Effect of Combined Plan, Vertical and Mass Irregularity on Torsional Performance of High Raised Buildings

Md Masihuddin Siddiqui[1], Prof N Murli Krishna[2]

[1]Asst. Professor, C.E.D; Muffakham Jah College of Engineering & Technology; Hyderabad, India
[2] Professor, C.E.D; CVR College of Engg.;Ibrahimpatnam, Ranga Reddy., India

***Abstract*: Torsional behaviour of asymmetric buildings is one of the most frequent causes of structural damage and failure during ground motion. Torsion in the buildings is due to the uneven distribution of plan, mass and stiffness which may cause serious damage in structural systems. In the present work, nonlinear dynamic analysis is performed on asymmetrical buildings of 12 stories, 15 stories and 18 stories. All models are analyzed for gravity and seismic forces using ETABS.By varying the stiffness parameters, the stiffness eccentricity is minimized and it is found that the base torsion and rotation joints are significantly reduced. The reduction in torsion was found up to 90% whereas the joint rotation has decreased up to 85%.**

***Keywords*: Torsional response; plan irregularity; stiffness irregularity; mass irregularity; centre of mass; centre of rigidity;non-linear time history analysis.**

I. INTRODUCTION

The earthquakes are the most unpredictable and devastating among all natural disaster. Earthquake is a phenomenon that occurs due to the geotechnical activities in the strata of the earth and causes heavy loss to both life and property if it occurs in populated regions. Thus, it is the responsibility of a structural engineer to draw out the parameters from previous experiences and consider all the possible hazards that the structure may be subjected to, in the future, for the purpose of safe design of the structure. It would be ideal if all buildings have their lateral-load resisting elements symmetrically arranged and earthquake ground motions would strike in known directions. Due to scarcity of land in big cities, architects often propose irregular buildings in order to utilize maximum available land area and to provide adequate ventilation and light in various building components. However, it is quite often that structural irregularity is the result of combination of both types. Most buildings have some degree of irregularity in the geometric configuration or the distribution of mass, stiffness or strength. Due to one or more of these asymmetries, the structures lateral resistance to the ground motion is usually torsionally unbalanced creating large displacement amplifications and high force concentrations within the resisting elements which can cause severe damages and at times collapse of the structure. Eccentric arrangement of non-structural components, asymmetric yielding, presence of rotational component in ground motions and the variations in the input energy imparted by the ground motions also contribute significantly to the torsional response of buildings[4].

II. TYPES OF IRREGULARITIES IN BUILDINGS

During an earthquake, failure of structure starts at points of weakness. This weakness arises due to discontinuity in mass, stiffness and geometry of structure. The structures having this discontinuity are termed as Irregular structures. Irregular structures contribute a large portion of urban infrastructure. Vertical irregularities are one of the major reasons of failures of structures during earthquakes. So, the effect of vertically irregularities in the seismic performance of structures becomes really important. Height-wise changes in stiffness and mass render the dynamic characteristics of these buildings different from the regular building.

There are two types of irregularities as per IS 1893-2002[3]

1. Plan Irregularities
2. Vertical Irregularities.

These irregularities are further divided into sub-divisions as follows

Table 1: Various Irregularities as per IS 1893-2002

S.No	Plan Irregularities	Vertical Irregularities
1	Torsion irregularity	Vertical Geometrical irregularity
2	Re-entrant corners	Stiffness irregularity
3	Openings	Mass Irregularity
4	Out-of-plane offsets	In-plane discontinuity in vertical elements resisting lateral force
5	Non-parallel systems	Discontinuity in capacity

In the present work an attempt is made to study the effect of combination of plan and vertical irregularities in the asymmetrical buildings of 12 storeys, 15 storeys and 18 storeys. The structure is designed in accordance with IS 456-2000[2] and seismic code IS 1893-2002 using non-linear time history method with the help of ETABS[1].

III. METHODOLOGY

During earthquake vibrations, asymmetrical structural system's inertia force (f_I) acts through the centre of mass while the resisting force (f_R) acts through centre of rigidity. The coupling of earthquake force (P_{eff}) and resistive force (f_R) will cause torsional moment (TM). The building will try to rotate about its centre of rigidity. Whereas, in the case of symmetrical building centre of mass and centre of rigidity will coincide. So, the building will move only in translation manner. Fig 1 shows the generation of torsional moment in building.

