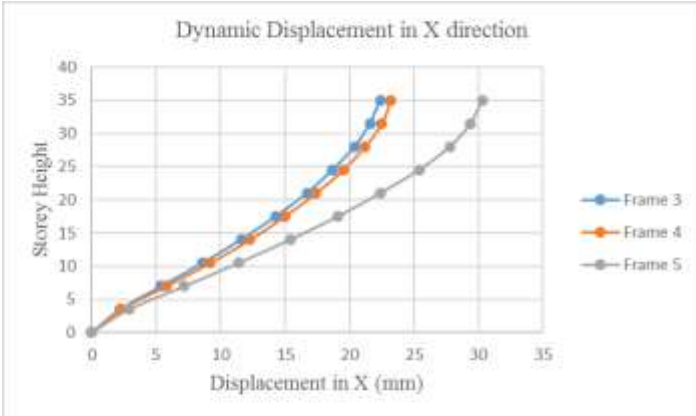

Figure 4 Comparison of Frame 3,4 and 5 in X direction displacement

B) Time Period

Considering first primary 3 mode shapes to find out change in Time period of frames

TABLE VI

COMPARISON OF TIME PERIOD IN FRAME 1 AND 2

	FRAME 1	FRAME 2
	Time Period (sec)	Time Period (sec)
Mode 1	1.109	1.186
Mode 2	1.052	1.129
Mode 3	0.929	0.994

TABLE VII

COMPARISON OF TIME PERIOD IN FRAME 3,4 AND 5

	Frame 4	Frame 5	Frame 6
	Time Period (sec)	Time Period (sec)	Time Period (sec)
Mode 1	1.501	1.519	1.607
Mode 2	1.401	1.419	1.5
Mode 3	1.222	1.236	1.297

C) Storey Shear

The storey shears as given by ETABS using IS 1893 part-1: 2002, are given in Table and also plotted as graph for X direction

TABLE VIII
DYNAMIC BASE SHEAR IN X DIRECTION FOR FRAME 1 AND 2

Storey Height (m)	Frame 1 Storey Shear (kN)	Frame 2 Storey Shear (kN)
27	225.0128	208.24
24	458.314	428.9312
24	641.6597	605.6323
18	791.1684	748.5833
15	919.6639	870.5002
12	1029.925	976.7693
9	1125.42	1071.048
6	1200.79	1152.405
3	1236.261	1206.987
0	1236.261	1206.987

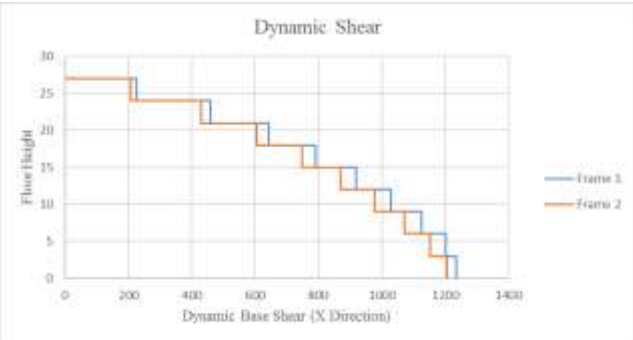

Figure 5 Dynamic base shear in X direction for frames 1 and 2

TABLE IX
DYNAMIC BASE SHEAR IN X DIRECTION FOR FRAME 3,4 AND 5

Storey Height (m)	Frame 3 Storey Shear (kN)	Frame 4 Storey Shear (kN)	Frame 5 Storey Shear (kN)
35	156.7486	158.4958	190.9724
31.5	319.6945	327.3888	386.3116
28	441.8095	457.9281	650.4076
24.5	533.066	554.7	758.2878
21	608.5558	629.7823	842.7016
17.5	675.503	692.6214	917.1744
14	738.0042	749.9058	990.5951
10.5	799.601	866.4249	1066.461
7	852.5811	924.447	1132.389
3.5	878.8428	951.4453	1164.944
0	878.8428	951.4453	1164.944

