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Performance Based Seismic Design of R.C.C. Buildings with Plan Irregularity

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Abstract: **Performance-based seismic design method is both efficient and effective to avoid future earthquake losses. Structural irregularities are important factors which decrease the seismic performance of the structures. Buildings which have structural irregularities may experience different drifts of adjacent stories, excessive torsion, etc. according to irregularity type and fail during an earthquake. In this work, performance based seismic design of buildings with plan irregularity is studied using Standard pushover analysis and Modal pushover analysis. Also to check accuracy for both the methods Non-linear time history analysis is carried out. For present study, building models of (G+6) storey regular and irregular buildings of 'L' shaped, 'C' shaped and 'T' shaped are generated by a computer program ETABs (version 9.7.3). The buildings shape in plan is selected in such a way that the total area in plan remains same so that value of dead and live load remains almost same. Different parameters such as pushover curves, performance point, plastic hinges mechanism and torsion are studied. The results shows that the Standard pushover analysis gives same results as compare to Modal pushover analysis and time history analysis for regular building, but for irregular buildings modal pushover analysis gives better results due to consideration of higher mode effects. It is also concluded that torsion produced in irregular buildings are almost 20% more than the regular building so it is necessary to take the effects due to torsion for irregular buildings. Also the performance based seismic design obtained by above procedure satisfies the acceptance criteria for immediate occupancy and life safety limit states for given intensities of earthquake.**

Keywords: Earthquake, Irregularity, performance point, plastic hinges, torsion.

1. INTRODUCTION

Amongst the natural hazards, earthquakes have the potential for causing the greatest damages. Since earthquake forces are random in nature & unpredictable, the engineering tools needs to be sharpened for analysing structures under the action of these forces. Performance based Seismic design is an elastic design methodology done on the probable performance of the building under input ground motions. This approach is not new, using this approach model Turbines, and Airplanes& Automobiles are made. The basic concept of Performance Based Seismic Design is to produce structures with predictable seismic performance. Performance-based seismic design is approximate way to control efficiently the seismic damage on the structure and ensure the predictable and safe performance [1].

During Earthquake, failure of structure starts at points of weakness. This weakness arises due to discontinuities. The structure having this discontinuity is termed as irregular structure [2]. There are basically two types of irregularities in building,

1. Plan irregularity 2. Vertical irregularity

There are various types plan irregularities such as,

a) Torsional Irregularity b) Extreme Torsional
c) Re-entrant Corners d)Diaphragm Discontinuity
e) Out-of-plane Offsets f)Nonparallel Systems

Buildings are complex structures made up of many structural elements which have different mechanical behavior from each other. Unexpected effects can be observed on irregular structures under various load patterns. Earthquake loads cause extra shear, torsion etc. on irregular structures. Therefore, structural irregularities decrease the seismic performance of buildings significantly. Irregular structures will be heavily damaged as a result of torsion effects on structural elements as shown in Figure 1.

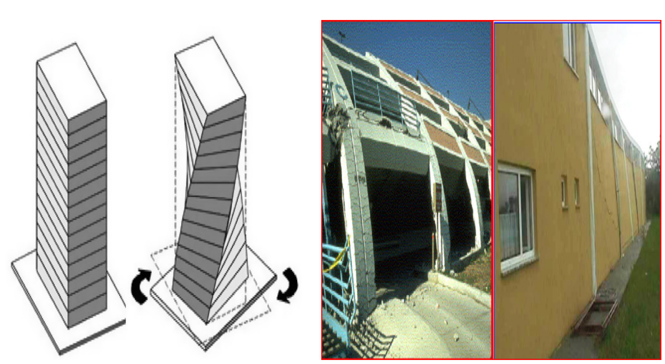


Fig. 1. Failure of irregular structure

2. TORSIONAL IRREGULARITY

For comfort and usage reasons, building plans are designed in various geometries. Complex building plans lead to nonsymmetrical and irregular structural systems, which is the main reason of torsion under earthquake loads Figure 2.

