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# Seismic Behaviour of Steel Structures with Mass Irregularity and Torsion Effect

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**ABSTRACT:** Mass irregularity and torsion are an important factor which affecting structural responses under seismic loads especially for asymmetric and irregular structures. In this paper the main objective is to study the seismic behaviour of steel structure with mass irregularity and the torsion effect under seismic demands as well. The seismic response are calculated by dynamic response spectrum analysis. The irregularity of mass is made by increasing the effective weight of few floors relative to other floors. The additional mass on these floors could be located in first floor, middle floors or on upper floors of the building structures. Fundamental time period, frequencies of the time period, base shear, maximum story displacement, maximum story drift, shear story, shear force and torsional moment are investigated by seismic demands. Buildings with irregular, asymmetry which located in high seismic zone are challenging for stakeholders. Therefore the stakeholders involved in designing, drafting and constructing the buildings should have taken special cares while designing such like complicated buildings.

**KEYWORDS:** Seismic Behaviour, Torsion Effect, Mass Irregularity, Response Spectrum Analysis.

## I. INTRODUCTION

According to Indian seismic code (IS -1893-2002), if the mass of any floor is greater than 200% of the mass of the adjacent floor, the structure has a mass irregularity. Also according to International Building Code (IBC, 2003) the mass irregularity is not necessary to consider if the drift at any story is less than 130% the drift at the above story and when the maximum horizontal displacement of any floor in the direction of the lateral force at one end of the floor is more than 1.5 times its minimum horizontal displacement at the far end of the same floor in that direction also when the natural period corresponding to the fundamental torsional mode of oscillation is more than those of the first two translational modes of oscillation along each principal plan directions. So, the effect of vertical irregularities on the seismic performance of structures becomes really important. Height-wise changes in stiffness and mass make the dynamic characteristics of the buildings different from the regular building. Also such type of irregularities causes concentration of forces and stresses in some floor, where there is change in mass, stiffness and strength. When a structure has an irregularity in mass, stiffness, strength or vertical geometric irregularity, the method of analysis to be used is the most important point. Based on these, the current building design codes of many countries recommend method of analysis of the buildings. These analysis methods are broadly classified as linear static, linear dynamic, nonlinear static and nonlinear dynamic analysis. From these types of analysis, the linear static and linear dynamic are suitable only when the structural loads are small and at no point the load will reach to collapse load. Nonlinear dynamic and static analysis is better than linear dynamic and static analysis to estimate seismic demand of buildings. In order to prevent collapse of building structures due to irregularity problem, seismic demand must be determined accurately.

## II. OBJECTIVES

The general objective of this paper work is to study the seismic behaviour of Steel structures with mass irregularity and torsion effect. Some specific objective of the present has been described as follows:

- To study the effect of mass and torsion on parameters of time period, base shear, story shear, Maximum story displacements, Maximum story drift and torsional moment during earthquake.
- To compare irregular without mass irregularity and with mass irregularity under seismic demands.