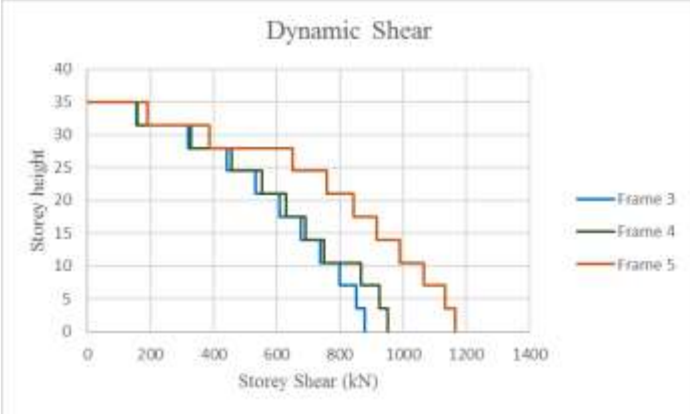

Figure 6 Dynamic base shear in X direction for frames 3,4 and 5

D) Storey Drift

Incremental lateral displacement over two consecutive story levels

Graphs for Storey drift for Regular and Irregular frames are plotted below.

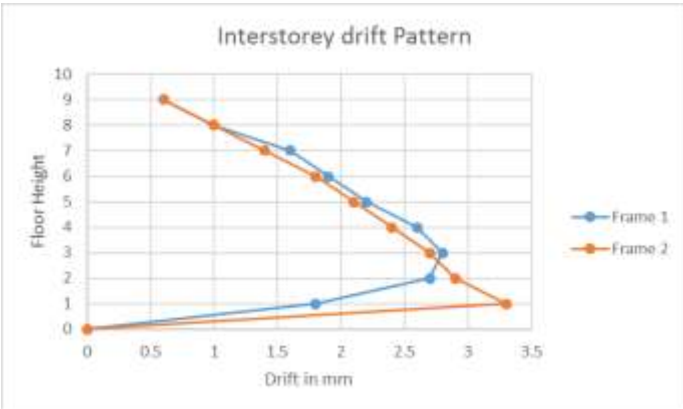

Figure 7 Inter storey drift for Frame 1 and 2 in X direction

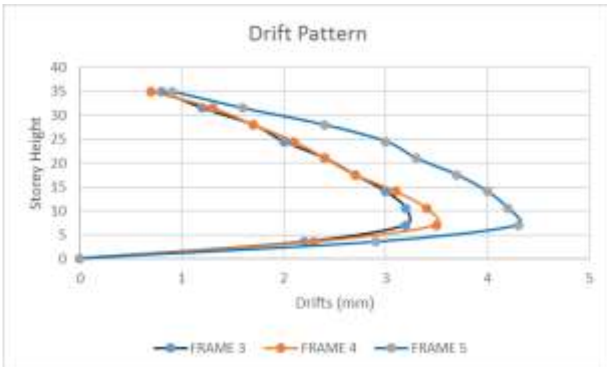

Figure 8 Inter storey drift for Frame 3,4 and 5 in X direction

V. DISCUSSIONS ON RESULTS

A) Considering Storey Displacement compared to Frame 1(Regular), Frame 2(Stiffness Irregular) has more displacement because of introducing stiffness irregularity in structure, as far as storey drift is concerned First Floor of frame 2 is needed to give more attention, because of abrupt change in storey drift is observed.

B) In case of Frame 3(Regular), Frame 4(Mass Irregular at 3rd Floor) and Frame 5(Mass Irregular at 8th Floor) it is observed that storey displacement is increased with increasing mass on structure and changing position of the mass from base. If it is unavoidable to neglect mass irregularity in structure, then placing masses nearer to the ground that will help the structure to reduce lateral displacements. Thus avoiding shifting of mass centroids and P-Delta Effects.

C) Considering time period, buildings with irregularity are having greater time period that of regular building. In case of Frame 2(Stiffness Irregular) increase in height of column, reducing the stiffness of storey thus increasing the time period. As time period increases the storey shear will be comparably less in case of stiffness irregularity compared to Regular building. (Frame 1 and Frame 2)

D) Though the Base shear of Frame 2(Irregular) is less than Frame 1(Regular) but the Lateral force at first floor level is 54.58 kN compared to 36.12 kN increasing the bending moment at external column by 17.41 kN.m

E) Mass irregularity introduced in frame 4(Mass Irregular at 3rd Floor) and frame 5(Mass Irregular at 8th Floor) increases the storey shear by 191.01% and 216.20%

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