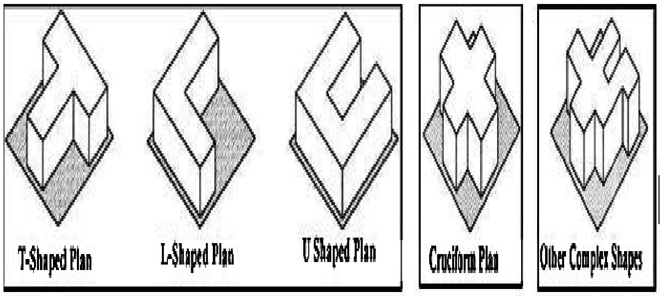


Fig. 2. Irregular building plans

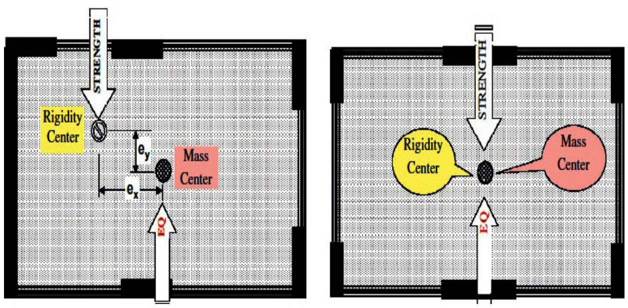


Fig. 3.(a)Torsional irregularity. (b)Regular structural system

Earthquake load acts at the center of mass of the structure. However, resisting force acts at a point called center of rigidity on the structure, which is the center of lateral resistance. Torsional problems take place when the mass center and center of rigidity are not located at the same place. The difference between center of mass and center of rigidity locations cause torsion in structures under lateral loads. [2] (Figure 3 (a), (b))

Several approaches for the PBSD method proposed by researchers have been briefly reviewed and also observed that more research work is needed especially for development of PBSD method for various other different types of structures [1]. The guideline of ATC- 40 [3] is more helpful for this study that provides the steps of pushover analysis and also calculating the performance point. After obtaining a clear overview of the main aspects of the expected inelastic response using the 'standard' pushover analysis, and after understanding shortcomings of standard pushover analysis method chopra and goel [4] developed the modal pushover analysis method. Performance based seismic design for various structures presented in literature such as symmetrical and unsymmetrical R.C.C. buildings [5-7], also damages caused by different plan irregularities in buildings situated in Mexico [8], buildings with re-entrant corners [9-10]. Various studies on consideration of torsional effects occurred due to various plan configuration of buildings are [11-12].

3. STRUCTURAL MODELING

3.1. Structural elements details

Four buildings representing regular and irregular of 'L' shaped, 'C' shaped and 'T' shaped building are considered in this study. For the present study, structures of (G+6) storey are chosen. These structures are designed according to Indian Standards. The details of structure are shown below.

1. Size of one slab panel on a floor= 4 m X 4 m
2. Floor to floor height = 3.0 m.
3. Thickness of slab = 0.12 m.
4. Live load = 3 KN/m^2 (assume)
5. Beam size = 230mm X 300mm
6. Column size = 300mm X 450mm
7. Grade of Concrete = M 25
8. Seismic Coefficient for Response Spectrum method as per IS:1893:2002

   a)Seismic Zone IV b) Zone Factor = 0.24

   c) Medium soil, Soil type II d) Residential building, Importance factor = 1.5

3.2. Modelling approach

The finite element program ETABs (Version 9.7.3) has been used for the analyses. A three dimensional models of each structure has been created as shown in figure 4 to undertake the non linear analysis. Beams and columns are modeled as nonlinear frame elements with lumped plasticity at the start and the end of each element. ETABs provides default hinge properties and recommends P-M-M hinges for columns and M3 and V2 hinges for beams as described in FEMA 356.

