Seismic Planning For Irregular Structures to Avoid Torsion in First Two Primary Modes

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Abstract— During strong earthquakes, it is likely that buildings with torsional irregularity in the plan have can be seriously damaged, partially collapsed or fully collapsed. This is because Torsionally Irregular Buildings may have significant aerodynamic torsion loads that increase the eccentricity between the center of mass and the center of rigidity, especially in dominant torsion modes. For this reason, torsion leads to excessive increase in lateral motions when dynamic loads excite the buildings. Torsional irregularity is one of the main failure causes during strong dynamic excitations due to earthquakes. Ignoring torsional irregularity in seismic design analysis can cause unexpected damages and losses. To enhance the safety and performance of buildings, most of the current seismic provisions address this irregularity in two main ways. The first is computing torsion-al moment at each floor by using equations provided in various current seismic code provisions. After they are applied on each floor, the seismic analysis will be performed. The second is shifting the centre of mass or stiffness to eliminate the eccentricity by putting additional masses or structural components such as braced frame systems on buildings. Recently, reports showing the damage caused by earthquakes indicate that, torsion-al effects often cause considerable damage to structures leading to their collapse. The response of asymmetric buildings towards torsion is one of the most crucial factors for their damage. Torsion in such buildings is due to irregularity in plan, mass and stiffness which may cause severe damage in structural systems. Due to various reasons structures acquire asymmetry. Asymmetric structures have irregular distribution of plan, stiffness and mass, its centre of mass and centre of rigidity do not coincide and hence cause the torsion-al effect on the structures which is one of the most important factor influencing the seismic damage of the structure. Structures with asymmetric distribution of mass and stiffness undergoes torsion-al motions during earthquake. The performance of the structures is assessed as per the procedure prescribe in IS 1893:2016. To assess the torsion-al effect on the structures in the present study, different models with irregular shapes with the different orientation of columns and other lateral load resisting elements were prepared and analyzed using E-tabs 2018 software. For the purpose of study, L shaped building of G + 30 storeys with same columns sizes subjected to gravity loads and seismic loads are analysed using linear dynamic analysis.

Keywords: Torsional Irregularity, Plan Irregularity, Sesimic Analysis, Base Shear, Drift, Displacement, IS 1893 – 2016, ETABS 2018

I. INTRODUCTION

An earthquake is a sudden and destructive shaking of the ground, resulting from released ground energy between the different layers of the earth. This released energy, called earthquake ground motion, sometimes can be brutal and unmerciful when the structures are not well-designed against a strong earthquake motion. It can leave thousands of people dead, wounded and/or homeless. For this reason, civil structures should be well-designed by taking the earthquake ground motion into account in the seismic analysis. The seismic analysis depends on two or three translational components of the earthquake ground motion in terms of design, safety and performance assessment of buildings. The rotational component of the ground motion might contribute significantly to the response and damage of these structures. However, its effect is undetermined because its intensity and frequency content are not measured by accelerographs. Therefore, an unpredictable spatial distribution of load and the effect 2 of the rotational component of the ground motion are usually ignored in seismic design practice (Moon 2012).

Earthquake Ground Motions (EQGMs) are the most dangerous natural hazards where both economic and life losses occur. Most of the losses are due to building collapses or damages. Earthquake can cause damage not only on account of vibrations which results from them but also due to other chain effects like landslides, floods, fires etc. Therefore, it is very important to design the structures to resist, moderate to severe EQGMs depending on its site location and importance of the structure. If the existing building is not designed for earthquake then its retrofitting becomes important.

Seismic requirements were not included in building codes as early as those for wind, although some experimentation had taken place in Europe and even more in Japan, which suffered from frequent seismic activity. Some of the early approaches yielded little result, but that did not stop curious minds from experimenting. The first application of Newton's first law to building codes dealing with seismic design was reportedly made in Italy following the 1911 Messina earthquake. The Present work is giving importance on the study of Seismic demands of irregular buildings using analytical techniques. There are various types of irregularities in the buildings depending upon their location and scope, but mainly, they are divided into two groups- plan and vertical irregularities. In the present paper, the irregularities are considered and described as follows:

A. *Plan Irregularities:*

According to clause 7.1 from Sixth revision of IS 1893-2016 (Part 1). Plan irregularities are classified as torsion irregularity, re-entrant corners, floor slabs having excessive cut-outs or openings, out-of-plane offsets in vertical elements and non-parallel lateral force system.

