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Effect of (Vertical & Horizontal) Geometric Irregularities on the Seismic Response of RC Structures

Zabihullah[1], Priyanka Singh[2] and Mohammad Zamir Aryan[3]
[1,3]M.Tech Student, Department of Civil Engineering,
Amity School of Engineering & Technology, Amity University Noida (Uttar Pradesh), India.
[2]Assistant Professor (III), Department of Civil Engineering,
Amity School of Engineering & Technology, Amity University Noida (Uttar Pradesh), India.

(Corresponding author: Zabihullah)
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ABSTRACT: The performance of a building affected by the earthquake ground motion primarily depends on its configuration. One of the influential reasons for the building's collapse recognized from the precedent earthquakes is the irregular configuration of building. In this way, the analysis and design of a building with irregular configuration particularly, the ones located in a severe seismic zone, turn into a matter of concern. Mostly, the buildings are possessed with a combination of complicated irregularities and considering a simple or individual irregularity may not govern a judicious prediction of the seismic performance of a building. While designing an irregular building, it is essential to select an appropriate type, degree and location of irregularity. The current study deals with the seismic response of RC structures having various individual and combined complicated geometric irregularities. A G+7 storeyed regular building frame is customized by integrating various geometric irregularities in its horizontal and/or vertical planes. Together with a regular configuration, six number of irregular configurations are analyzed and compared using the Response Spectrum Method as per IS-1893 (Part-1): 2016. The comparison among all the models is carried out based on the Base shear, Fundamental period, Storey Stiffness, Lateral- displacement, Storey Drift, Eccentricity and Torsional irregularity. Out of building models with individual irregularity, the horizontally irregular model (M-V) is verified as the most susceptible during the considered earthquake. Oppositely, the vertically irregular model (M-III) is recognized to have a superior seismic performance. Among the building models with a combination of geometric irregularities, M-VII has displayed a better seismic performance indicating that certain combinations of irregularities may decline the seismic response of a building.

Keywords: Geometric irregularity, Lateral Displacement, Storey Drift, Storey Stiffness, Torsional irregularity.

Abbreviations: IS, Indian Standard;G+7, Ground plus Seven; RC, Reinforced Concrete; M-I, Model-I; M-II, Model-II; M-III, Model-III; M-IV, Model-IV; M-V, Model-V; M-VI, Model-VI; M-VII, Model-VII; DL, Dead Load; LL, Live Load; EQX, Earthquake Static Load in X-direction; EQY, Earthquake Static Load in Y-direction; RSX, Response Spectrum Load in X-direction; RSY, Response Spectrum Load in Y-direction; Δ_{max}, Maximum-displacement; Δ_{min}, Minimum-displacement; UX, Translation in X-direction; UY, Translation in Y-direction; RZ, Rotation about Z-direction.

I. INTRODUCTION

The structural configuration and arrangement of structural elements strongly affect the building's behaviour. Experience from the past earthquakes has shown that the buildings having simple and uniform configuration experience less damage [1]. When a building is exposed to the seismic dynamic load, inertia forces are produced in it, which concentrate at the center of mass of the building [2]. The lateral resistanting forces of vertical structural elements such as columns and shear walls resist the earthquake inertia forces and their resultant gets concentrate at a point termed center of stiffness of the building. In case, center of mass does not coincide with the center of stiffness, it will cause to create eccentricity in the building [3-6]. Eccentricity occurs in a building because of its irregular configuration which produces torsion in the building. Location, size and orientation of structural elements have a significant influence on the torsion, due to which a building gets damaged [7].

Regular buildings have no significant discontinuities of mass, stiffness or strength, in horizontal or vertical planes. Oppositely, irregular buildings possess such discontinuities which cause the concentration of forces and deformations where the discontinuity occurs. This may lead to the failure of structural elements at the joints and collapse of the building [8-11]. The uneven distribution of stiffness, mass and geometry along the height of the building is termed as vertical irregularity, while discontinuity in the plan of building, is categorized as horizontal irregularity [12]. These irregularities are usually provided in the buildings for aesthetics and utility purposes. Besides this, the demand of the current generation and growing population has made the engineers inevitable towards the planning of buildings with irregular configurations [13]. The magnitude of the building's response mainly depends upon the position, type, and degree of irregularities provided in that. If all these parameters are considered judiciously in the design of buildings, their performance under the influence of seismic load can be assured [14].

II. RESEARCH SIGNIFICANCE

The current study deals with the seismic response of RC buildings possessing various complicated types of single and combined geometric irregularities in horizontal and/or vertical planes. The study aims to find out the most critical and vulnerable irregularity among all the considered cases and to select an appropriate building model meeting all the demands of a well-built structure. The most important seismic response parameters of all the models will be discussed and assessed judiciously to achieve an authentic and reliable conclusion that could help in the earthquake resistant design of irregular buildings without compromising their performance.

III. METHODOLOGY

A. Method of Seismic Analysis

There are different methods for seismic analysis of buildings with different degrees of accuracy and efficiency. The choice of seismic analysis method usually depends upon the factors such as; Type of externally applied loads (Static or Dynamic), the behaviour of the structure or structural materials (Elastic or Elastic-Plastic) and type of selected structural model (1D, 2D or 3D) [14]. The methods of analysis preferred in this study are both linear analysis i.e. Equivalent Static Analysis and Response Spectrum Analysis.