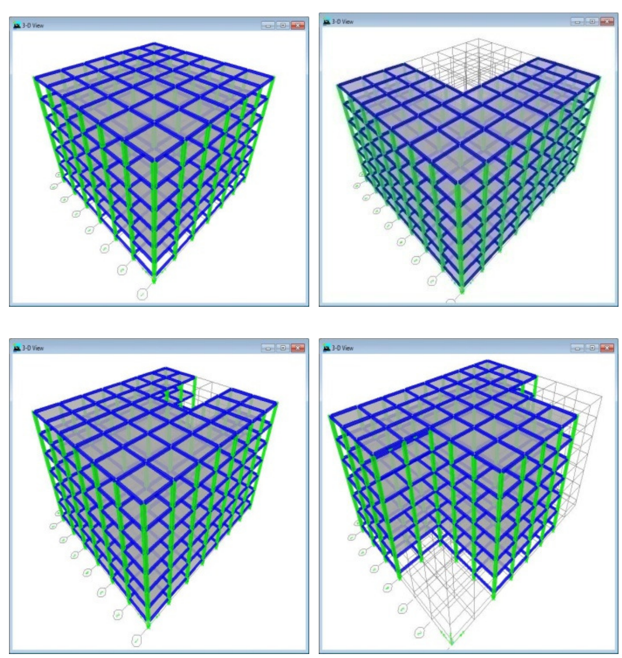


Fig. 4. 3D computational model of the Regular building and irregular shaped buildings

4. RESULTS AND DISCUSSIONS

In this section the computational results present study are briefly described.

4.1. Comparison and Interpretation of Results

Pushover curves obtained from standard pushover analysis and modal pushover analysis are compared in Figure 5, Figure 6, Figure 7 and Figure 8. for regular, 'L', 'C' and 'T' shaped building respectively. Also to check accuracy and the best suited pushover method for regular and irregular buildings Non-linear time history method is carried out which is well known most accurate method of analysis (results are plotted in terms of maximum top displacement at the Centre of mass versus the corresponding base shear.)

4.1.1. Pushover curves

Pushover curves from standard pushover analysis and modal pushover analysis are plotted and compare with non-linear time history analysis results for regular and irregular buildings are shown in Figure.5 to Figure 8.

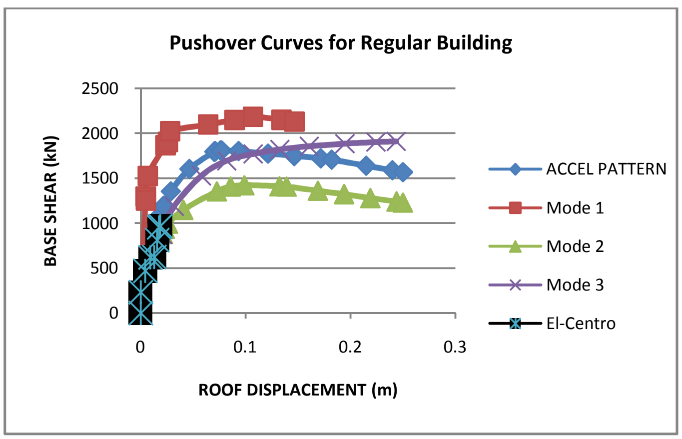


Fig. 5. Pushover curves for Regular building

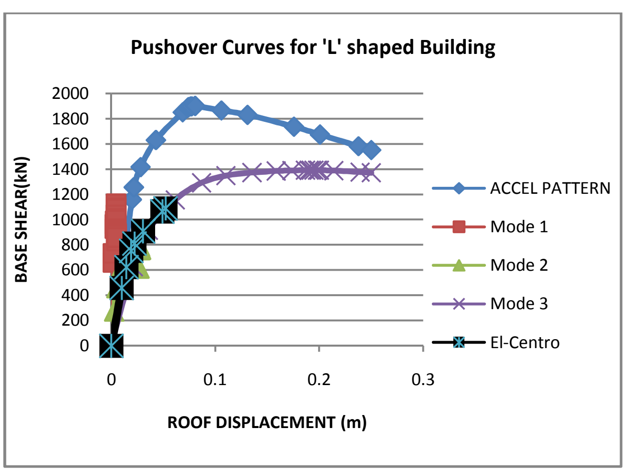
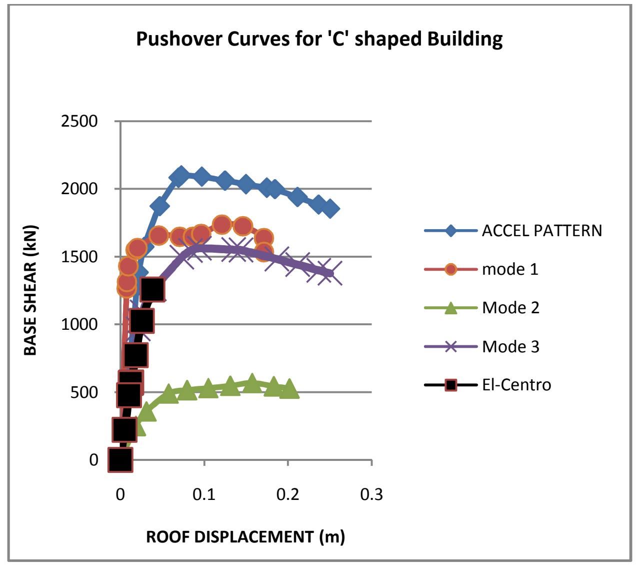