- Torsion Irregularity: A building is said to be torsion-ally irregular, when maximum horizontal displacement of any floor in the direction of the lateral force at one of the floor is more than 1.5 times its minimum horizontal displacement at the far end in that direction.
- Vertical Irregularities: According to clause 7.1 from Sixth revision of IS 1893-2002 (Part 1). Vertical irregularities are classified as mass irregularity, vertical geometrical irregularity, stiffness irregularity, In-plane Discontinuity in Vertical Elements Resisting Lateral Force and Mass Irregularity:
- Mass irregularity shall be considered to exist, when the seismic weight of any floor is more than 150 percent of that of its adjacent floors. This provision of 150 percent may be relaxed in case of roofs.
- Vertical Geometric Irregularity: Vertical geometric irregularity shall be considered to exist, when the horizontal dimension of the lateral force resisting system in any storey is more than 125 percent of that in its adjacent storey.

The purpose of this hypothetical study is to evaluate the seismic properties and characteristics for regular and plan irregular structures. The main aspect of this analysis is to obtain the sustainability of the building regarding the performance of the buildings by using the aid of capacity and the demand of the structure for a designed strong motion earthquake characteristics using the different method of analysis.

II. Objectives of the Study

- To study the behavioural pattern of structures and their torsion-al behaviour during earthquakes having irregularities in plan.
- To study the parameters of storey displacements, Maximum storey drift of all models during earthquake.
- To study the time periods & mass participating ratios in different modes.
- To study the effect of core walls, shear walls, bracing system, base isolation system etc in irregular structures.

III. Methodology

The purpose of the carrying out the process of seismic analysis is to find actually the several parameters which purely included the force, the deformation, capacities of each of the components in the building structure. These analysis methodologies are listed in a hierarchical order as follows:

1) Linear static analysis (Equivalent Static Analysis)
2) Linear dynamic analysis (Response Spectrum Analysis)
3) Non-linear dynamic analysis (Time History Analysis)

1) LINEAR STATIC ANALYSIS (Equivalent Static Method):

This is one of the simple most analysis procedures which makes ease for the structural designer to perform and carry out the design process. This analytical method is also prescribed in almost all the cod-al formats used for seismological analysis and is used mostly for the building which has some regular parameters of components for the purpose of design. This method is also popular by the name lateral forces method as the effects in this method of seismic motion are purely assumed to be the similar one as that which becomes as a result from the static transverse loads. The different cod-al provision gives their own methods to obtain and to distribute the static forces so that to obtain the effects of seismic ground motion on the structural frames. Generally the expression is initially defined to set a prescribed value of the minimal lateral seismic force, which is also named as the base shear force. The single basic general requirement for the building structure with respect to the application of this methodology is purely that the natural vibration period of the building structure must be limited to a maximal values, which certainly results to a minimal values of frequency or the stiffness. This is because of the fact that often reacts is primarily determine by its first modes of vibrations. Resulting therefore in minimal values of frequency the contribution of the higher modes can be generally neglected.

2) LINEAR DYNAMIC ANALYSIS (Response Spectrum Analysis)

The linear dynamic method of analysis has been proved to be the efficient ever design methods and almost mostly used and suggested by the structural designers for the purpose of analysis and design of the RC framed structure and their respective components. When we carry out the dynamic analysis, the inelastic response is empirically purely reviewed, as the non linear behavioural properties of the buildings which purely govern the designing under the strong ground motion. Due to these reasons the designers suggests and they too prefer the simplex methodology to carry out the analysis with the help of the elastic dynamic analysis methods. The consideration of the modal contributions of each mode is the very important parameter in case of the multi storied buildings. A unique deformation possess at each single modes. The several important factors of the building structures are purely depend on the contributions from these vibration modes. The modal contributions resulting from the higher modes is smaller for the seismic response of a short to medium rise buildings because of the influencing property of the fundamental mode is very larger that is in the range of about 70-90% . Here in this method it is mostly important to consider the vibrations at the initial stages so that we get the results in a almost nearer exactly conditions.

B. Modelling and Analysis of Building

In this paper, for analysis purpose, Different models for L-shaped G+30 storey Building has been prepared with different orientation of columns for reducing the value of torsion in primary translation modes. Other models will be prepared using shear wall, bracing system and base isolation to remove the torsion in primary modes and their effects will be compared.