(i) Linear Static (Equivalent Static) Analysis: This is the simplest method of seismic analysis in which the magnitude of the lateral force depends upon the fundamental period of the structures, defined by an empirical formula of the code. The concept of this method is a dynamic analysis into a partial static and partial dynamic [14]. This method is limited to a single mode of vibration of the structures and is recognized as an appropriate method for the seismic analysis of lower height buildings with regular and even distribution of stiffness and mass.

(ii) Linear Dynamic (Response Spectrum) Analysis: Response spectrum analysis which is also called the multi-mode method of analysis, estimates the maximum response of each mode of the building using a spectrum curve and then combines all the responses with the help of model super-possession [14]. As per IS 1893 (Part-1): 2016, dynamic analysis is recommended for all the buildings, other than the regular buildings situated in the seismic Zone-II and of the height lower than 15m.

B. Load Consideration

To understand the various types of loads and their most critical and worst combinations which may apply to the structure during its life span, is a significant consideration for a safe and satisfying design of the structure. The dominant loads mostly applied to any of the structures are Dead load, Live load and Earthquake or Seismic load. The gravity loads (Dead load and Live load) act in the direction of gravity and are resisted by the vertical members of the structure [15, 16], while earthquake load usually acts in the lateral direction for which the structure should be strengthened laterally.

C. Load Combinations

All the international standards recommend that the loads must be increased by specific load factors to assure that the design strength of the structure is more than the maximum load which may be applied to it. These factors are obtained from the division of theoretical design strength by the maximum actual load expected to be applied in the service life on a building. Various loads acting on the building should be combined following the provisions in the relevant design standard. The worst combination which develops the most destructive influence in the structural members should be adopted [17, 18]. As per IS-875 (Part-5): 1987 – clause 8.0 and IS 1893 (Part-1): 2016, the load combinations containing Dead load, Live load and seismic load based on Equivalent static analysis and Response spectrum analysis, are as follows;

1) $1.5\ DL$
2) $1.5\ (DL + LL)$
3) $1.2\ (DL + LL \pm EQX)$
4) $1.2\ (DL + LL \pm EQY)$
5) $1.5\ (DL \pm EQX)$
6) $1.5\ (DL \pm EQY)$
7) $0.9DL \pm 1.5EQX$
8) $0.9DL \pm 1.5EQY$
9) $1.2\ (DL + LL + RSX)$
10) $1.2\ (DL + LL + RSY)$
11) $1.5\ (DL + RSX)$
12) $1.5\ (DL + RSY)$
13) $0.9DL + 1.5RSX$
14) $0.9DL + 1.5RSY$

D. Software Used

(a) AutoCAD-2013: For convenience in the selection of degree and position of irregularity and a suitable shape for the building, all the models are first visualized in different views using AutoCAD. Once the shape of building and type of irregularity are finalized for all the models, the same are then modelled in ETABS software for further analysis.

(b) ETABS-2017: All the considered models of this study are modelled and analyzed one by one in ETABS software and their obtained results are then converted to tabular, graphical and/or chart form for further discussion to accomplish a better and transparent conclusion.

E. Problem of the Study

A G+7 storeyed regular building model (M-I), is modified by incorporating various geometric irregularities to form six number of irregular models (M-II – M-VII). Out of irregular models, four are possessing individual geometric irregularity while the remaining two are possessed with a combination of geometric irregularities. The aim is to analyze all these models and then compare them based on the seismic response parameters such as Base shear, Fundamental period, Lateral displacement, Storey drift, Eccentricity, and Torsional irregularity.

F. Structural Details and Input Parameters

Following are the structural details and input parameters which are to be applied on all the models.

Table 1: Structural details and input parameters.

Geometric parameters	
Storey height	3m
Overall height of the building	24m
Over all dimension of plan in X-direction	7 bays @ 4m = 28m
Over all dimension of plan in Y-direction	5 bays @ 3.5m = 17.5m
Dimensions of structural members	
Column size	450mm x 450mm
Beam size	400mm x 450mm
Slab thickness	150mm
Thickness of interior wall	125mm
Thickness of exterior wall	250mm
Thickness of parapet wall	120mm
Height of parapet wall	1000mm
Material Properties	
Grade of concrete	M 25
Poisson's ratio	0.2
Grade of steel	Fe 415
Loads Considered	
Unit-weight of Reinforced Concrete	25 kN/m^3
Unit-weight of brick masonry	19 kN/m^3
Floor Finish Load	1.5 kN/m^2
Live Load	4 kN/m^2
Seismic parameters	
Building type	Office
Frame type	SMRF
Seismic zone	Zone-IV
Seismic Zone factor (Z)	0.24
Type of Soil	Medium (Type-II)
Response Reduction Factor (R)	5
Importance factor (I)	1.5
Support condition	Fixed

IV. MODELLING AND ANALYSIS

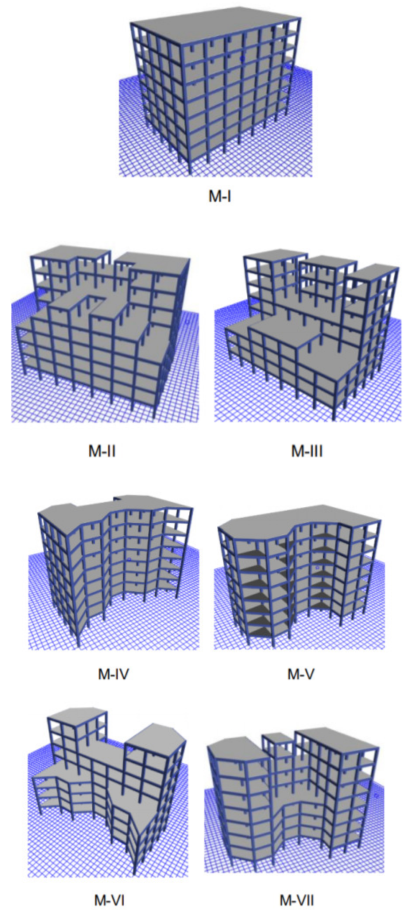


Fig. 1. Considered Building models (M-I – M-VII) adopted in the analysis.