Fig. 6. Pushover curves for 'L' shaped building



Figu. 7. Pushover curves for 'C' shaped building

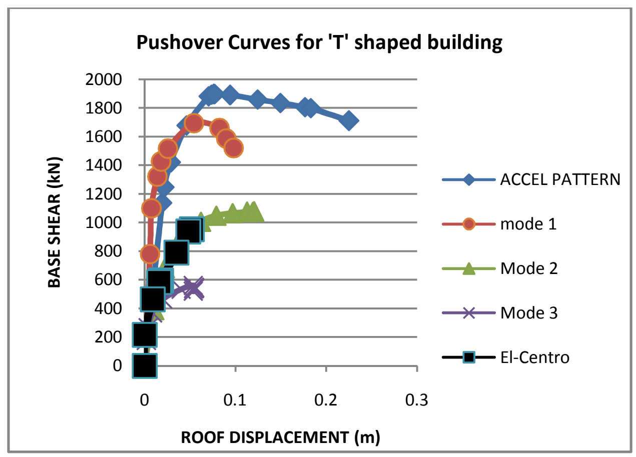


Fig. 8. Pushover curves for 'T' shaped building

Pushover curves from standard pushover analysis, modal pushover analysis and time history analysis shows that, for regular building all curves shows similar nature, But for irregular buildings such as 'L','C' and 'T' shaped building model, modal pushover analysis gives accurate pushover curve as compare to standard pushover analysis method which is verified by time history analysis method i.e. for 'L' shaped building mode 3 pushover curve, for 'C' shaped building mode 3 pushover curve and for 'T' shaped building mode 2 pushover curve matches with pushover curve from time history analysis.

4.1.2. Performance Point by Capacity Spectrum Method

Performance point is the point of interseection of capacity curve and demand curve.Performance point obtained by capacity spectrum method for all selected building models are shown in Figure 9, Figure 10, Figure 11 and Figure 12. In figure green curve shows capacity curve and yellow curve shows demand curve.