Details of Models:

- Model 1 – L shaped building with orientation of columns in x direction
- Model 2 – L shape building with orientation of columns in y direction
- Model 3 – L shape building with orientation of exterior columns in y direction and interior columns in x-direction

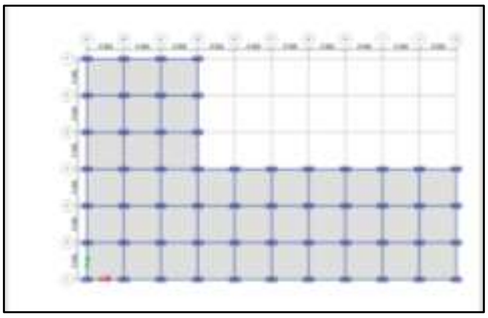
- Model 4 – L shape building with orientation of exterior columns in x direction and interior columns in y-direction
- Model – 5 - L shaped building with shear wall at corners
- Model – 6 - L shaped building with shear wall at centre
- Model – 7 - L shaped building with bracing at corners
- Model – 8 - L shaped building with bracing at centre
- Model – 9 - L shaped building with LRB base isolators

The properties and building configurations in the present study are summarized below:

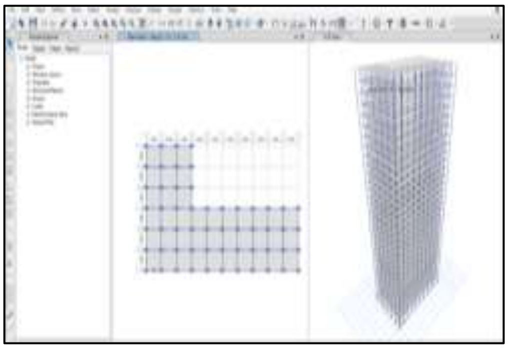
General Properties	
No. of storeys	G+30
Typical Storey Height	3.6 m.
Size of Column	600 mm x 1200 mm
Size of Beam	400 mm x 600 mm
Thickness of Slab	150 mm.
Thickness of Wall	230 mm.
Material Properties	
Grade of Concrete	M 35
Grade of Steel Rebar	Fe 500
Type of Loading	
Wall Load	13.5 KN/m
Live Load	2 KN/m^2
Floor Finishing	1.5 KN/m^2
Seismic Details (IS 1893:2016)	
Seismic Zone	V
Zone Factor	0.36
Importance Factor	1
Type of Soil	II - Medium
Building Type (R)	5 (SMRF)

The response spectrum method plays an important role in analysis and design of multi storied buildings for seismic loads. The maximum response of the building is estimated directly from the elastic and inelastic design spectrums. The building codes are characterized for earthquake motions are based on simplification of the response spectrum method, so this method is extremely significant in the analysis and design procedures. The load combinations will be used for analysis of these models will be according to IS code 1893:2016.