V. RESULTS AND DISCUSSION

The comparison of all the models is mostly carried out considering the short (Y)-Direction of the building.

A. Base Shear

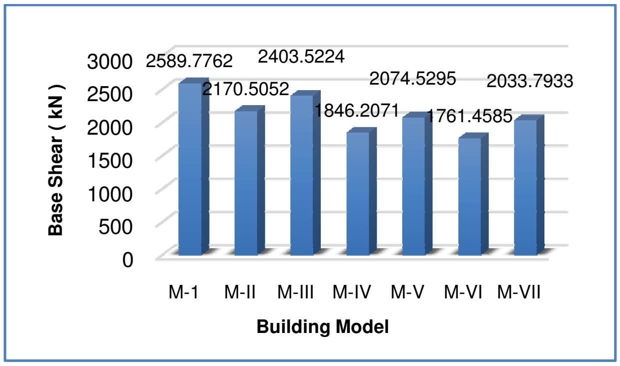
Table 2: Seismic weight and Base Shear.

Building Model		M-I	M-II	M-III	M-IV	M-V	M-VI	M-VII
Seismic weight (kN)		56842.1	42036.53	47822.57	42091.94	46000.95	34202.76	42515.87
BaseShear (kN)	X-Dir	2589.776	2170.505	2403.522	1846.207	2074.53	1761.459	2033.793
	Y-Dir	2623.305	2364.895	2553.082	1933.893	2106.508	1845.77	2077.525

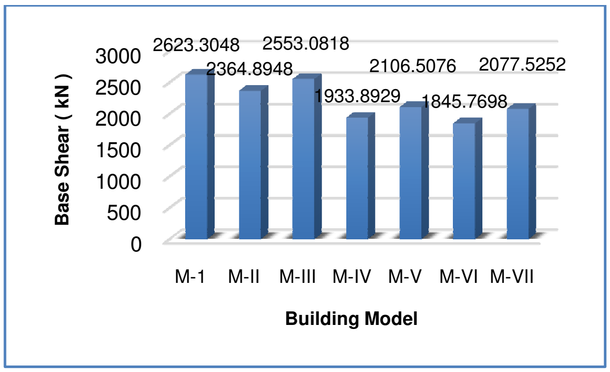
Table 3: Seismic weight and Base Shear in Percentage.

Building Model		M-I	M-II	M-III	M-IV	M-V	M-VI	M-VII
Seismic weight (%)		100	73.953	84.132	74.050	80.927	60.171	74.796
Base Shear (%)	X-Dir	100	83.810	92.808	71.288	80.104	68.015	78.531
	Y-Dir	100	90.149	97.323	73.719	80.299	70.360	79.194

Due to the change in degree and position of irregularity, the seismic weight of all models vary, which directly affect the base shear of the buildings.



(a) Base Shear in X-Direction.



(b) Base Shear in Y-Direction

Fig. 2.

B. Fundamental Time Period

Fig. 2 (b), shows that, with the change in degree and position of irregularity in (plan, elevation or both), the base shear of the building varies.

Model-II and Model-III are vertically geometric irregular with almost same ratio of setback that is assigned from 3rd storey in Model-II and 4th storey in Model-III. The base shears of M-II and M-III are less than that of regularone by 9.85% and 2.68% respectively. This variation is because of the change in position of irregularity of each model.

Model-IV and Model-V are horizontally geometric irregular with different percentage of re-entrant corners. M-IV has 34.28% of re-entrant corners while it is 22.85% in M-V. The base shears of M-IV & M-V are less than that of regular one by 26.28% and 19.7% respectively. This variation is because of the change in the amount of re-entrant corners of each model.

Model-VI and Model-VII are possessed with a combination of vertical and horizontal geometric irregularities. The percentage of re-entrant corners for M-VI & M-VII is same as for M-IV & M-V respectively. The ratio of vertical setback in M-VI is more than that in M-VII that is assigned from 4th storey in both the models. The base shears of M-VI & M-VII are less than that of regular one by 29.64% and 20.8% respectively. This variation is because of the change in the amount of re-entrant corners and vertical setback of each model.

The base shear is found to be maximum (2623.305 kN) for the regular building model (M-I) while it was minimum (1845.77 kN) for the irregular building model (M-VI) that is possessed with a combined geometric irregularity.

