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SEISMIC ANALYSIS OF RC MULTI-STORIED IRREGULAR BUILDING WITH TORSIONAL EFFECTS

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ABSTRACT

During strong earthquakes, it is likely that buildings with torsion-al irregularity in the plan have can be seriously damaged, partially collapsed or fully collapsed. This is because Torsion-ally Irregular Buildings may have significant aerodynamic torsion loads that increase the eccentricity between the centre of mass and the centre of rigidity, especially in dominant torsion modes. For this reason, torsion leads to excessive increase in lateral motions when dynamic loads excite the buildings. Torsion-al irregularity is one of the main failure causes during strong dynamic excitations due to earthquakes. Ignoring torsion-al 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 regular and plan irregularities were prepared and analyzed using E-Tabs 2018 software. For the purpose of study, regular and irregular buildings of G + 12 storeys with same columns sizes subjected to gravity loads and seismic loads are analysed using linear static analysis.

***Keywords**: Torsional Irregularity, Plan Irregularity, Sesimic analysis, Base Shear, Drift, Displacement, IS 1893 – 2016, ETabs 2018.*

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.

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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:

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.

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 shear, storey displacements, Maximum storey drift of all models during earthquake.
- To study the frequencies and periods in different modes.
- To study the effect of core walls, shear walls etc in regular and irregular structures.

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:

Linear static analysis (Equivalent Static Analysis)

Linear dynamic analysis (Response Spectrum Analysis)

Non linear dynamic analysis (Time History Analysis)

- **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

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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.

- **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.

Modelling and Analysis of Building

In this paper, for analysis purpose, regular and irregular building models with plan irregularity, with certain percentage of irregularities have been used with constant heights of G+12 Stories. The buildings are modelled using finite element software ETABS and dynamic linear analysis (RSA) is performed.
The problem considered for this study is taken from IS 1893-part 1: 2016. In this problem configuration of frames is as given below:

Model 1:- Vertically Regular Building

Model 3 - C Shaped Frame

Model 5 – L Shaped Frame

Model 7 – T shaped Frame

For better enhacement of results, the stiffness of all the models have been increased by introducing the core wall and shear wall at the certain locations in the building. And the results of all the models have been compared and discussed. The models whose stiffness been increased are mentioned below:

Model 2 – Regular Frame with shear and core wall

Model 4 - C Shaped Frame with shear and core wall

Model 6 – L Shaped Frame with shear and core wall

Model 8 – T shaped Frame with shear and core wall

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

RCC Structure	–	G+12 Building
Floor Height	–	3.5 m.
Grade of Concrete	–	M 30
Grade of Steel	–	Fe500
Slab thickness	–	150 mm
Size of Columns	–	400 mm x 1000 mm
Size of Beams	–	400 mm x 500 mm
Brick Wall Thickness	–	230 mm