TM= P_{eff}*e, where, e = stiffness eccentricity (offset between centre of mass and rigidity)

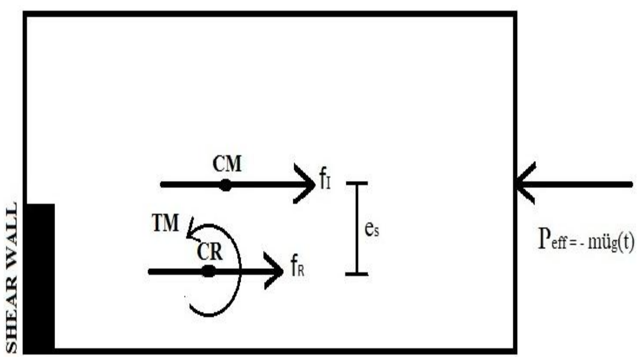


Figure 1: Generation of the Torsional moment

The stiffness of the structure is predominantly dependent upon the stiffness of Lateral Load Resisting Elements (LFREs), which are R.C. Columns in this case. Hence to vary the stiffness eccentricity the LFREs sizes should be altered. In this work, the columns cross sectional dimensions are modified to change the position of stiffness eccentricity, thereby reducing the Torsional Moment of the structure.

IV. CASE STUDY

To evaluate the effect of stiffness eccentricity on Plan as well as vertically asymmetric buildings three U Shaped buildings and three buildings with openings has been analysed. The description of the models is given in the Table 2

Table 2: Desciption of the models

Model 1	12 storied U shape building
Model 2	15 storied U shape building
Model 3	18 storied U shape building
Model 4	12 storied building with openings
Model 5	15 storied building with openings
Model 6	18 storied building with openings

The basic models considered are reinforced concrete ordinary moment resisting frame of uniform column sizes. All these buildings have been analysed by non- linear dynamic analysis [time history analysis]. The typical storey height is 3m for all models. The "Bhuj" earthquake data is used as ground motion data for performing non-linear time history analysis. The typical plan configurations for all the models are as shown in the fig '1' & '2'

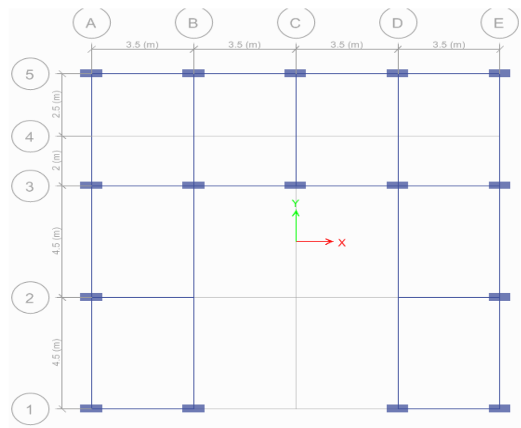


Fig 1 Plan view of Model 1, 2 & 3

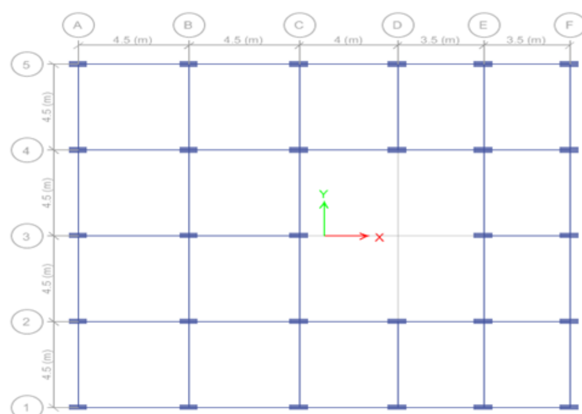


Fig 2 Plan view of Model 4, 5 & 6

4.1 Torsionally irregular buildings

Model 1, 2 & 3 represents the buildings with torsional irregularity. As per IS 1893-2002, the condition for Torsional Irregularity in that

$\Delta_{max} > 1.5*(\Delta_{min})$, where Δ_{max} is the max.displacement&Δ_{min} is the min. displacement of the same storey.

After performing the equivalent static analysis for the structures the following displacements were observed.

Model 1:

$\Delta_1 = 21.783$ mm (Δ_{min}), $\Delta_{14} = 34.795$ mm (Δ_{max}),

→$\Delta_{max} > 1.5*(\Delta_{min})$, hence the condition of torsional irregularity is satisfied.