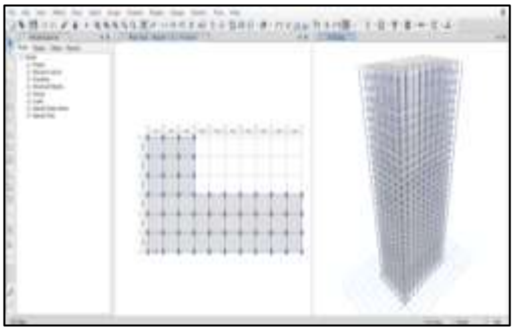
C. *Plan of the Building*



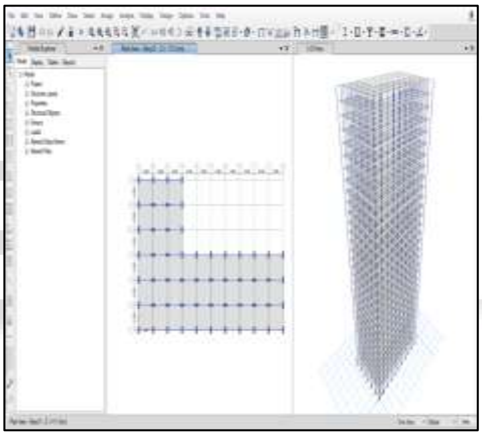
MODEL 1



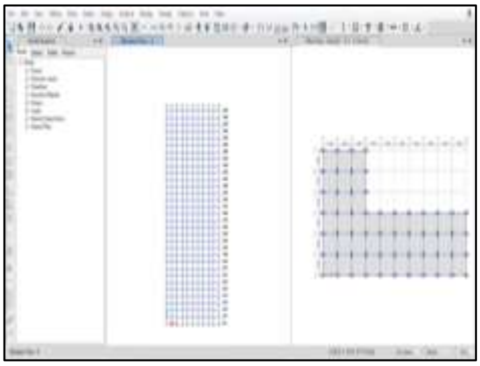
MODEL 2



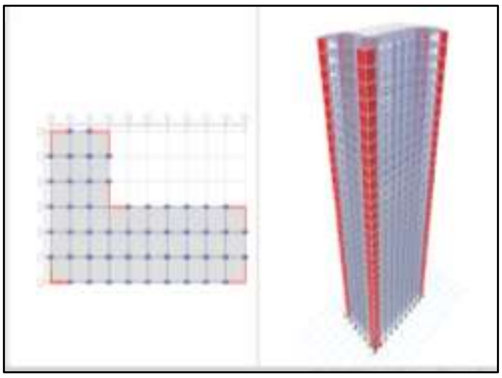
MODEL 3



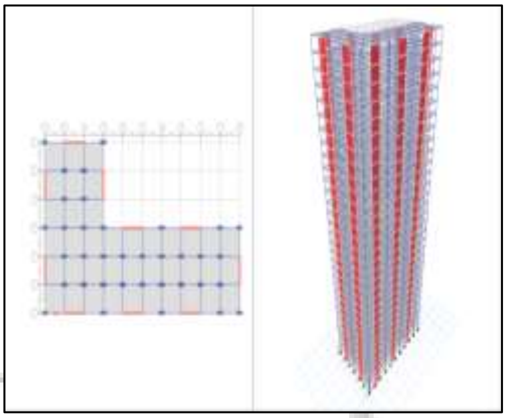
Model 4



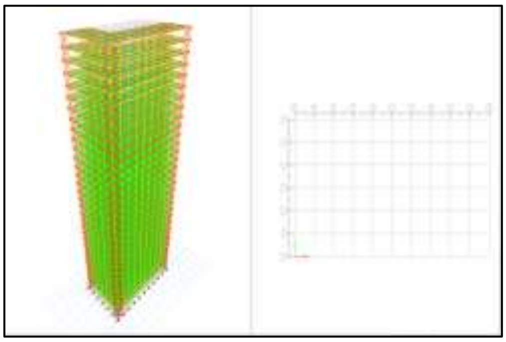
Model 5



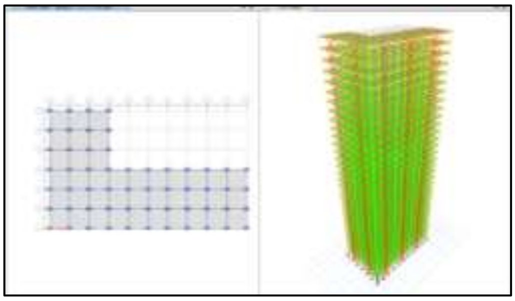
Model 6



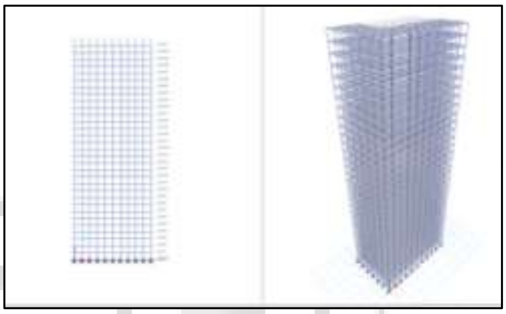
Model 7



Model 8

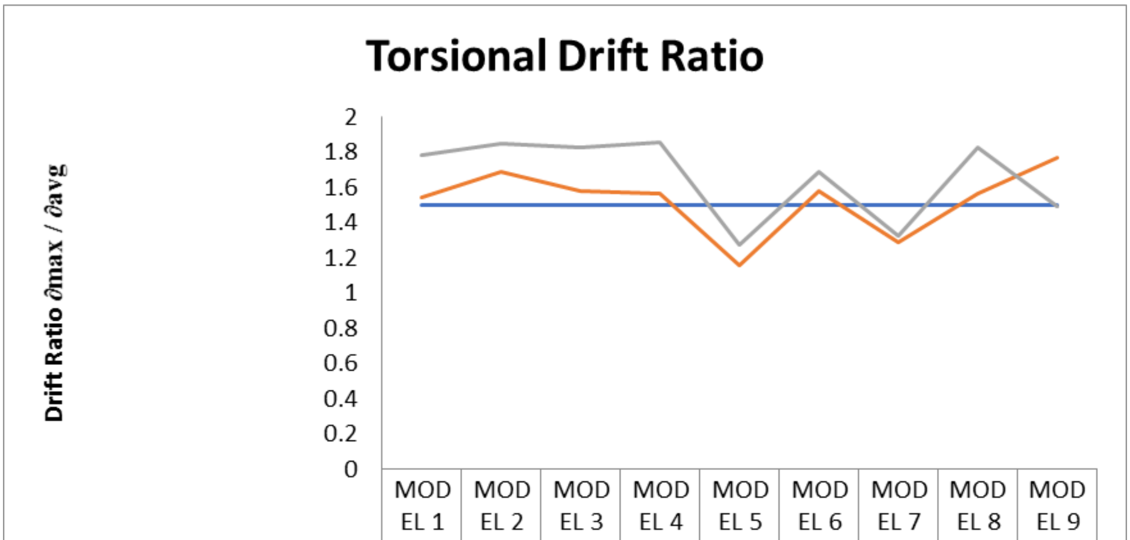


Model 9

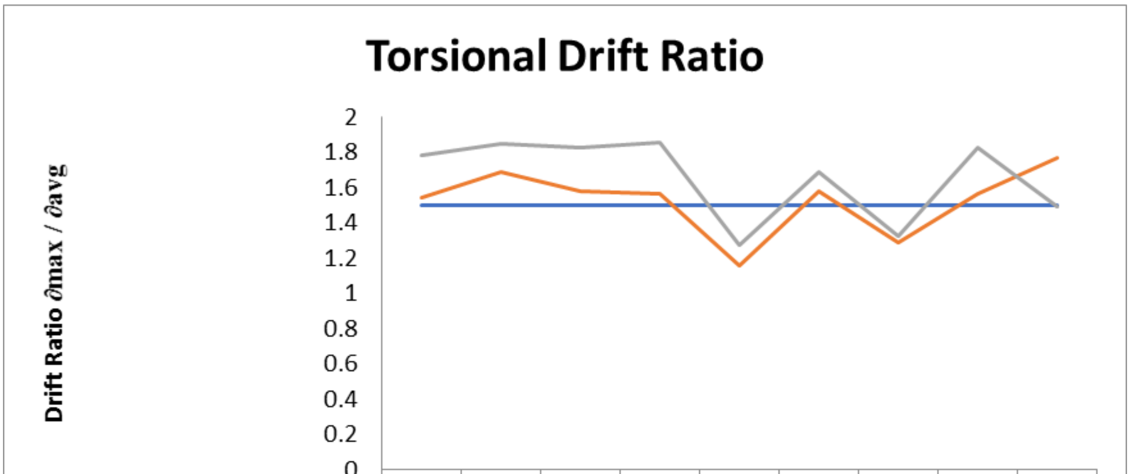


IV. Results

In this study, the results were presented in tabular form and graphs were also presented. The results of maximum storey drifts, maximum storey displacements & torsion-al drift are presented for all the models, and simultaneously the results of irregular building is compared with different configuration and the performance of these models / buildings were observed for seismic loads.



	MODEL 1	MODEL 2	MODEL 3	MODEL 4	MODEL 5	MODEL 6	MODEL 7	MODEL 8	MODEL 9
Limiting Value as per IS	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
Drift ratio in X direction	1.543	1.685	1.581	1.561	1.16	1.578	1.291	1.567	1.771
Drift Ratio in Y direction	1.785	1.845	1.826	1.852	1.272	1.689	1.327	1.83	1.492