### III. METHODOLOGY

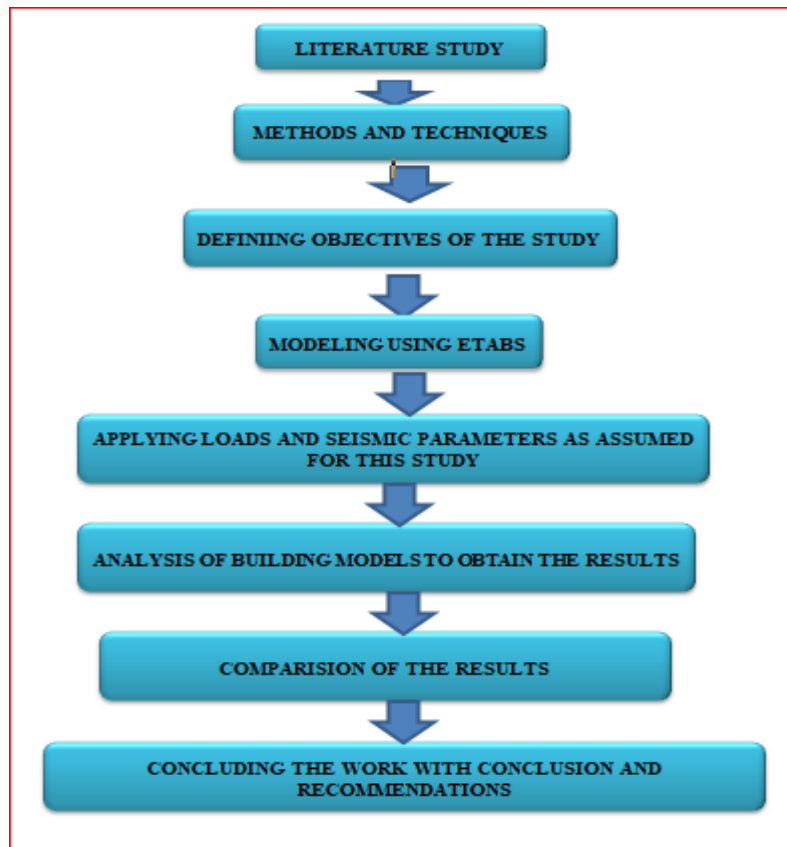


Figure 1: Flow Chart for Methodology

### IV. MODELLING

The study in this thesis is based on basically on dynamic response spectrum analysis ( RSA ) of asymmetric steel structures with external X bracing of the models of four asymmetric structures of G+10 stories , with mass irregularity in different locations that's , Model A ( irregular structure without mass irregularity ) , Model B ( irregular structure with mass irregularity at the bottom story ) , Model C ( irregular structure with mass irregularity at middle ) and Model D ( irregular structure with mass irregularity at top story ) by ETABS software 2018 based on Indian standard , IS 1893 ( part 1 ) : 2002 .

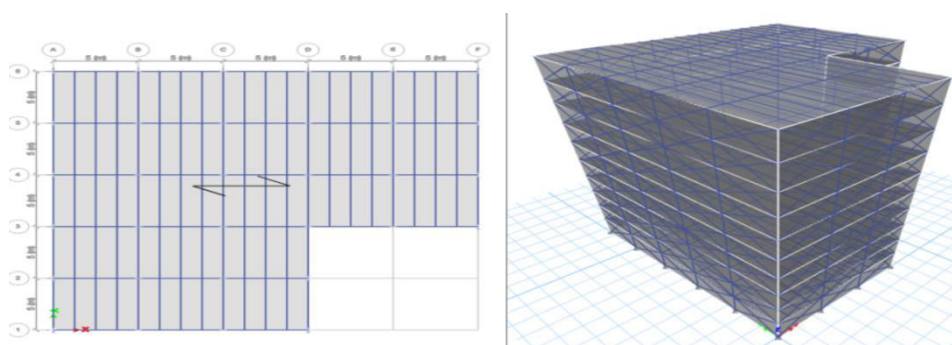


Figure2: Plan and Isometric View of Building  
BUILDING DESCRIPTION.

Table1: parameter of given data for the structure

Parameters	Type/value
Structure type	Steel structure
Shape of structure	irregular
Area of building	525 m <sup>2</sup>
Number of stories	10
Ground to 1st floor height	3.2m
from 1st -10th floor height	3m
Bay width in X & Y direction	5m
Slab/deck Thickness ( Regular )	76.2mm or 3"
Column size	ISWB 450
Beam size	ISLB 400
Composite beams	ISLB 275
X Bracing	ISLB 200
Live Load	3KN/m <sup>2</sup>
FLOOR FNISH	1.5KN/m <sup>2</sup>
Earthquake load	As per the IS code
Wind load	As per the IS code
Grade of Steel	Fe410
Seismic zone	IV ( 0.24 )
Response reduction factor	5 ( SMRF)
Importance factor	1 .0
Soil type	II ( medium )
Accidental eccentricity	5%