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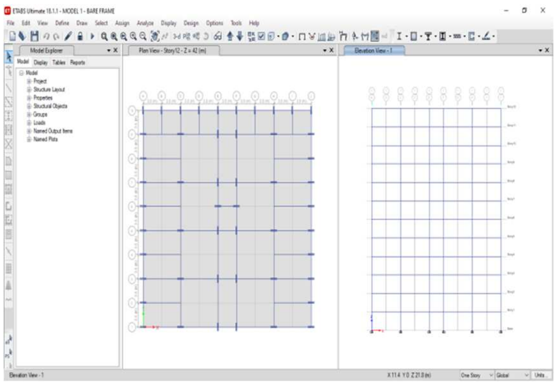
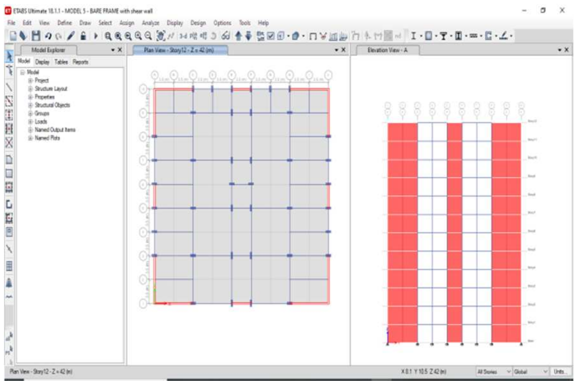
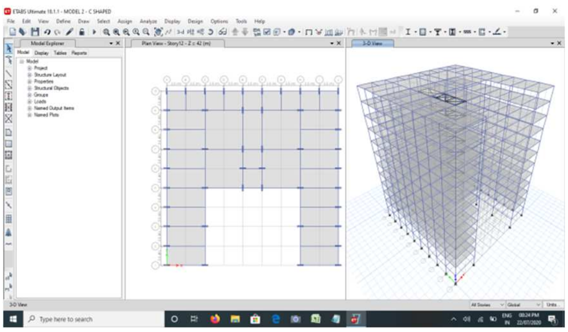
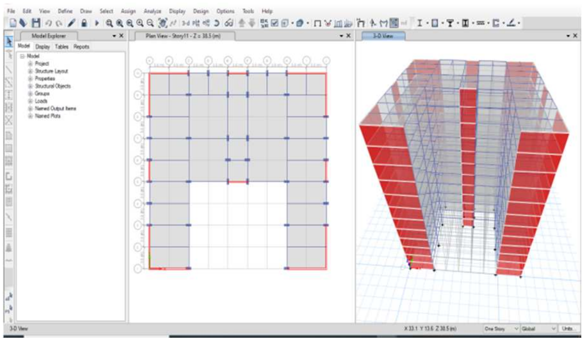
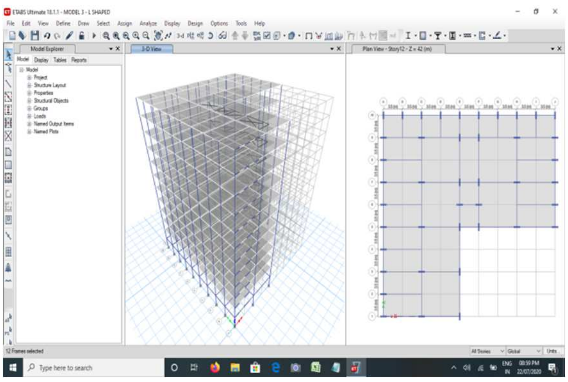
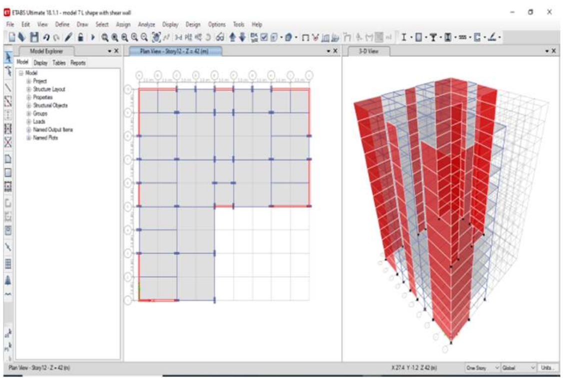
Live Load	–	3 KN/m^2
Seismic Zone	–	V
Importance Factor	-	1
Soil Type	–	II Medium

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.