	MODEL 1	MODEL 2	MODEL 3	MODEL 4	MODEL 5	MODEL 6	MODEL 7	MODEL 8	MODEL 9
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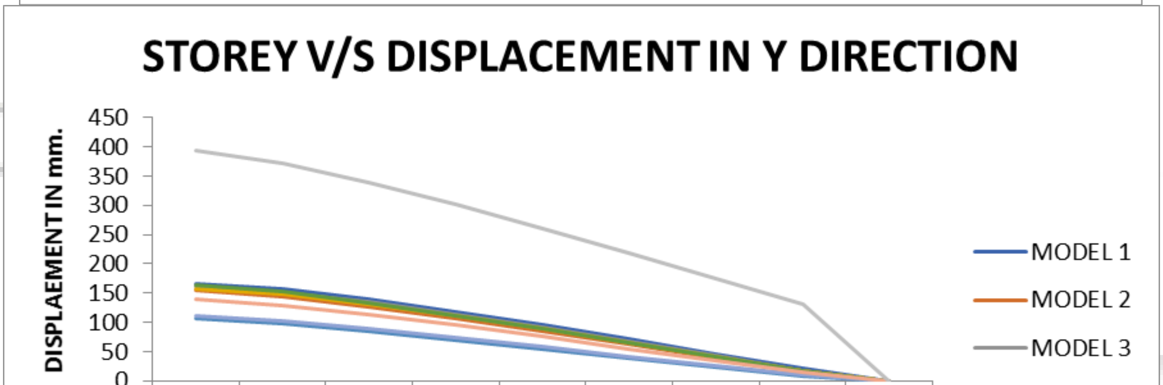
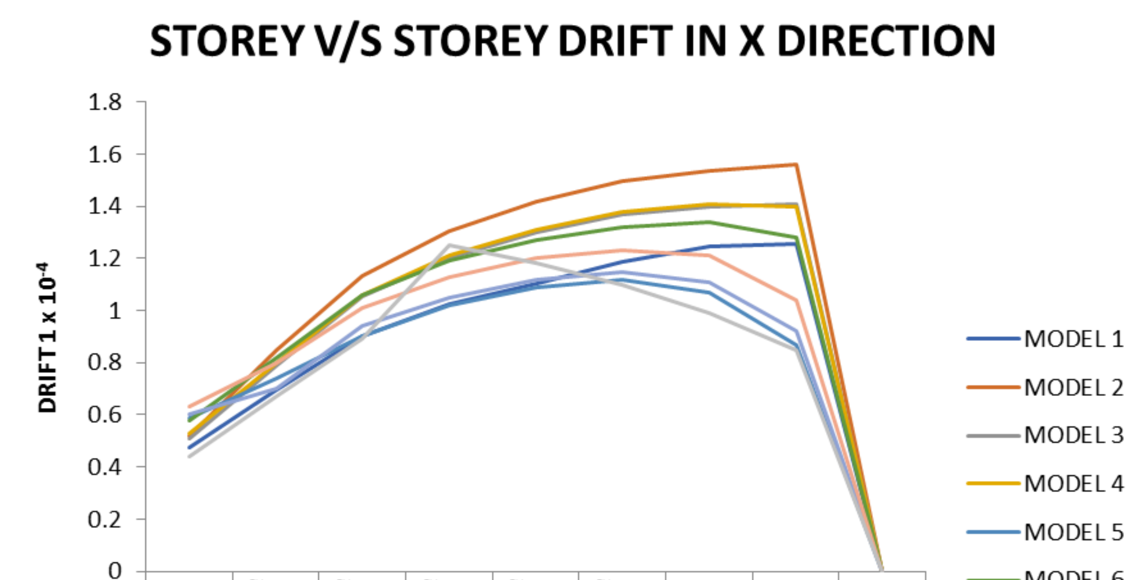
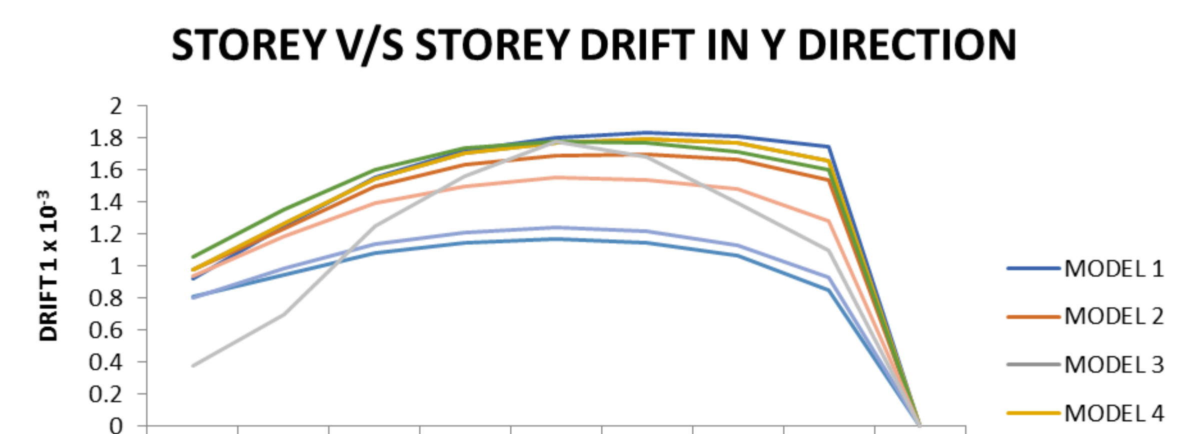