## V.ANALYSIS AND RESULT

### A. MODE PERIOD AND FREQUENCIES

Table 2: Mode Period (Sec) For Modes of Vibration

Model	X-X ( Mode 1 )	Y-Y (Model 2)	Torsion (Model 3)
A	0.642	0.593	0.356
B	0.643	0.595	0.357
C	0.704	0.654	0.392
D	0.762	0.699	0.411

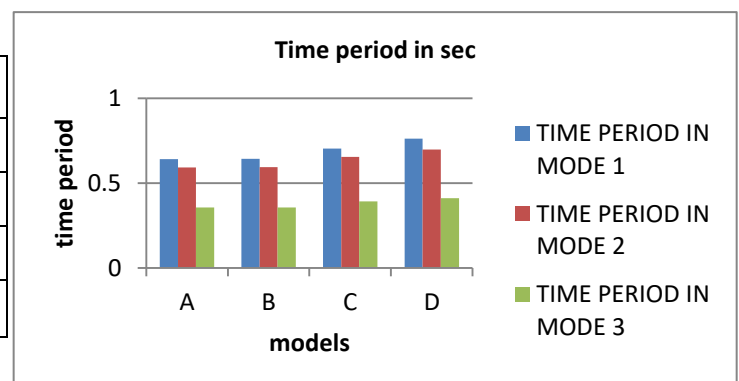


Figure 3: Mode period vs models

from the above graph ,it is observed that the time period at X-X (MODE-1) the time period in MODEL A are decreased by 0.16% ,8.81% and 15.75% than MODEL B , MODE C and MODEL D respectively. in Y-Y (MODE-2 ) the time period in MODEL A are decreased by 0.28%, 9.33% and 15.16% Than Model B ,MODEL C and MODEL D . In TORSION (MODE 3), the time period in MODEL A is increased by 0.28%, 9.18% and 13.38% than MODEL B, MODEL C, and MODEL D respectively.

Table 3 :Frequencies for the Modes of Vibration

Mode no.	Model A	Model B	Model C	Model D
1	1.555	1.421	1.312	1.558
2	1.682	1.529	1.431	1.686
3	2.8	2.548	2.431	2.81

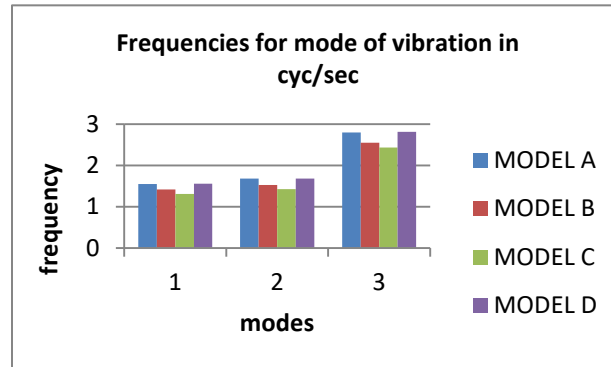


Figure 4: Frequencies vs modes

From the above graph, it has been observed that, the frequencies for the modes of vibration are increased with increasing the number of modes increased in all the models (MODEL A, MODEL B, and MODEL C & MODEL D). In another meaning frequencies have proportional relation with number of modes in all the four models.

## B. STOREY DRIFTS

Table 4: maximum story drift (m)

STORY	Model A		Model B		Model C		Model D	
	X-X	Y-Y	X-X	Y-Y	X-X	Y-Y	X-X	Y-Y
10	0.000212	0.000214	0.000247	0.000249	0.000205	0.000207	0.0003	0.000299
9	0.000275	0.000273	0.00032	0.000317	0.000263	0.000262	0.000346	0.000339
8	0.000325	0.00032	0.000378	0.000373	0.000308	0.000306	0.000377	0.000369
7	0.00036	0.000355	0.000419	0.000413	0.000344	0.00034	0.000399	0.000389
6	0.000383	0.000376	0.000445	0.000438	0.000405	0.0004	0.000409	0.000399
5	0.000392	0.000385	0.000456	0.000448	0.000416	0.00041	0.00041	0.000399
4	0.00039	0.000382	0.000454	0.000444	0.000413	0.000406	0.000401	0.00039
3	0.000376	0.000367	0.000437	0.000427	0.000398	0.00039	0.000382	0.00037
2	0.000353	0.000343	0.000411	0.000399	0.00037	0.000362	0.000355	0.000343
1	0.00029	0.000286	0.000338	0.000334	0.000355	0.000336	0.000289	0.000283