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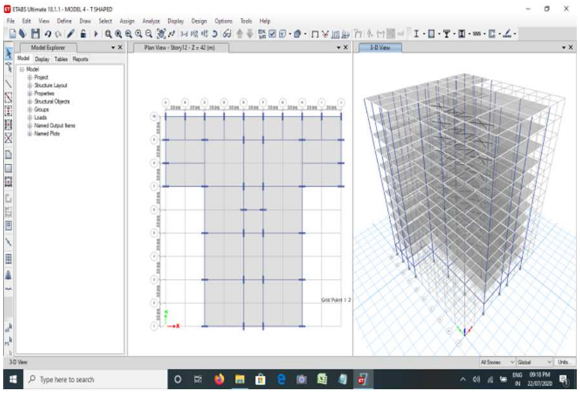
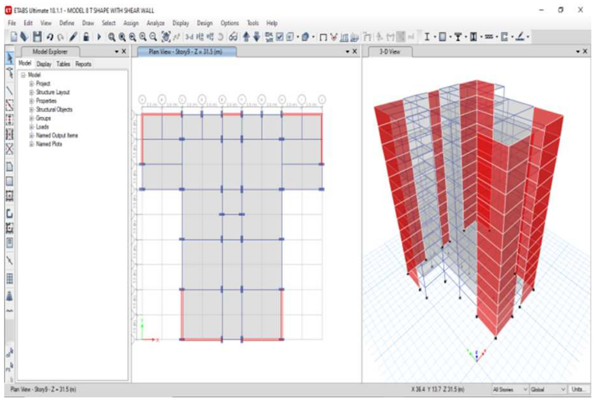
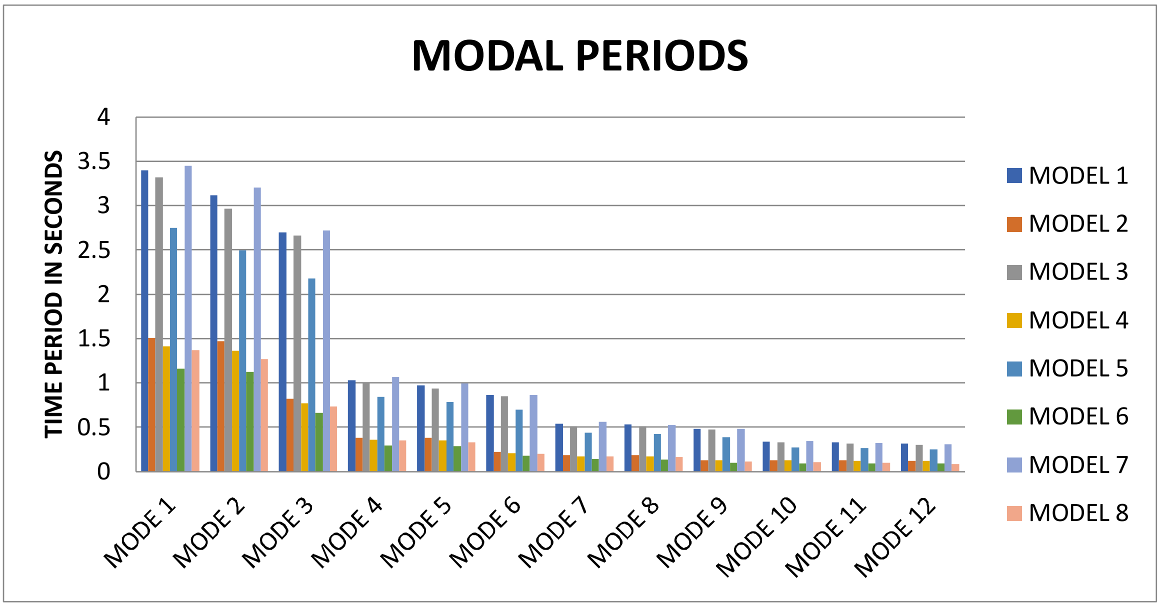




RESULTS

In this study, the results were presented in tabular form and graphs were also presented. The results of time periods and frequencies, maximum storey drifts, maximum storey displacements are presented for all the models, and simultaneously the results of regular building is compared with irregular building and the performance of these models / buildings were observed for seismic loads.

The twelve mode numbers versus the natural period of vibration are depicted in Figure below. The T-Shaped structure (model IV) has shown the maximum natural period of 3.452 seconds and the lowest is found for the L shaped structure with shear and core walls (model VI) with 1.157 seconds, implying that the structure with higher period of vibration have low resistance to seismic actions.