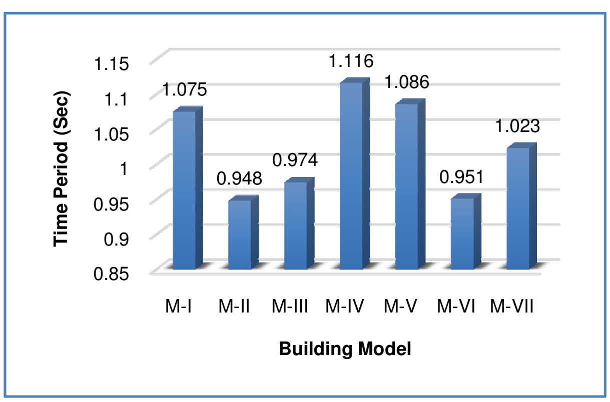
Since the overall dimensions of all the models are same, therefore the fundamental time period calculated by the empirical formula of code ($Ta = 0.09h/\sqrt{d}$), is the same for all the models.

Table 4: Time period calculated by the empirical formula of IS-1893:2016 Part-I (7.6.2).

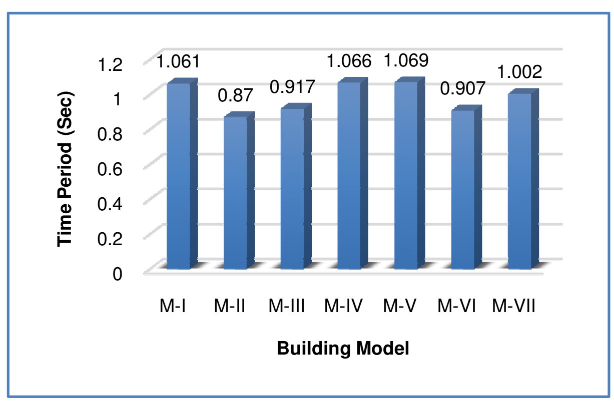
Building Model		M-I	M-II	M-III	M-IV	M-V	M-VI	M-VII
Time- Period (sec)	X-Dir	0.41	0.41	0.41	0.41	0.41	0.41	0.41
	Y-Dir	0.51	0.51	0.51	0.51	0.51	0.51	0.51

Table 5: Time period calculated by ETABS software.

Building Model		M-I	M-II	M-III	M-IV	M-V	M-VI	M-VII
Time- Period (sec)	X-Dir	1.075	0.948	0.974	1.116	1.086	0.951	1.023
	Y-Dir	1.061	0.87	0.917	1.066	1.069	0.907	1.002



(a) Time Period in X-Direction.

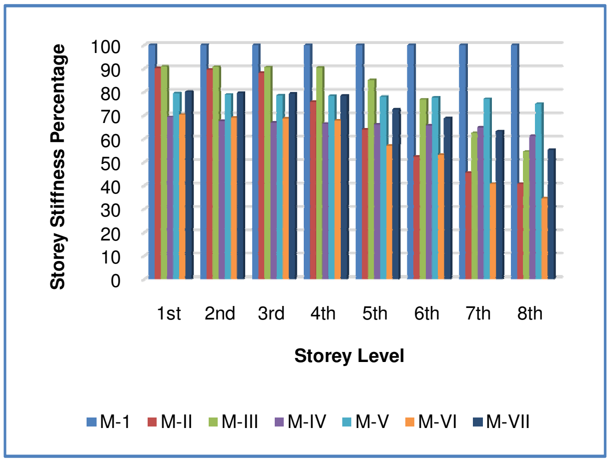


(b) Time Period in Y-Direction.

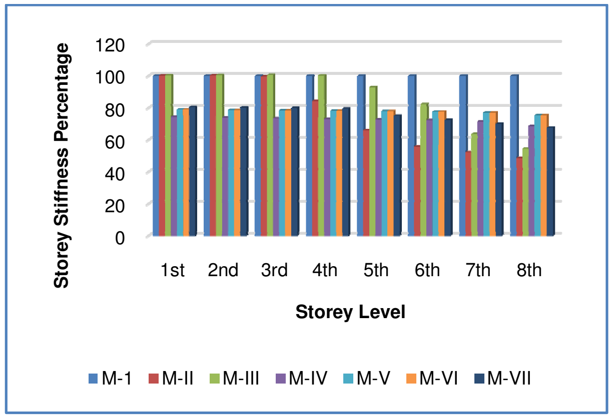
Fig. 3.

As the Time period estimated by the software, is varying for each model, it indicates that the fundamental period of an irregular framed building, is not only dependent on the building's height and base width as recommended in IS-1893 (Part-1) but, it also depends upon the degree of irregularity and the location where it is generated.
The time period in the considered direction is found to be maximum for horizontally irregular building model (M-V) and minimum for vertically irregular building model (M-II).
An incredible change is seen in the time period of few models which might be due to the irregular variation in stiffness and mass of the buildings.

C. Storey Stiffness



(a) Storey Stiffness % in X-Direction.



(b) Storey Stiffness % in Y-Direction

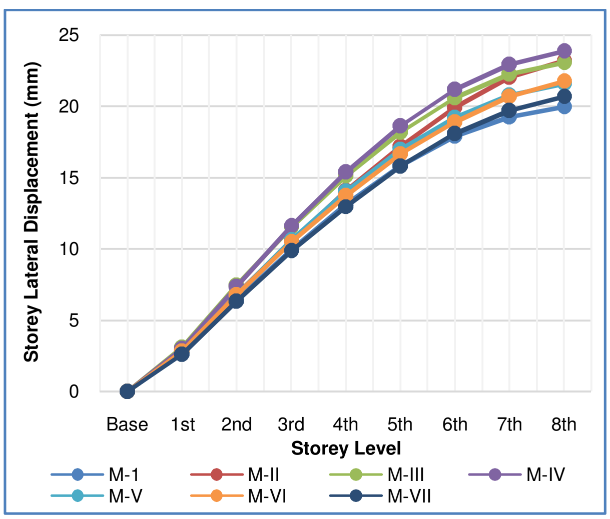
Fig. 4.