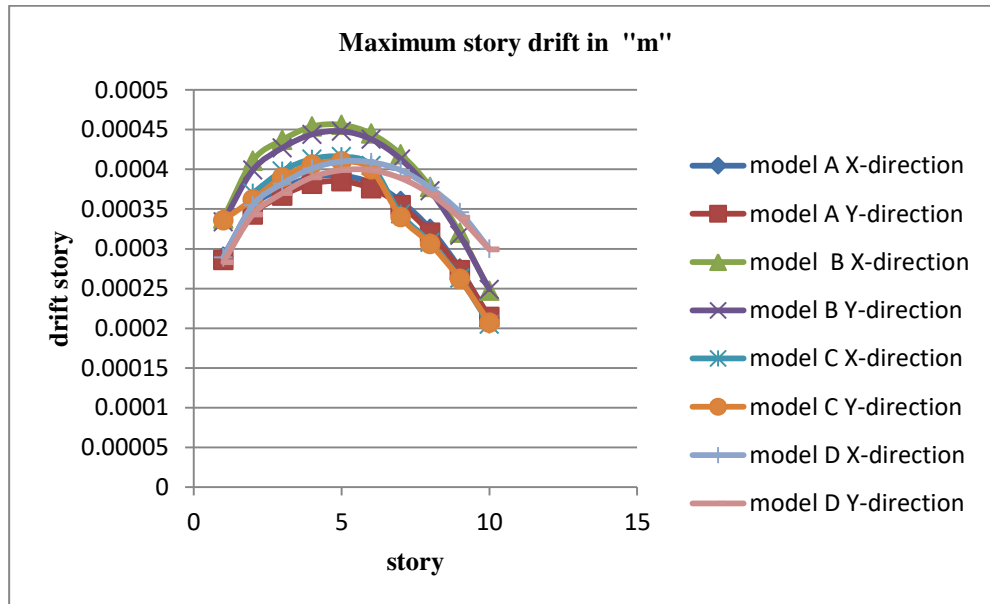


Figure 5: Graph of Story Drift Vs. No of Stories

From the above Graph, it has observed that in MODEL A, Maximum story drift at Story 1 are increased by 36.79% and 36.64% than story 10 in X-X and Y-Y direction respectively. In MODEL B the maximum drift story in story 1 are increased by 36.84% and 34.14% than story 10 in x and y direction respectively. In MODEL C maximum drift story in story 1 is increased by 73.17% and 62.32% than story 10 in X and Y direction respectively. In MODEL D, the maximum drift story at story 1 is decreased by 3.67% and 5.65% than story 10 in X and Y direction respectively. In general except in MODEL D all the maximum drift story in story 1 is higher than the top story, whereas in MODEL D the maximum drift story in story 1 is lower than the top story.

### C. STOREY DISPLACEMENTS

Table 5: story displacement (mm)

STORY	Model A		Model B		Model C		Model D	
	X-X	Y-Y	X-X	Y-Y	X-X	Y-Y	X-X	Y-Y
10	10.128	9.957	11.783	11.59	10.503	10.326	11.064	10.8
9	9.491	9.316	11.042	10.844	9.888	9.705	10.164	9.904
8	8.665	8.497	10.082	9.892	9.099	8.918	9.126	8.886
7	7.691	7.536	8.949	8.773	8.174	8	7.994	7.778
6	6.61	6.472	7.692	7.535	7.142	6.979	6.798	6.609
5	5.461	5.344	6.356	6.222	5.928	5.78	5.57	5.411
4	4.284	4.189	4.987	4.879	4.68	4.551	4.34	4.213
3	3.114	3.044	3.627	3.546	3.442	3.333	3.138	3.044
2	1.987	1.943	2.316	2.266	2.248	2.162	1.993	1.934
1	0.927	0.914	1.083	1.068	1.137	1.076	0.926	0.906