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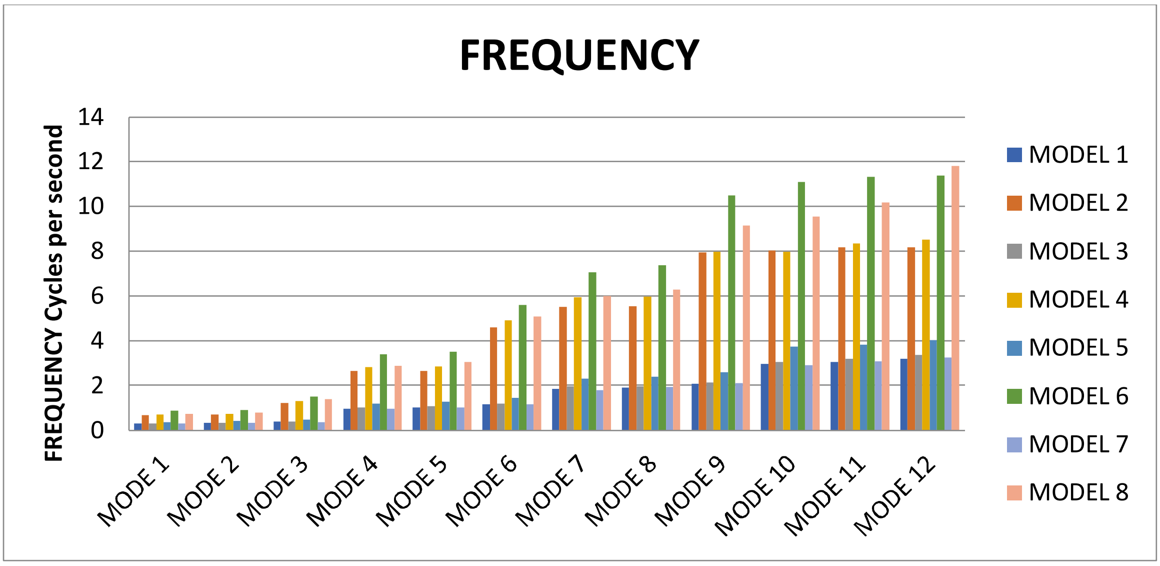
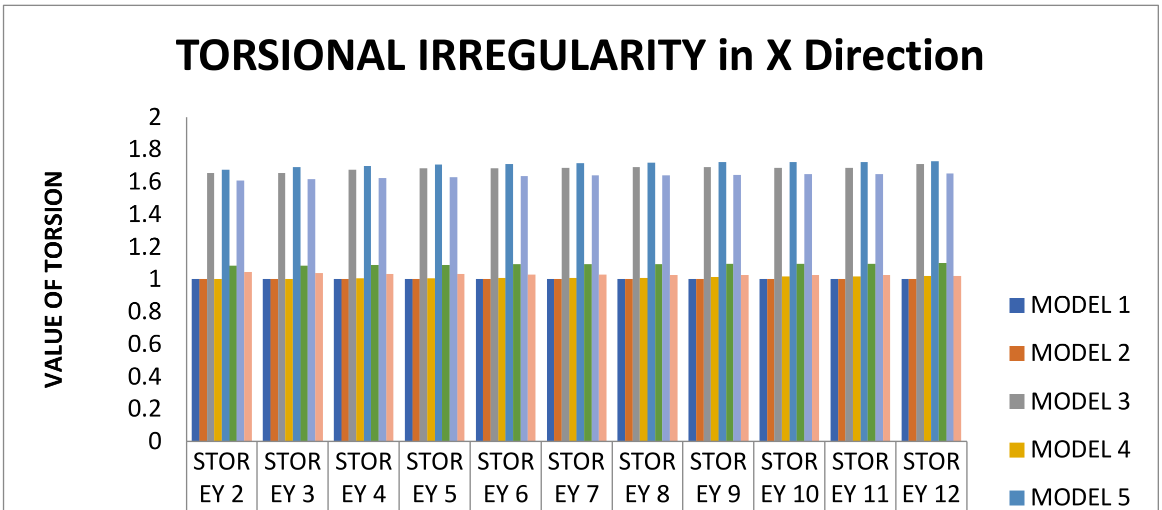


The torsion-al irregularity or drift ratios of models I to VIII are shown in below figure. From the graph it is evident that symmetric structure has got least percentage of variation of maximum to average drift ratio and similar maximum to average drift ratios are exhibited in all stories. Asymmetric structure of L shape exhibited maximum drift ratios and indicates it has got higher degree of irregularity. Models III & VII exhibited almost same range of irregularity, which implies that the structural elements that are being introduced also promote to the torsion effects. In case of model I no lift core, stair loads etc were introduced which in turn made the structure to have equal mass and stiffness distribution.