The storey stiffness of irregular building models has been reduced as compared to the regular one. This is because of their irregularities, which have decreased the number of columns and their corresponding stiffness, where they exist.
In Fig. 4 (b), it is observed that the stiffness of both horizontally irregular models is reduced as compared to the regular one but, remain stable throughout the building's height. Oppositely, the building models with vertical setbacks display a variable stiffness along the height of the building. Out of building models with the vertical setbacks, M-II has the lowest stiffness in upper storeys.

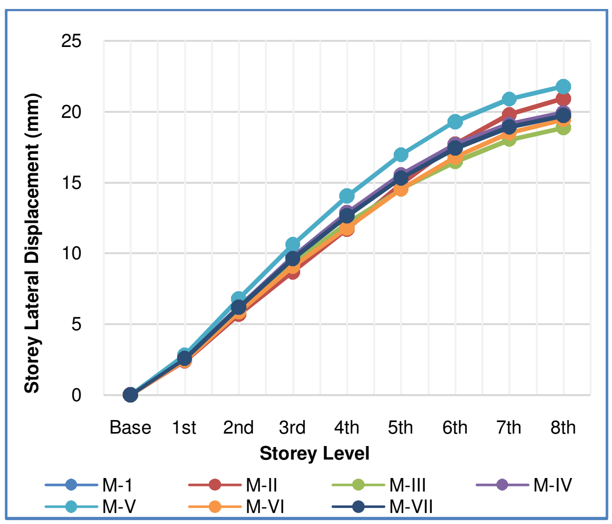
D. Storey Lateral Displacement

Table 6: Top-Storey Lateral Displacement in Percentage.

Building Model		M-I	M-II	M-III	M-IV	M-V	M-VI	M-VII
Top-Storey Lateral Displacement (%)	X-Dir	100	116.210	115.644	119.669	108.160	109.027	103.604
	Y-Dir	100	106.153	95.687	101.085	110.430	98.741	100.040



(a) Storey Lateral Displacement in X-Direction.

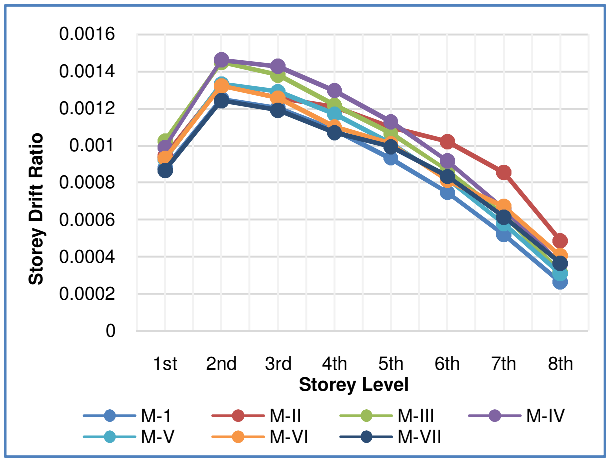


(b) Storey Lateral Displacement in Y-Direction.

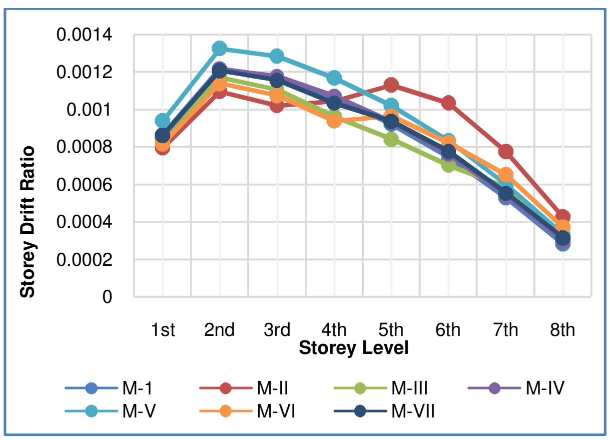
Fig. 5.

As per Fig. 5 (b), the vertically irregular model (M-III) shows the best performance in overall lateral displacement with a minimum top-displacement of (18.862 mm), while the horizontally irregular model (M-V) displays the worst performance with a maximum top-displacement of (21.768mm). The Maximum-Lateral displacements of all the models are within the permissible limit prescribed by the code i.e. (< 0.004H = 96mm), where H is the overall height of the building.

E. Storey Drift



(a) Storey Drift Ratio in X-Direction.



(b) Storey Drift Ratio in Y-Direction.

Fig. 6.

Let us eradicate the confusion between the Storey drift and Storey drift ratio.

Storey drift is the lateral displacement of a storey relative to another storey above or below which is actually a length, while Storey drift ratio is the ratio of Storey drift to the Storey height which is unitless [21]. In fact, both of them describe the same behaviour of a building.