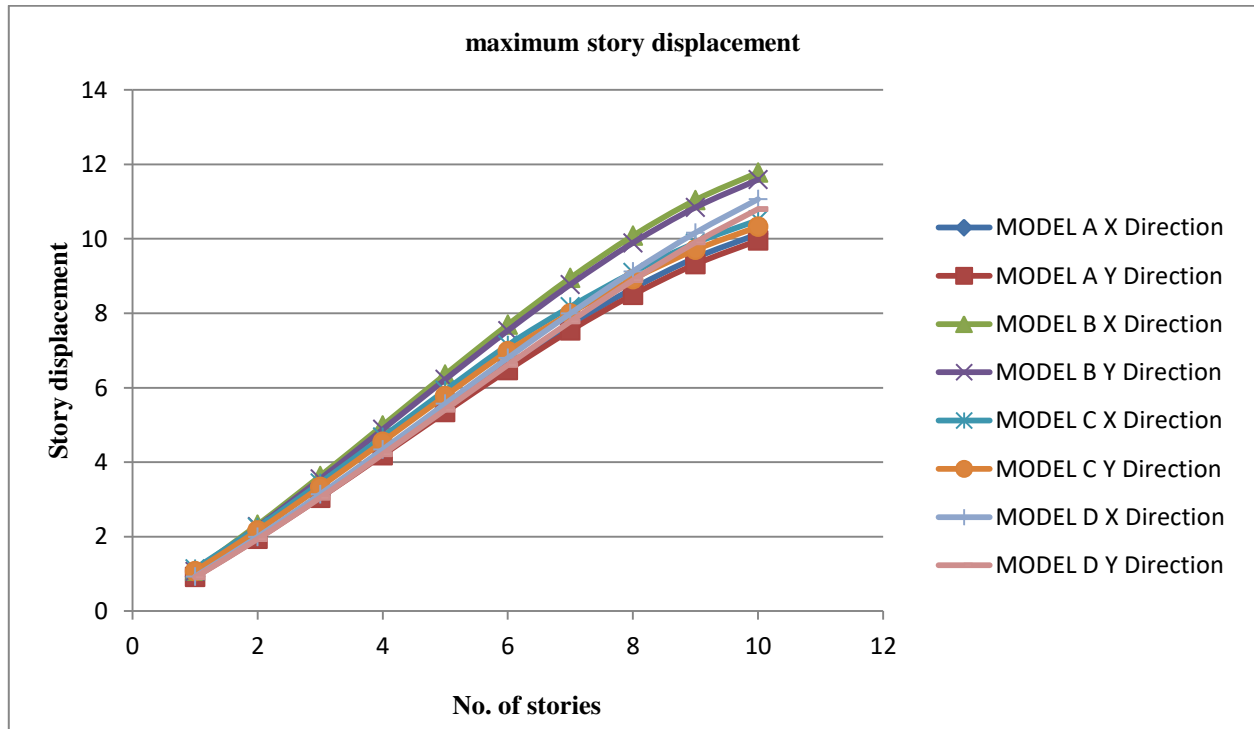


Figure 6: Graph of maximum story displacement vs. no. of stories

From the above graph of maximum displacement of the story, it has observed that, story displacement at the top story is higher than that of the bottom story in all the four models ,MODEL A, MODEL B ,MODEL C & MODEL D .in general maximum displacements are occurred at the top story and minimum displacement are occurred at bottom story . Displacements at story 1 at model A, Model B and Model C are decreased by 90.85%. Than displacement at story 10. In Model D the maximum Displacement story at story 1 are decreased by 89.58% than story 10. From this study it has concluded that as the number of story increased, displacement was increased.