Model 2:

$\Delta_1 = 23.004$ mm (Δ_{min}), $\Delta_{11} = 38.387$mm(Δ_{max})

$\Delta_{max} > 1.5*(\Delta_{min})$, hence the condition of torsional irregularity is satisfied.

Model 3:

$\Delta_1 = 29.085$ mm (Δ_{min}), $\Delta_{11} = 50.045$mm (Δ_{max})

$\Delta_{max} > 1.5*(\Delta_{min})$, hence the condition of torsional irregularity is satisfied.

4.2 Buildings with Openings

Model 4, 5 & 6 represents the buildings with buildings with opening. As per IS 1893-2002, the condition for openings in buildings which are considered irregular is that area of opening should be less than 0.5 times the total area of the floor, i.e.,

$A_{Opening} < 0.5\ A_{Total};$

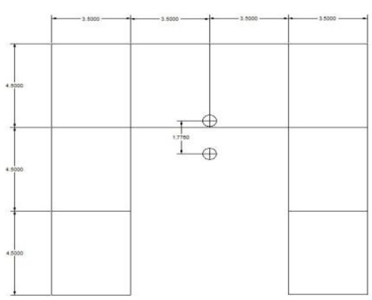
For models 4, 5 and 6 (as they have same plan),

$A_{opening} = 67.5\ m^2$

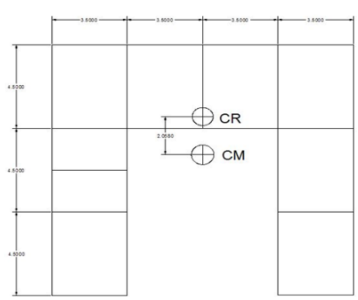
$A_{Total} = 360\ m^2$

Hence $A_{Opening} < 0.5\ A_{Total};$

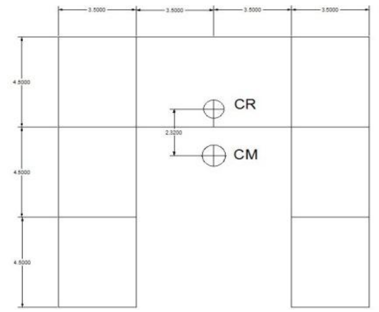
The stiffness eccentricities for all the models are calculated.



Model 1 Stiffness ecc. = 1.776 m.

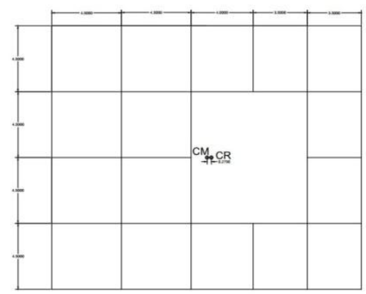


Model 2 Stiffness ecc. = 2.058 m

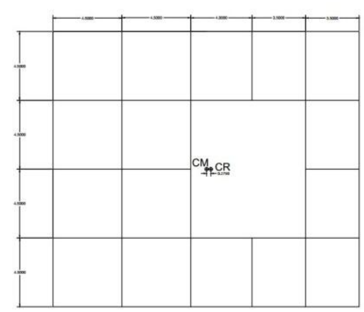


Model 3 Stiffness ecc. = 2.32m.

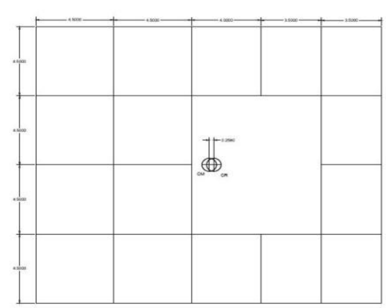
Fig 3a Stiffness Eccentricities of Model 1, Model 2 & Model 3



Model 4 Stiffness ecc. = 0.289 m.



Model 5 Stiffness ecc. = 0.279 m.



Model 6 Stiffness ecc. = 0.258 m.

Fig 3b Stiffness Eccentricities of Model 4, Model 5 & Model 6

The base torsion is evaluated by performing nonlinear time history analysis. The sizes of columns of all the six models are modified such that their eccentricities are minimised and the modified models are re-analysed, to evaluate the effect on torsion in the buildings.

V. RESULTS AND DISCUSSIONS

The following results are obtained by carrying out the nonlinear dynamic analysis (FNA) in ETABS.