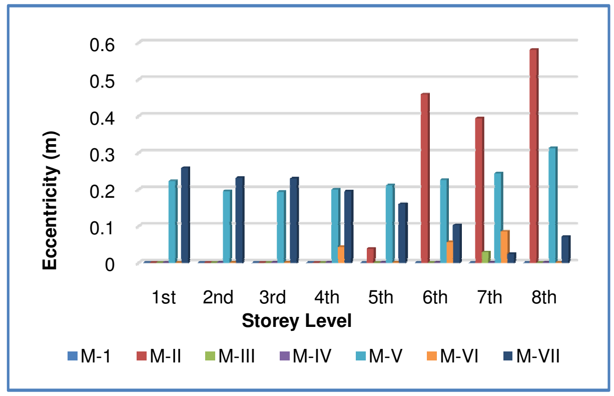
As per Fig. 6 (b), the vertically irregular model (M-III) shows the best performance, while the horizontally irregular model (M-V) comes up with the worst performance in overall Storey drift.

All the models excluding M-II have the maximum Storey drift in their 2ndstorey.

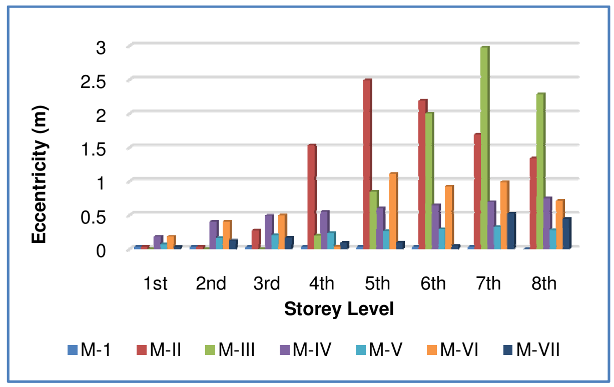
A sudden increment is observed in the storey drift from storey 4thto 5thin M-VI and from storey 3rdto 5thin M-II, which might be because of a sudden reduction in their stiffness due to setbacks.

The Storey Drift ratios of all the models are within the permissible limit prescribed by the code i.e. (< 0.004).

F. Eccentricity



(a) Eccentricity in X-Direction



(b) Eccentricity in Y-Direction

Fig. 7.

Usually, in the buildings with irregular distribution of mass and stiffness, the center of mass and center of resistance locate far from each other and their coincidence is disturbed. This disturbance causes a coupled action in the building due to the application of earthquake-generated inertial forces and the lateral resisting forces of the building, which try to twist the building about its vertical axis.

As per Fig. 7, M-V & M-VII which are asymmetric about both horizontal directions, have shown higher eccentricity in X-Direction as compared to the Y-Direction.

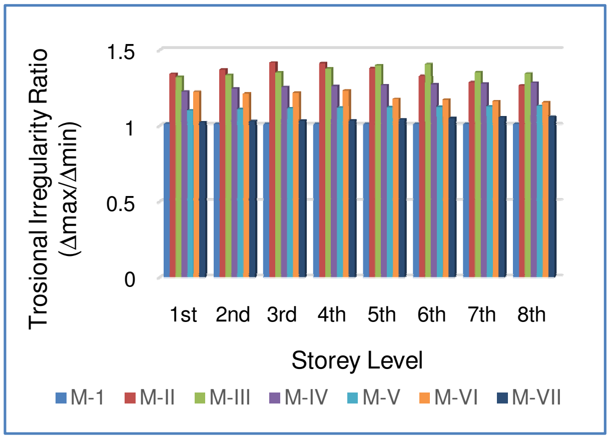
M-II with asymmetric upper storeys has displayed higher eccentricity in both horizontal directions for the upper storeys.

M-III with asymmetric upper storeys only about X-Direction, has shown the highest eccentricity for the 7thstorey in Y-Direction.

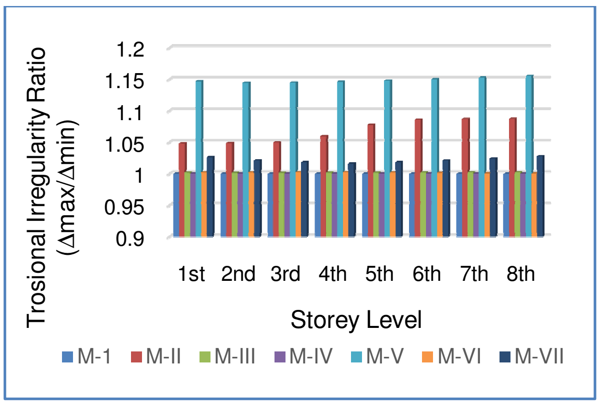
M-IV & M-VI which are asymmetric about X-Direction, have displayed eccentricity only in the Y-Direction.

G. Torsional Irregularity

A building is termed as torsional irregular when; (i) its ratio of maximum-lateral displacement at one end to minimum-lateral displacement at the far end ($\Delta max/\Delta min$)of any floor in the lateral force direction, is greater than 1.5 and (ii) the fundamental period of the third (torsional) mode is greater than those of the first two (transitional) modes [22].



(a) Torsional Irregularity Ratio in X-direction.



(b) Torsional Irregularity Ratio in Y-direction.

Fig. 8.

The graphical representation shows that the Torsional irregularity ratios of all the models are within the permissible limit prescribed by the code i.e. (<1.5). However, the aim is to compare this ratio among all the models.

The buildings with no eccentricity must have Torsional irregularity ratio of 1 or close to 1.