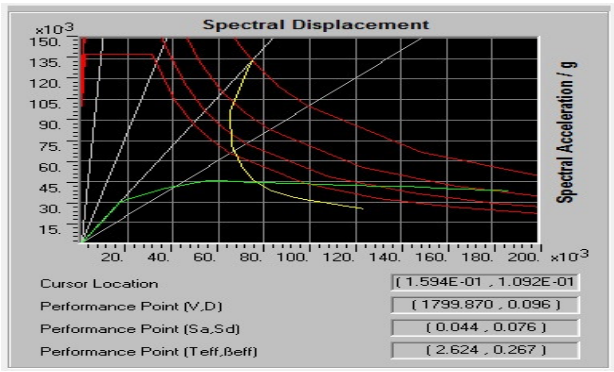


Fig. 9. Performance point for Regular building

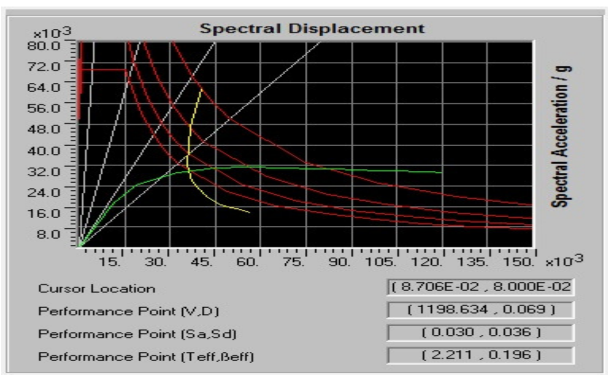


Fig. 10. Performance point for 'L' shaped building

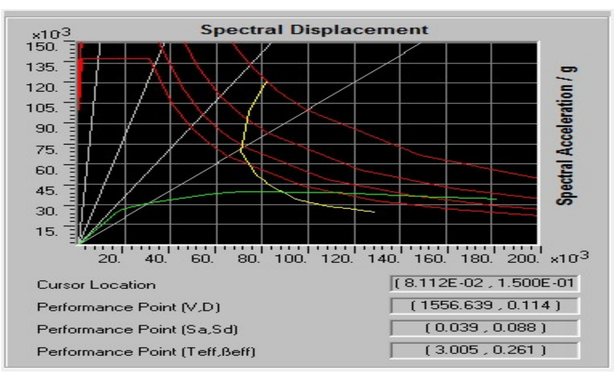


Fig. 11. Performance point for 'C' shaped building

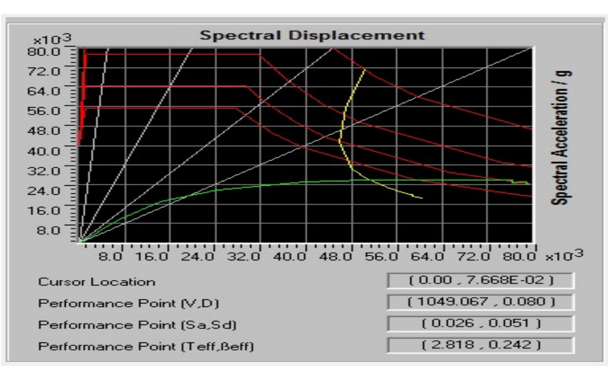


Fig. 12. Performance point for 'T' shaped building

4.1.3. Torsion

Horizontal twisting occurs in buildings when centre of mass and centre of rigidity do not coincide. The distance between these two is called eccentricity (e). Lateral force multiplied by this 'e' cause a torsional moment. Due to plan irregularity centre of mass and centre of rigidity does not coincides with each other as shown in Table 1 for regular and Table 2 – Table 4 for L, C and T shaped building respectively. Also in these tables torsional moments in both directions due to irregularity is also calculated. As the total area in plan of all the buildings is same so that value of dead and live load remains almost same, so that comparison of torsion is made for regular and irregular buildings.

TABLE 1. Torsional Moment due to seismic force for Regular building

Storey	XCCM (m)	XCR (m)	YCCM (m)	YCR (m)	Storey shear X-direction (kN)	Storey shear Y-direction (kN)	esi (m)	esi (m)	0.05*bi	edi_x	edi_y	Torsional Moment X-direction (kN.m)	Torsional Moment Y-direction (kN.m)
1	12	12	12	12	12.34	12.69	0	0	1.2	1.2	1.2	14.81	15.23
2	12	12	12	12	117.81	133.1	0	0	1.2	1.2	1.2	141.37	159.72
3	12	12	12	12	285.04	301.16	0	0	1.2	1.2	1.2	342.05	361.39
4	12	12	12	12	528.96	544.48	0	0	1.2	1.2	1.2	634.75	653.37
5	12	12	12	12	852.04	866.54	0	0	1.2	1.2	1.2	1022.4	1039.8
6	12	12	12	12	1255.29	1268.39	0	0	1.2	1.2	1.2	1506.6	1522.1