	STOREY 2	STOREY 3	STOREY 4	STOREY 5	STOREY 6	STOREY 7	STOREY 8	STOREY 9	STOREY 10	STOREY 11	STOREY 12
MODEL 1	1	1	1	1	1	1	1	1	1	1	1
MODEL 2	1	1	1	1	1	1	1	1	1	1	1
MODEL 3	1.653	1.655	1.673	1.681	1.684	1.687	1.689	1.69	1.687	1.688	1.708
MODEL 4	1.001	1.001	1.005	1.006	1.008	1.008	1.009	1.012	1.015	1.017	1.019
MODEL 5	1.675	1.689	1.699	1.706	1.711	1.715	1.718	1.72	1.722	1.723	1.726
MODEL 6	1.083	1.084	1.086	1.088	1.089	1.091	1.092	1.094	1.095	1.096	1.098
MODEL 7	1.607	1.616	1.623	1.628	1.633	1.637	1.64	1.643	1.646	1.648	1.651
MODEL 8	1.043	1.036	1.032	1.03	1.027	1.026	1.025	1.024	1.023	1.022	1.021

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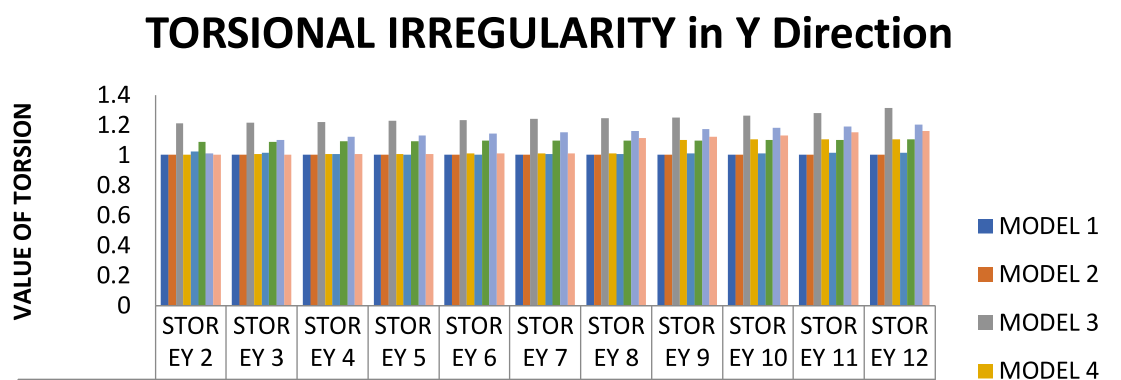
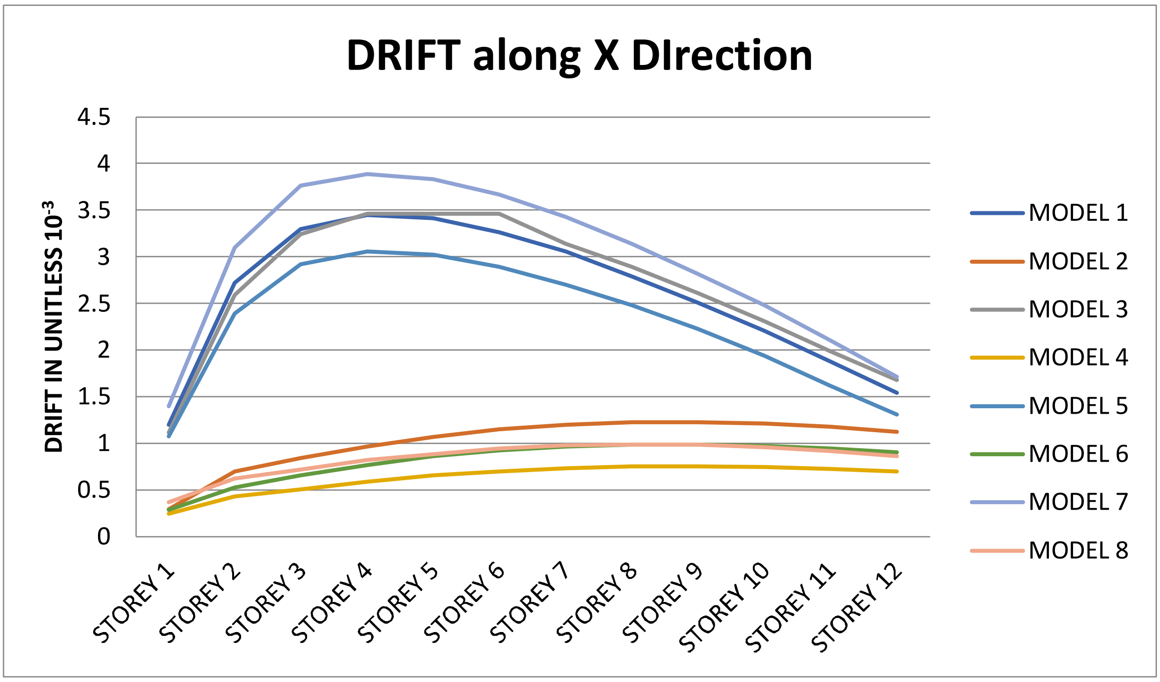
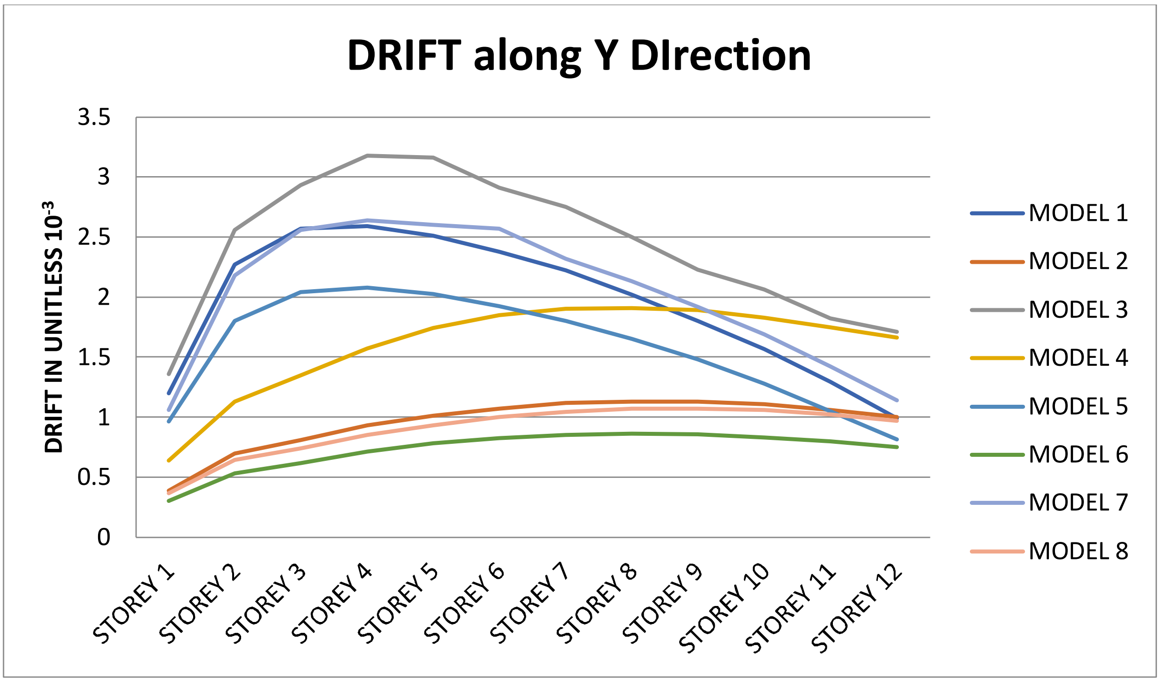