Torsional irregularity has a direct relation with eccentricity but their axis of occurrence get changed, means that if a building has eccentricity in X-Direction it will experience Torsional irregularity in the Y-Direction, and vice versa.

M-I, M-III, M-IV and M-VI had no eccentricity in X-direction, therefore, they have not experienced Torsional irregularity in Y-Direction.

M-II which had a higher eccentricity in both horizontal directions displays higher Torsional irregularity ratio in both directions.

M-III which had a higher eccentricity in Y-Direction shows a higher Torsional irregularity ratio in X-Direction.

M-V & M-VII which had higher eccentricities in X-Direction as compared to Y-Direction shows higher Torsional irregularity ratios in Y-Direction when compared to the X-Direction.

M-VII which has the same plan configuration as M-V, had a greater eccentricity in upper storeys than that of M-V along the Y-Direction but, still has a lower torsional irregularity ratio when compared to M-V in the X-Direction. This may be the effect of combined geometric irregularity in M-VII, which indicates that certain combinations of irregularities may decline the seismic response of a building.

Table 7 shows the modal period of the first three modes for all the models. In all cases, it has been observed that the third torsional mode's period is less than those of the first two transitional modes.

Since, both the checks of the torsional irregularity are passed for all the models, it means none of them is torsional irregular as per IS-1893 (Part-I): 2016 Clause 7.1.

From Table 8, it can be observed that the sum of total modal masses of the considered number of modes is more than 97 percent of the total seismic mass in all cases. This percentage is recommended in IS-1893 (Part-1): 2016 (Clause 7.7.5.2) as (>90%). Hence the considered number of modes is enough according to the code.

Table 7: Modal Period of the first three modes.

Mode	Modal Period (sec)						
	Building Model						
	M-I	M-II	M-III	M-IV	M-V	M-VI	M-VII
Mode-1	1.075	0.948	0.974	1.116	1.086	0.951	1.023
Mode-2	1.061	0.87	0.917	1.066	1.069	0.907	1.002
Mode-3	1.007	0.765	0.809	1.021	1.014	0.862	0.993

Table 8: Modal Mass Participation Ratio of the Considered Modes.

Mode	Modal Mass Participation Ratio											
	Building Model											
	M-I			M-II			M-III			M-IV		
	UX	UY	RZ	UX	UY	RZ	UX	UY	RZ	UX	UY	RZ
1	0.8234	0	0.0003	0.519	0.0056	0.2633	0.6012	4.49E-06	0.2131	0.7179	6.88E-07	0.1001
2	0	0.8223	0	0.0112	0.7382	0.0003	7.45E-06	0.8069	0	1.17E-06	0.8198	0
3	0.0003	0	0.8245	0.2184	0.0066	0.4526	0.2114	3.21E-06	0.5858	0.1021	7.60E-07	0.7205
4	0.0986	0	3.75E-05	0.1429	0.0005	0.028	0.0791	8.76E-06	0.0226	0.0904	0	0.0116

5	0	0.101	0	0.0006	0.1473	0.0007	1.37E-05	0.1029	1.11E-06	0	0.103	0
6	3.76E-05	0	0.0981	0.0034	0.001	0.1522	0.018	6.71E-06	0.0833	0.0105	0	0.0897
7	0.0366	0	1.44E-05	0.0469	5.81E-07	0.0006	0.042	0	0.0012	0.0344	0	0.0029
8	0	0.0365	0	0	0.0468	1.28E-05	0	0.0427	0	0	0.0368	0
9	1.44E-05	0	0.0365	0.0016	0.0001	0.0428	0.0002	0	0.0445	0.0028	0	0.034
10	0.0193	0	7.68E-06	0.0274	0.0001	0.0007	0.0229	0	0.0009	0.0185	0	0.0012
11	0	0.0191	0	0.0001	0.0265	0.0003	0	0.0232	0	0	0.0192	0
12	7.74E-06	0	0.0191	8.70E-06	0.0005	0.0288	0.0002	0	0.0228	0.0011	0	0.0181
SUM	0.9783	0.9788	0.9786	0.9714	0.9731	0.9704	0.975	0.9757	0.9742	0.9776	0.9788	0.9782
%	97.83	97.88	97.86	97.14	97.31	97.04	97.5	97.57	97.4201	97.76	97.88	97.82

Mode	Building Model								
	M-V			M-VI			M-VII		
	UX	UY	RZ	UX	UY	RZ	UX	UY	RZ
1	0.76	0.02	0.0431	0.6526	0	0.1498	0.6941	0.0049	0.107
2	0.03	0.76	0.0241	0	0.7866	5.49E-07	0.0518	0.5892	0.1714
3	0.03	0.04	0.7559	0.1394	0	0.6207	0.0624	0.2165	0.5415
4	0.09	0	0.0046	0.0718	4.49E-06	0.0583	0.1015	0.0006	0.0066
5	0	0.1	0.0033	1.03E-05	0.1192	2.67E-06	0.0016	0.1013	0.0049
6	0	0	0.0917	0.0407	7.95E-06	0.0738	0.004	0.0059	0.0899
7	0.04	0	0.0009	0.0424	0	0.0001	0.0394	7.96E-06	0.0001
8	0	0.03	0.0014	0	0.0432	1.05E-06	1.62E-05	0.0353	0.0037
9	0	0	0.0343	1.56E-05	1.34E-06	0.0452	1.17E-05	0.0037	0.0335
10	0.02	0	0.0003	0.0246	3.22E-06	0.0022	0.0218	2.27E-06	1.58E-05
11	0	0.02	0.0008	8.01E-06	0.0251	1.39E-05	5.14E-06	0.019	0.0016
12	0	0	0.0181	0.0013	2.22E-05	0.0224	5.18E-06	0.0016	0.0182
SUM	0.98	0.98	0.9786	0.9729	0.9742	0.9725	0.9766	0.9781	0.9784
%	97.8	97.9	97.86	97.29	97.42	97.25	97.66	97.81	97.84

Table 9: Modal Mass distribution among UX, UY and RZ in the first three modes in %.