TABLE 2. Torsional Moment due to seismic force for 'L' shaped building

Storey	XCCM(m)	XCR(m)	YCCM(m)	YCR(m)	Storey shear X-direction	Storey shear Y-direction	esi_x (m)	esi_y(m)	0.05(bi_x)	0.05(bi_y)	edi_x	edi_y	Torsional Moment in X direction	Torsional Moment in Y direction
1	12.739	12.371	10.74	10.411	21.81	28.46	0.368	0.329	1.4	1.6	1.952	2.0935	42.5731	59.581
2	12.743	12.395	10.744	10.449	119.42	137.81	0.348	0.295	1.4	1.6	1.922	2.0425	229.525	281.477
3	12.744	12.419	10.746	10.481	280.64	300.45	0.325	0.265	1.4	1.6	1.8875	1.9975	529.708	600.149
4	12.745	12.453	10.746	10.524	513.86	533.17	0.292	0.222	1.4	1.6	1.838	1.933	944.48	1030.62
5	12.745	12.509	10.747	10.589	831.83	840.13	0.236	0.158	1.4	1.6	1.754	1.837	1459.03	1543.32
6	12.746	12.611	10.747	10.693	1205.7	1222.6	0.135	0.054	1.4	1.6	1.6025	1.681	1932.18	2055.22

TABLE 3. Torsional Moment due to seismic force for 'C' shaped building

Storey	XCCM(m)	XCR(m)	YCCM(m)	YCR(m)	Storey shear X-direction (kN)	Storey shear Y-direction (kN)	esi_x (m)	esi_y (m)	0.05(bi_x)	0.05(bi_y)	edi_x	edi_y	Torsional Moment X-direction	Torsional Moment Y-direction
1	12.762	12.715	12	12	21.16	28.07	0.047	0	1.2	1.4	1.2705	1.4	26.88	39.29
2	12.874	12.752	12	12	126.94	146.09	0.122	0	1.2	1.4	1.383	1.4	175.6	204.5
3	12.896	12.787	12	12	309.81	331	0.109	0	1.2	1.4	1.3635	1.4	422.4	463.4
4	12.906	12.833	12	12	577.4	598.43	0.073	0	1.2	1.4	1.3095	1.4	756.1	837.8
5	12.911	12.906	12	12	932.15	952.22	0.005	0	1.2	1.4	1.2075	1.4	1125.57	1333.11
6	12.914	13.037	12	12	1375.14	1393.54	0.123	0	1.2	1.4	1.0155	1.4	1396.45	1950.96

TABLE 4. Torsional Moment due to seismic force for 'T' shaped building

Storey	XCCM(m)	XCR(m)	YCCM(m)	YCR(m)	Storey shear X-direction (kN)	Storey shear Y-direction (kN)	esi_x (m)	esi_y (m)	0.05(bi_x)	0.05(bi_y)	edi_x	edi_y	Torsional Moment X-direction	Torsional Moment Y-direction
1	16	16	13.986	14.146	12.4	16.12	0	0.16	1.2	1.6	1.2	1.84	14.88	29.66
2	16	16	13.973	14.129	118.8	135.47	0	0.156	1.2	1.6	1.2	1.834	142.6	248.5
3	16	16	13.97	14.114	288.68	306.75	0	0.144	1.2	1.6	1.2	1.816	346.4	557.1
4	16	16	13.969	14.093	536.91	554.62	0	0.124	1.2	1.6	1.2	1.786	644.3	990.6
5	16	16	13.968	14.06	865.83	882.58	0	0.092	1.2	1.6	1.2	1.738	1039.00	1533.92
6	16	16	13.968	14.006	1276.5	1291.7	0	0.038	1.2	1.6	1.2	1.657	1531.81	2140.45

Where,
XCCM = Centre of mass in X –direction
YCCM = Centre of mass in Y –direction
XCR = Centre of rigidity in X –direction
YCR = Centre of rigidity in Y –direction
edi = Design eccentricity at i^{th} floor
esi = Static eccentricity at i^{th} floor
bi = Floor plan dimension of i^{th} floor perpendicular to the direction of force.

5. CONCLUSIONS

In this work, Performance based seismic design of a (G+6) storey regular building and building having plan irregularity of various shapes such as 'L', 'C', and 'T' shaped building has been done by using standard pushover analysis and modal pushover analysis. From the Literature review of the research work and by analyzing the structure using Standard pushover analysis, modal pushover analysis and Non linear time history analysis method, it is concluded that:

1. For regular building standard pushover analysis and modal pushover analysis gives same profile of capacity curve. But for irregular buildings modal pushover analysis gives better capacity curves when compared to time history analysis. So modal pushover analysis is necessary to evaluate the performance of irregular buildings where the higher mode effect is to be considered due to irregularity in plan.