	Top	Storey 28	Storey 24	Storey 20	Storey 16	Storey 12	Storey 8	Storey 4	Base
MODEL 1	166.7	156.43	139.02	118.39	95.53	71.2	46.04	20.57	0
MODEL 2	153.92	143.5	126.6	106.999	85.58	63	39.75	16.43	0
MODEL 3	162.24	151.69	134.28	113.85	91.35	67.49	42.87	18.06	0
MODEL 4	157.57	147.34	130.4	110.58	88.83	65.82	42.09	18.11	0
MODEL 5	106	97	84	70	54	39	23	9	0
MODEL 6	163	152	133	112	89	66	42	18	0
MODEL 7	112.21	103	89	74	58	42	25	10	0
MODEL 8	139	129	113	95	76	55	34	14	0
MODEL 9	393.97	371	338	301	260	218	174	131	0



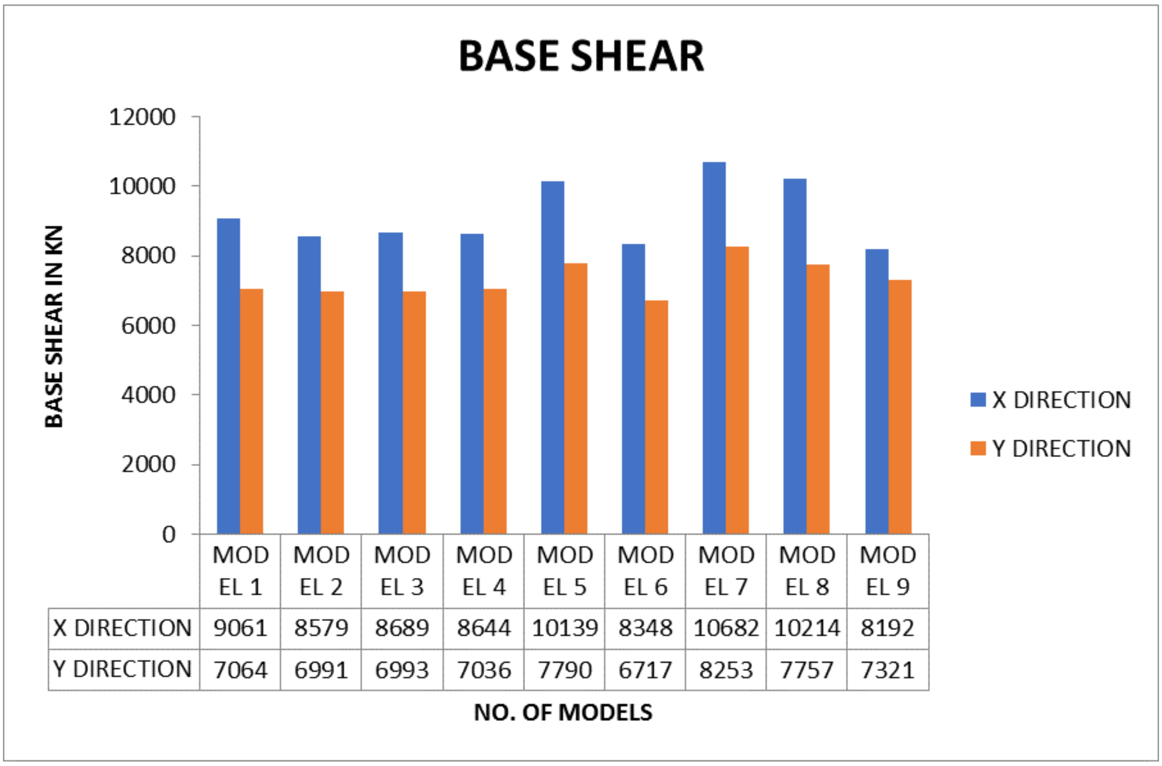
	Top	Storey 28	Storey 24	Storey 20	Storey 16	Storey 12	Storey 8	Storey 4	Base
MODEL 1	0.475	0.694	0.9	1.026	1.105	1.189	1.247	1.258	0
MODEL 2	0.52	0.847	1.133	1.305	1.417	1.496	1.537	1.559	0
MODEL 3	0.51	0.79	1.055	1.2	1.3	1.367	1.399	1.408	0
MODEL 4	0.528	0.8	1.058	1.21	1.309	1.377	1.41	1.397	0
MODEL 5	0.59	0.74	0.9	1.02	1.09	1.12	1.07	0.87	0
MODEL 6	0.58	0.82	1.06	1.19	1.27	1.32	1.341	1.28	0
MODEL 7	0.6	0.7	0.94	1.05	1.12	1.15	1.11	0.92	0
MODEL 8	0.63	0.8	1.01	1.13	1.2	1.23	1.21	1.04	0
MODEL 9	0.44	0.67	0.89	1.25	1.18	1.1	0.99	0.85	0