#### D. BASE SHEAR

Table 6: Base Share ofthe Models

Model	Base Shear(KN) In X-X	Base Shear (KN) In Y-Y
Model A	1262.6144	1167.1742
Model B	1475.6327	1364.7515
Model C	1341.9732	1246.9959
Model D	1255.6262	1151.6465

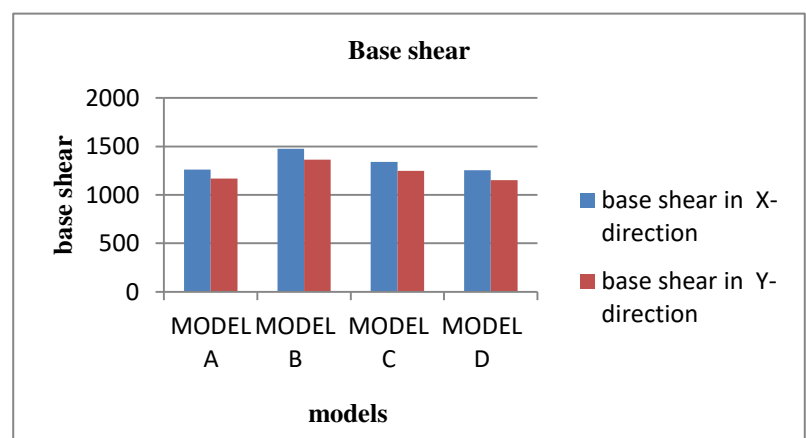


Figure 7: graph of base shear vs models

From the above graph, it is observed that, base shear in model-A was nearly decreased by 16.92%, 6.29% , 0.55% when compared to model-B , Model C respectively and increased by 0.55% than model D by response spectrum analysis in X-X direction. The base shear in model An in Y-Y direction also decreased by 16.93%, 6.84% when compared to Model B, Model C respectively. And increased by 1.33% than Model D.

## E.STORY SHEAR.

Table 7: story shear

STORY	Model A		Model B		Model C		Model D	
	X-X	Y-Y	X-X	Y-Y	X-X	Y-Y	X-X	Y-Y
10	319.73	295.56	371.82	343.88	292.54	271.84	606.75	556.50
9	586.05	541.75	681.52	630.31	536.21	498.26	790.02	724.60
8	796.86	736.62	926.67	857.04	729.10	677.49	935.10	857.66
7	958.64	886.18	1114.80	1031.04	877.12	815.04	1046.44	959.78
6	1077.88	996.40	1253.46	1159.28	1172.94	1089.93	1128.49	1035.04
5	1161.04	1073.28	1350.18	1248.72	1249.04	1160.64	1185.73	1087.53
4	1214.62	1122.81	1412.48	1306.35	1298.06	1206.19	1222.60	1121.35
3	1245.09	1150.97	1447.91	1339.11	1325.94	1232.09	1243.56	1140.58
2	1258.92	1163.76	1464.00	1354.00	1338.60	1243.86	1253.09	1149.32
1	1262.61	1167.17	1475.63	1364.75	1341.97	1247.00	1255.63	1151.65