2. The modal pushover analysis estimate of seismic demand due to an intense ground motion has been shown to be accurate for irregular buildings to a similar degree as it was for a regular building. This conclusion is based on a comparison of the modal pushover estimate of demand and its exact value determined by non-linear time history analysis.

3. The overall performance level for all building models was found between LS-CP (life safety to collapse prevention). The hinge status and location has been determined and it is noted that most of the hinges begin to form in B-IO range onwards.

4. The results evidenced that in 'L' shaped building model torsion produced is 22.02% more than the regular building in X direction. Also the torsion produced in 'T' shaped building is 21% more than the regular building in Y direction. So it is concluded that the structures are more vulnerable when they are more irregular. This increase in torsion may be reduced by providing separation joints at re-entrant corners of building.

5. Torsion caused in irregular buildings mostly because of eccentricity between center of mass and center of rigidity. Under excessive torsion, structural elements may reach to their torsional moment capacity or the whole structure may be forced to deflect beyond its lateral deflection limit. Therefore, torsional irregularity may cause failure of any structural system.

6. Since torsion is the most critical factor leading to major damage or complete collapse of buildings therefore, it is very essential that irregular buildings should be carefully analysed for torsion.

7. The performance based seismic design obtained by above procedure satisfies the acceptance criteria for immediate occupancy and life safety limit states for given intensities of earthquake.

REFERENCES

[1] Dalal Sejal P., Vasanwala S. A., Desai A. K., "Performance based seismic design of structure: A review", *International Journal of Civil And Structural Engineering Volume 1, No 4, 2011.*

[2] H. Gokdemir, H. Ozbasaran, M. Dogan, E. Unluoglu, U. Albayrak," Effects of torsional irregularity to structures during earthquakes", *Science Direct Engineering Failure Analysis 35 (2013) 713–717.*

[3] *Applied Technology Council*, "Seismic Evaluation and Retrofit of concrete Buildings, ATC-40", *Volume 1 and 2, Seismic Safety Commission, Redwood City, 1996.*

[4] Chopra, A.K. and Goel, R.K., "A modal pushover analysis procedure to estimate seismic demands for unsymmetric-plan

buildings”. *Earthquake Engineering and Structural Dynamics. 33 (2004), pp. 903-927.*

[5] A. R. Akhare, Abhijeet A. Maske, “Performance based seismic design of R.C.C. Buildings with plan irregularities” *International Conference on Advances in Civil and Mechanical Engineering Systems, 19-20 Dec.2014, Paper ID: C175, Page No. 52, http://acmes2014.in*

[6] Syed Ahamed, Dr. Jagadish.G.Kori,” Performance Based Seismic Analysis Of An Unsymmetrical Building Using Pushover Analysis”, *International Journal of Engineering Research-Online, Vol.1.Issue.2.2013, ISSN : 2321-7758.*

[7] Sudhanshu sood, Dr. Naveen Kwatra“ Performance based seismic design of building” July 2010.

[8] Raul Gonzalez Herrera and Consuelo Gomez Soberon, “Influence of plan irregularity of buildings”, *14th World conference on Earthquake Engineering,2008.*

[9] T. Mahdi and V. Soltan Gharaie, “Plan irregular RC frames: Comparison of Pushover with Nonlinear dynamic analysis”, Asian journal of civil engineering (building and housing) vol. 12, no. 6 (2011) pages 679-690.

[10] Rucha S. Banginwar, M. R. Vyawahare, P. O. Modani, “Effect of Plans Configurations on the Seismic Behaviour of the Structure By Response Spectrum Method”, *International Journal of Engineering Research and Applications (IJERA) ISSN: 2248-9622,Vol. 2, Issue 3, May-Jun 2012, pp.1439-1443.*

[11] P. B. Prajapati, “Influence of Plan Irregularity on Seismic Response of Buildings”, *International Journal of Engineering Research and Applications, ISSN: 2248-9622, Vol. 4, Issue 6(Version 6), June 2014, pp.85-89.*

[12] Amin Alavi, Prof. P.Srinivasa Rao, “Influence of Torsional Irregularities of RC Buildings in High Seismic Zone”, *Australian Journal of Basic and Applied Sciences, 7(13) November 2013, Pages: 16-23.*