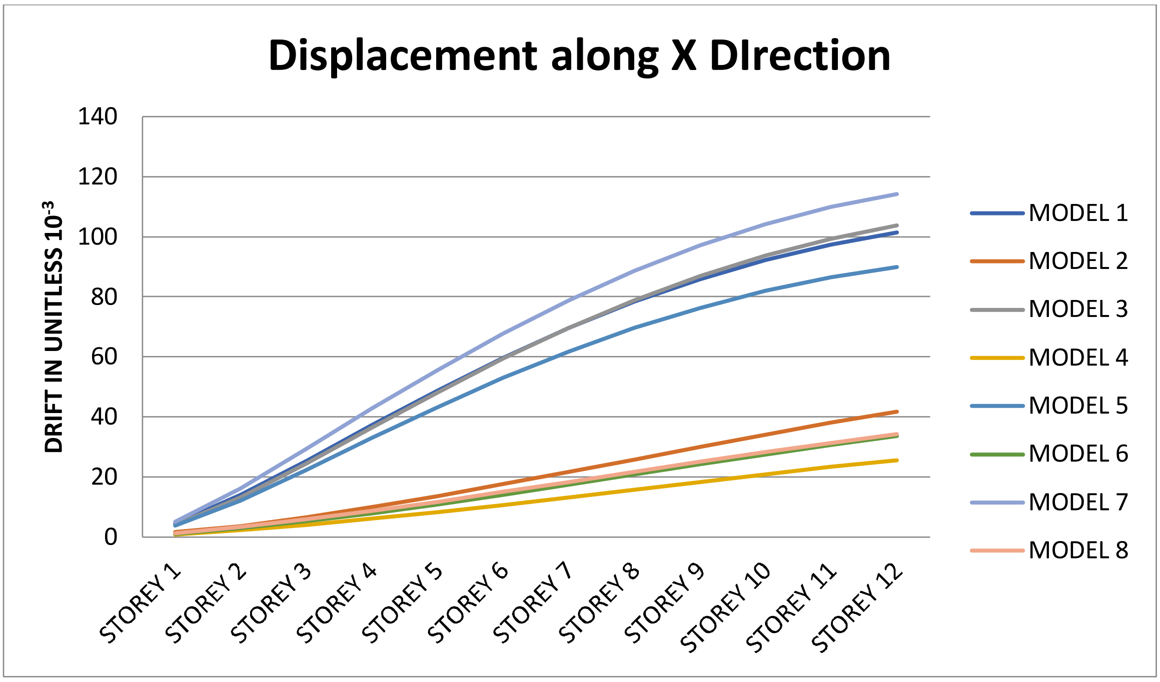
	STOREY 2	STOREY 3	STOREY 4	STOREY 5	STOREY 6	STOREY 7	STOREY 8	STOREY 9	STOREY 10	STOREY 11	STOREY 12
MODEL 1	1	1	1	1	1	1	1	1	1	1	1
MODEL 2	1	1	1	1	1	1	1	1	1	1	1
MODEL 3	1.21	1.216	1.22	1.226	1.23	1.24	1.245	1.25	1.26	1.28	1.31
MODEL 4	1.003	1.005	1.005	1.006	1.008	1.009	1.009	1.1	1.102	1.103	1.105
MODEL 5	1.024	1.014	1.007	1.002	1.002	1.005	1.007	1.009	1.011	1.013	1.015
MODEL 6	1.087	1.088	1.089	1.091	1.093	1.094	1.096	1.097	1.099	1.1	1.102
MODEL 7	1.008	1.1	1.12	1.13	1.14	1.15	1.16	1.17	1.18	1.19	1.2
MODEL 8	1.001	1.002	1.005	1.006	1.008	1.009	1.11	1.12	1.13	1.15	1.16

Below figures compares the drift of all the four models along both X and Y directions. The drift values exceed the permitted drift range which is suggested by IS 1893:2016 Cl 7.11.1[3]. Along X direction model VII has got higher drift value in all stories when compared with other structures. It has got the value of 0.00389 in the fourth storey. The code recommends a maximum permitted drift value of 0.004H where H is the storey height(H=3.5m) and the permissible drift value is 0.014. Along Y direction model III (C-shaped structure) holds the higher drift value of 0.00323.