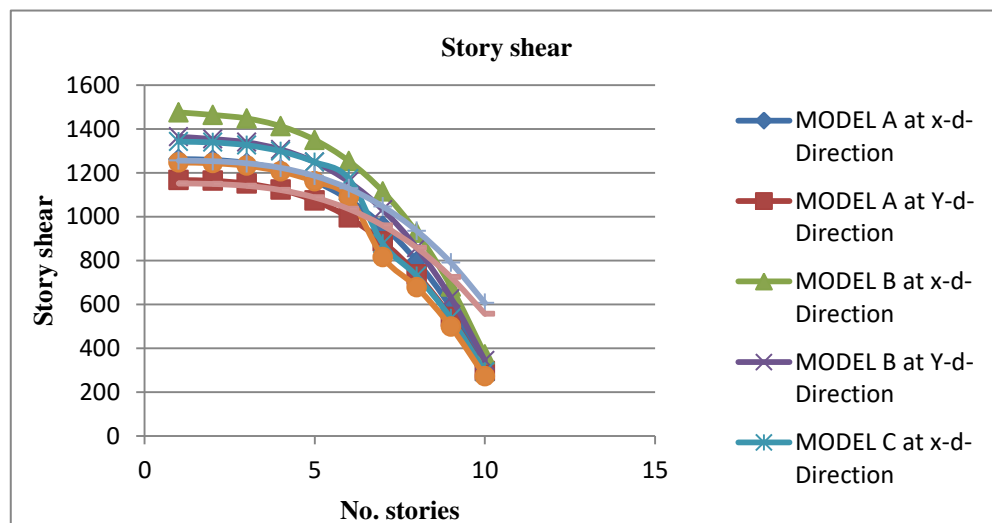


Figure 7: graph of story shear vs. No. of stories.

From the above Graph ,it has observed that, the story shear at story 10 on MODEL A , MODEL B ,MODEL C and MODEL D are decreased nearly by 74.68 % , 74.80 % , 78.20% and 51.68 % than storey-10 respectively in both X and Y directions . From this calculated result understood that story shear is high in base and less in 10th story.



## F. TORSION MOMENT

Table 8: torsion moment

STORY	Model A		Model B		Model C		Model D	
	X-X	Y-Y	X -X	Y-Y	X-X	Y-Y	X-X	Y-Y
10	4449.425	3275.9704	5174.2	3811.5	4071.1	3013.0	8448.4	6163.7
9	8153.7038	6006.3219	9482.0	6988.1	7460.3	5524.2	10997.6	-8028.1
8	11085.9241	8167.6042	12891.8	9502.7	10143.2	7512.0	13015.5	9503.8
7	13336.2094	9826.2455	15508.7	11432.5	12202.1	9037.5	14564.1	10636.4
6	14994.6833	11048.6742	17437.3	12854.7	16320.4	12082.8	15705.5	11471.0
5	16151.4693	11901.3186	18782.6	13846.8	17378.8	12867.0	16501.6	12053.2
4	16896.691	12450.607	19649.2	14485.8	18060.7	13372.2	17014.4	12428.3
3	17320.4721	12762.9677	20142.0	14849.3	18448.4	13659.5	17306.1	12641.6
2	17512.936	12904.829	20365.8	15014.3	18624.5	13790.0	17438.5	12738.5
1	17564.27	12942.6679	20527.7	15133.5	18671.5	13824.8	17473.8	12764.3