Modal Mass distribution among UX, UY and RZ in %												
Mode	Building Model											
	M-I			M-II			M-III			M-IV		
	UX	UY	RZ	UX	UY	RZ	UX	UY	RZ	UX	UY	RZ
1	99.9636	0	0.036421	65.8713	0.71075	33.41795	73.829876	0.000552	26.1696	87.7628	8.41E-05	12.237
2	0	100	0	1.493931	98.46605	0.040016	9.23E-04	99.99908	0	1.43E-04	99.99986	0
3	0.03637	0	99.96363	32.2314	0.974026	66.79457	26.517706	0.000402	73.4819	12.4119	9.23E-05	87.588

Mode	Building Model								
	M-V			M-VI			M-VII		
	UX	UY	RZ	UX	UY	RZ	UX	UY	RZ
1	92.3	2.47	5.24714	81.33101	0	18.66899	86.11663	0.60794	13.27543
2	3.97	93.1	2.93652	0	99.99993	6.98E-05	6.376169	72.5258	21.09798
3	3.84	4.42	91.7466	18.33969	0	81.66031	7.606046	26.3896	66.00439

Usually, in regular buildings, the first two modes of oscillation should be of pure translation and the third one should be of pure torsion. This mechanism is mostly not applicable in case of irregular buildings which may have some other types of oscillation in the first three modes [23].

As per Table 9, in almost all the irregular building models, some of the modal mass of the first two transitional modes is dissipated by torsion instead of pure translation or displacement in a specific direction. This mechanism interrupts and reduce the lateral displacement but, may cause a stress concentration in some of the structural and/or non-structural members of the building. Here we would like to compare all the models based on the percentage of unexpected mass dissipation by Torsion in the first two modes as follows.

Vertically geometric irregular models M-II & M-III have dissipated more modal mass by Torsion as compared to all other irregular models in the first mode. It means that they are more vulnerable to Torsion in the first mode.

M-IV & M-VI have the same plan configuration, out of which M-VI possess vertical setbacks also, and therefore shows a higher percentage of mass dissipation by Torsion as compared to M-IV in the first mode. The same condition is seen among M-V & M-VII also.

M-V & M-VII have shown a mixed type of oscillation in their second and third mode which may be because of being asymmetric about both horizontal axes.

The overall observations indicate that the buildings with vertical geometric irregularity or vertical set backs, are more susceptible against Torsion, particularly, in the first mode of oscillation.

VI. CONCLUSION

After evaluating the tabular and graphical results of all the models, the following conclusions have been drawn from this study.

– The seismic weight of the building varies due to the variation in degree and position of irregularity which directly affects the base shear of the building.

– The fundamental time period of an irregular framed building is not only dependent on the building's height and/or base width as prescribed in the code IS-1893 (Part-1) but, it also depends upon the degree of irregularity and the position where it is initiated. Hence, the effects of irregularity should be considered in calculating the time period of an irregular building.

– Due to providing geometric irregularity in a building, the building's mass and stiffness get reduce as compared to the same size of a regular building. If the percentage of mass reduction is more than that of stiffness reduction in an irregular building, it will own less time period than that of a regular one, and vice versa. Hence, the proportion between the reduction of mass and stiffness should be maintained carefully.

– The lateral displacement of a building mainly depends upon, its lateral stiffness and the lateral force applied to it. But sometimes, in the buildings with irregular configuration for which the first two modes are not pure transitional, it also depends upon the torsional irregularity. This is because, some of the modal mass in the first two modes, is dissipated by the unexpected Torsion which interrupts the lateral displacement.

– The more asymmetric a building is, the more will be its lateral displacement and storey drift.

– A sudden increment was noticed in the storey drift of buildings with the vertical setbacks because the presence of vertical setbacks causes a sudden reduction in the stiffness of building. Hence, the points where the vertical setback initiates should be strengthened.

– The more asymmetric a building is, the more will be its eccentricity as well as torsional irregularity. It is just because, eccentricity functions as an arm for the torsion moment.

– Irregularities do not always magnify the seismic response but, certain combinations of irregularities may decline the seismic response of a building.

– In irregular buildings, some of the modal mass of the first two modes is dissipated by torsion instead of pure translation or displacement in a specific direction which interrupts and reduce the lateral displacement but, may cause a stress concentration in some of the structural and/or non-structural members of the building.

– Based on the overall comparison, the building model M-V is verified as the most critical and vulnerable among all irregular building models, while the building model M-III is recognized to have a superior seismic performance during the considered earthquake. It does not mean that the building model M-III is completely safe against the considered earthquake but, relative to the other irregular models, it was the best one.

VII. FUTURE SCOPE

The scope of future study is to identify an appropriate and effective structural system to eradicate all the shortcomings of the considered irregular building models.

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