The storey displacements of all the four models are depicted in Figure below. It shows an increase in storey displacement along the height of the structure. Model VII shows the maximum displacement along X direction followed by different models.



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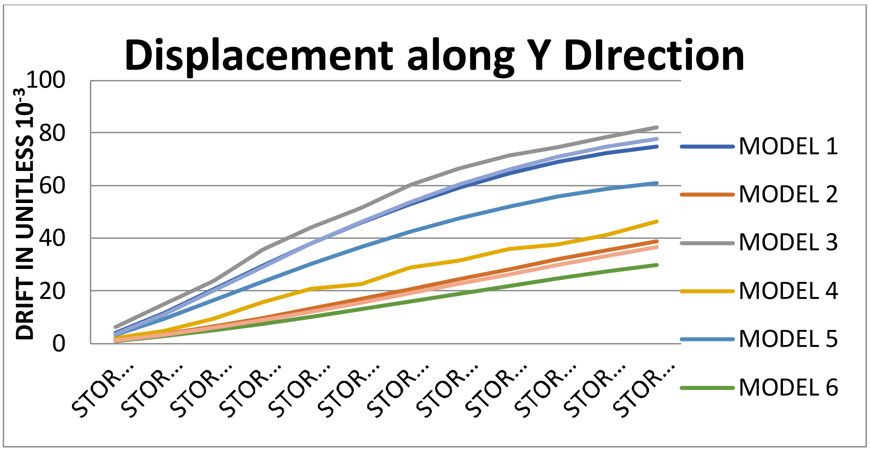
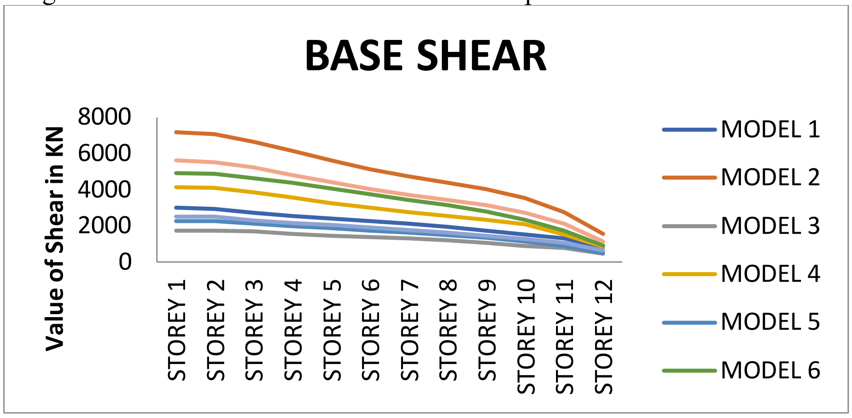


Storey displacement is the predicted movement of a structure under lateral loads, in medium rise structures, the higher the axial forces and deformations in the column and the accumulation of their effects over a greater height, all these causes the flexural component to become dominant. Apart from translational motion there is also floor rotation for displacement.

The value of base shear mainly depends on the stiffness factor of the structure and it is found more in model II than other models indicating that structure is much stiffer for seismic response due to its overall mass distribution.



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.
2. From the analysed models, the estimated time period for first modes indicated that the regular model shown less vulnerability to seismic actions. Also, it can be concluded that flexible longer period design may be expected to experience proportionately lesser accelerations than a stiffer building.
3. The permissible limit of ΔMax / ΔMin < 1.5 as per IS 1893(part-1):2016. The maximum torsion-al irregularity ratio was found for model V which was the L-shaped structure due to its irregularity in both direction
4. Proper use and positioning of bracing elements like shear walls, core walls etc will reduce the torsion-al irregularity. Also due to torsion-al irregularity, the shear forces in columns are high.
5. 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 torsion-al related parameters is observed due to plan asymmetry.
6. The value of base shear is found more in model II than other models indicating that structure is more stiffer for seismic response
7. 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 more in model V as of its asymmetrical shape.

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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 complete 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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