5.1 Comparison of Base Torsion.

The base torsion which is a crucial parameter in the seismic evaluation of asymmetrical building is compared. Table 5 represents the comparison between the base torsion of Original Models with that of Modified Models (Minimized ecc. Models)

Table 5 Comparison of Eccentricities andTorsion

Model	Eccentricity		Torsion (kNm)		Reduction in Torsion
	Original Models	Modified Models	Original Models	Modified Models	
Model 1	1.776	0.639	5825.631	1588.826	73%
Model 2	2.058	1.046	7466.670	1749.878	77%
Model 3	2.320	1.390	9344.246	2566.915	73%
Model 4	0.289	0.036	1274.596	270.171	79%
Model 5	0.279	0.023	1540.977	227.309	85%
Model 6	0.258	0.017	1678.938	162.205	90%

The comparison of the torsion values for each building is shown in fig 4-9

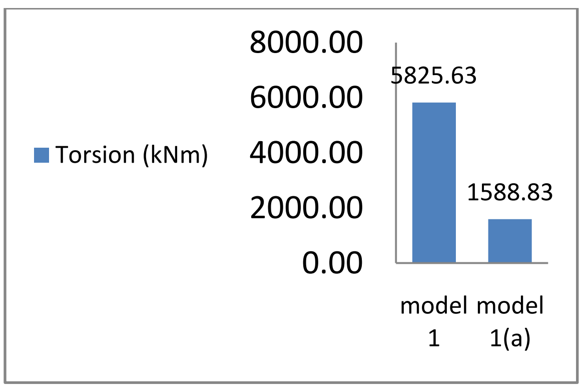


Fig 4 Variation of Torsion for Model 1

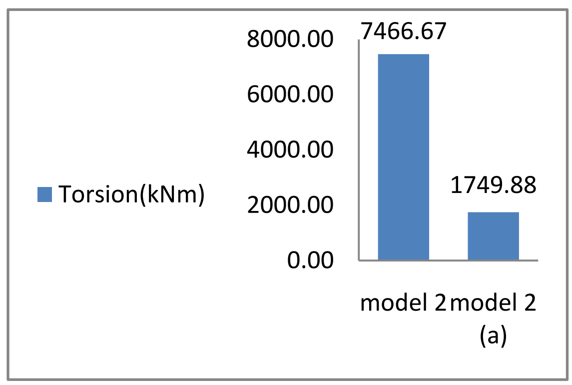


Fig 5 Variation of Torsion for Model 2

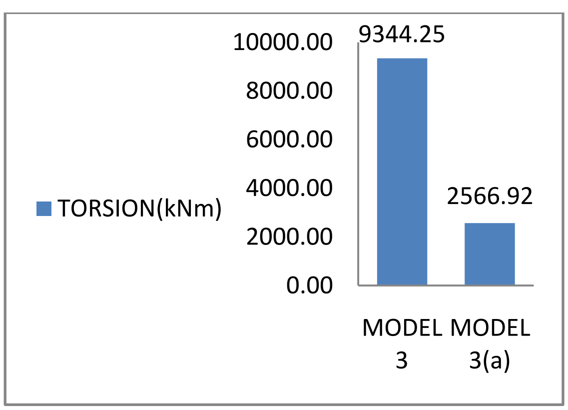


Fig 6 Variation of Torsion for Model 3

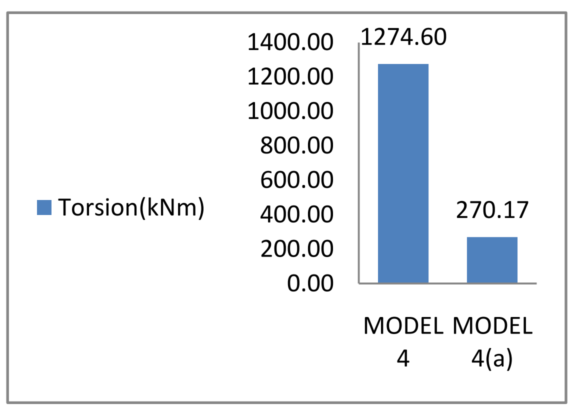


Fig 7 Variation of Torsion for Model 4

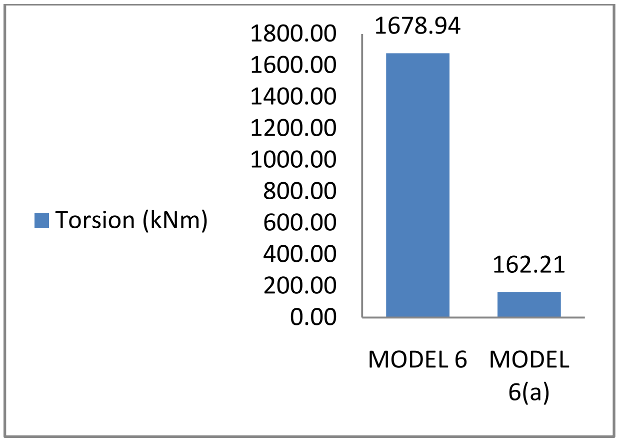


Fig 8 Variation of Torsion for Model 5

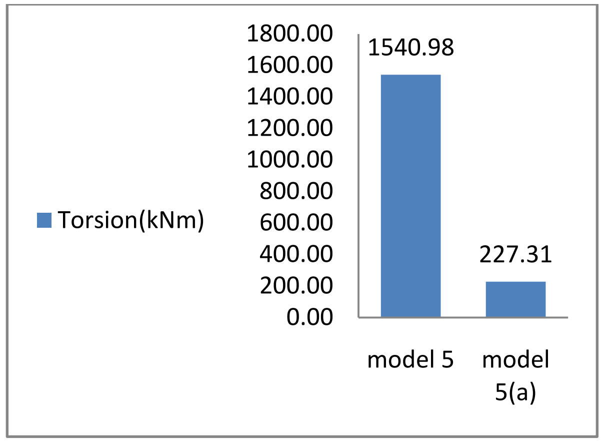


Fig 9 Variation of Torsion for Model 6

5.2Comparison of Joint Rotation

Joint Rotation of the Top Storey is also compared for the Original& Modified Models, and they are shown in fig. 10-15