NO. OF STOREYS



	Top	Storey 28	Storey 24	Storey 20	Storey 16	Storey 12	Storey 8	Storey 4	Base
MODEL 1	0.926	1.254	1.554	1.722	1.803	1.833	1.812	1.749	0
MODEL 2	0.977	1.234	1.498	1.632	1.687	1.696	1.666	1.536	0
MODEL 3	0.979	1.263	1.549	1.702	1.773	1.794	1.768	1.655	0
MODEL 4	0.979	1.263	1.549	1.702	1.773	1.794	1.768	1.655	0
MODEL 5	0.81	0.95	1.08	1.15	1.17	1.15	1.07	0.85	0
MODEL 6	1.06	1.35	1.6	1.74	1.78	1.77	1.71	1.6	0
MODEL 7	0.8	0.99	1.14	1.21	1.241	1.22	1.13	0.93	0
MODEL 8	0.94	1.19	1.39	1.5	1.55	1.54	1.48	1.28	0
MODEL 9	0.38	0.7	1.25	1.56	1.78	1.68	1.39	1.1	0

NO. OF STOREYS



V. CONCLUSION

The results obtained for the building carried out through response spectrum analysis approach will be near to realistic response of the structure to the actual. Following conclusions are made on the basis of the study -

1) The plan irregularities in structures have significant impact on the seismic response of the structure especially in terms of displacement and drift. The value of displacement and drift has been varied for x and y direction due to different symmetries in the respective direction. The use of shear wall reduces the value of drift and displacement for irregular models.
2) Building with irregular plan configuration causes severe damage than the regular building during earthquake in high seismic zones caused due to increase in drift and displacement. The value of displacement and drift are found less in model V as of the use of shear wall in such locations. It is found to be 20% lower than the conventional column building.
3) From the analysed models, the estimated time period for first modes indicated that the model with base isolation shown less vulnerability to seismic actions as compare to other irregular models. Also, it can be concluded that flexible longer period design may be expected to experience proportionately lesser accelerations than a stiffer building.
4) The permissible limit of $\Delta Max / \Delta Min < 1.5$ as per IS 1893(part-1):2016. The maximum torsional irregularity ratio was found for model III which was the L-shaped structure with column orientation in horizontal direction which concludes that the correct orientation of columns is also a key point to remember while design such structures in severe seismic zones.
5) Proper use and positioning of bracing elements like shear wall, core wall etc will reduce the torsional irregularity. Also due to torsional irregularity, the shear forces in columns are high.
6) From the study it is also been observed that though the outside perimeter of the buildings are almost similar, a significant variation in values of torsional related parameters is observed due to plan asymmetry with and without lateral load resisting elements.
7) The value of base shear is found more in model V than other models indicating that structure is much stiffer for seismic response. It is found that the value of base shear for such building with shear wall is 2.4 times higher than the value of base shear for other buildings without shear wall.
8) Special moment resisting frame is more suitable in severe seismic zones than ordinary moment resisting frame.
9) In case of irregular shape structure the centre of mass do not coincide with the centre of rigidity due to asymmetrical positioning of stiff elements with respect to stiffness. Since torsion is the most critical factor leading to major damage or collapse of building therefore, it is very essential that irregular buildings should be carefully analyzed for torsion and designer should try avoid excess irregularities especially in the multi storied building.

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