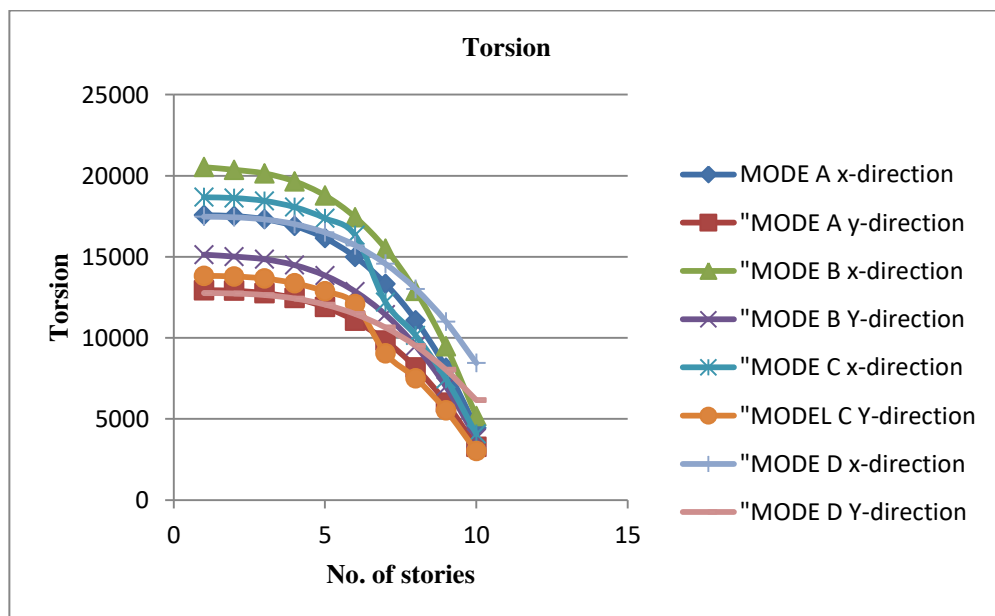


figure 8: graph of torsional moment vs. no of stories

From the above table, it is observed that the twisting moment (torsion) at MODEL A is decreased by 74.67% in story 10 when compared to story-1, in model B is decreased by 74.69% in storey-10 when compared to storey-1, in model C is decreased by 78.20% in story-10 when compared to story-1 and in MODEL D is decreased by 51.65% in story -10 when compared to story-1 in X & Y directions.

In general from this table of torsional moment it has concluded that the twisting moment (torsion) are maximum in bottom story and as it has in the table the torsional moment of MODEL B is greater than MODEL A means irregular structure with mass irregularity is higher torsional moment than irregular structure without mass irregularity.

## VI. CONCLUSION

Based on analytical study of the 10 story building models, following conclusions are made.

- BASE SHEAR

The mass of the building in MODEL-B lead to increase in base shear compared to other models (MODEL A, MODEL C and MODEL D. This shows that increase in mass in model-B increases the base shear compared to other models. In general the base shear in structure with mass irregularity at bottom is higher than base shear in structure with mass irregularity at middle & top. Base shear is high in bottom and minimum at top story.

- MODE PERIOD

The mode period of MODEL-D with mass irregularity in top stores is found to be maximum when compared to other models. From analysis it is found that model-A without mass irregularity in stories has less mode period as compared to other models. The mode period of model-D increases by 18.69%, 18.51% and 8.24% compared to model-A, model-B, model-C respectively in mode-1. The mode period of model-D increases by 17.88%, 17.48%, 6.88% when compared to model A, model B, Model C respectively in mode-2 and mode period of model D is increased by 15.45%, 15.13% and 4.85% when compared to model A, Model B & C in mode-3. Mode period increases as the location of mass irregularity increase towards the top of the structure as in case of model-D.

- STOREY DRIFT

The story drift, it has been found that model-B shows more story drift and direction compared other models. Whereas model-1 and model-2 shows less story drift compared to other models. So distribution of mass should be equal in all the stories which will results in the less story drifts. In general story drift is higher in a structure with mass irregularity at bottom story and less in structure with mass irregularity in middle story.

- MAXIMUM STORY DISPLACEMENT

story displacement at the top story is higher than that of the bottom story in all the four models ,MODEL A,MODEL B ,MODEL C & MODEL D .in general maximum displacements are occurred at the top story and minimum displacement are occurred at bottom story . Displacements at story 1 at model A, Model B and Model C are decreased by 90.85%. Than displacement at story 10. In Model D the maximum Displacement story at story 1 are decreased by 89.58% than story 10. From this study it has concluded that as the number of story increased, displacement was increased.

- TORSION

Twisting moment (torsion) of the structure will depend on the distribution of mass in each model. Model-D is affected by more torsion as the mass irregularity is at the bottom stories compared to all other models.

Out of all four models model-A shows better performance to resist lateral loads due to earthquake compared to all other models such as mass irregularity in alternate stories, bottom stories, middle stories and top stories. Hence any structure with equal distribution of mass in all the stories will give better performance.

## VII. RECOMMENDATION FOR THE FUTURE STUDY

Parametric study of the structures by varying the story height of the structure and its torsional effect can be recommended.

In this paper mass irregularity is introduced only at single floor, so for the future study will cover mass irregularity at many floors over height of the building are recommended.

In this paper the study method are response spectrum analysis only, so for the future by time history analysis, pushover is recommended with vertical geometric structure.

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