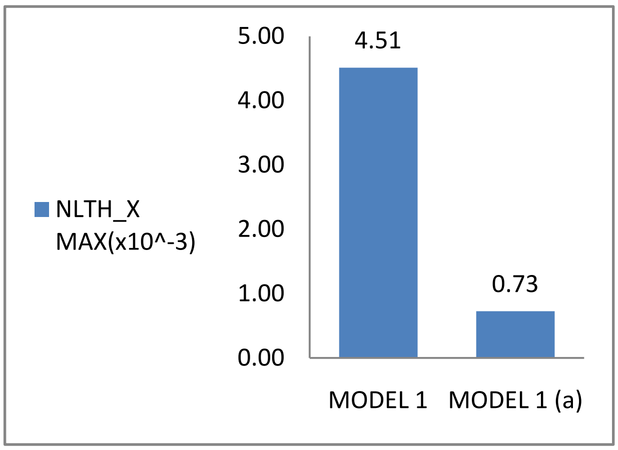


Fig 10 Variation of Joint Rotation of Model1

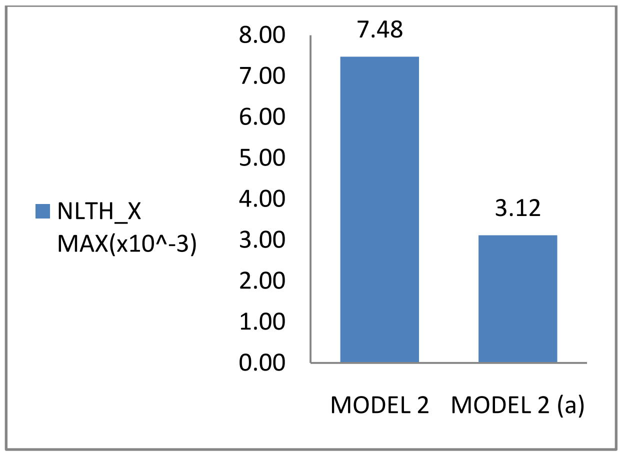


Fig 11 Variation of Joint Rotation of Model2

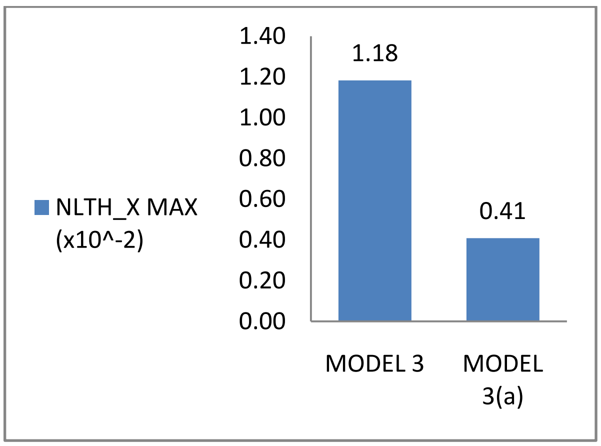


Fig 12 Variation of Joint Rotation of Model3

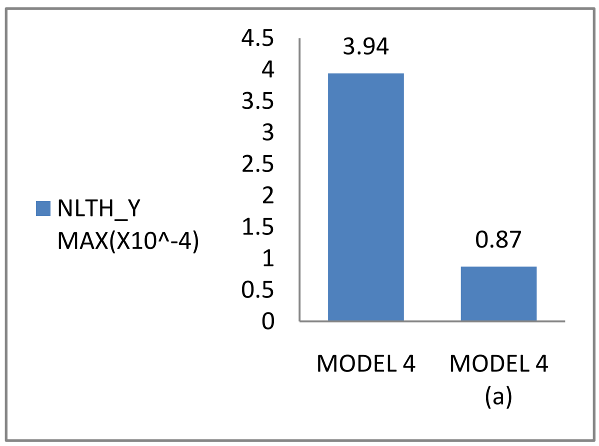


Fig 13 Variation of Joint Rotation of Model4

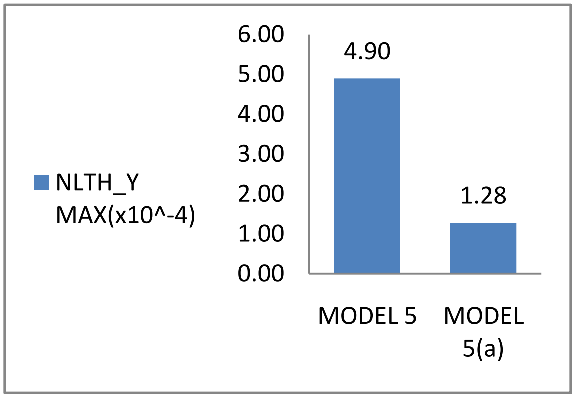


Fig 14 Variation of Joint Rotation of Model5

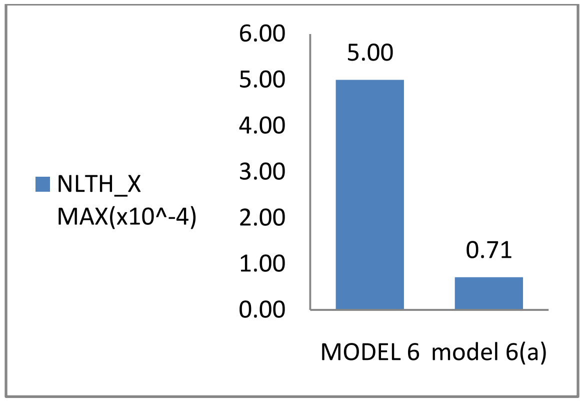


Fig 15 Variation of Joint Rotation of Model6

5.3 Effect of Combination of irregularities on Base Torsion.

To Study the effect of combine irregularities 3 more models of 15 storey are modelled and analysed in ETABS. Table 6 represents the comparison of that effect.

Table 6Torsion Variation

Model	Effect of Plan Irregularity onTorsion (kNm)	Effect of Combined Plan, vertical and mass irregularity on Torsion (kNm)
Model A (U shape 15 storey)	9545.29	9553.69
Model B (Openings 15storey)	1682.14	1596.12
Model C (L shape 15 storey)	4192.55 in X direction 1873.51 in Y direction	3894.22 in X direction 1691.26 n Y direction

VI. CONCLUSIONS

The following are the conclusions drawn from the present work:

1) Among the two plan irregularities considered in this work, torsionally irregular buildings are more hazardous when compared to buildings with opening.
2) There is a significant reduction in base torsion and joint rotation of the asymmetric building when stiffness eccentricity is minimised. However the reduction is high in building with openings with respect to torsionally irregular buildings
3) The base torsion for torsionally irregular building with combined effect of plan, mass and stiffness irregularity is almost equal to effect of only plan irregularity. Whereas for thebuilding with openings, the base torsion decreased by 5.11% and for re-entrant corners torsion decreased by 7.11% in X-direction & 9.72% in Y-direction.
4) Combined effect of plan & vertical irregularity does not have much effect on the torsional parameters in the models considered.

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