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Comparative Study on Stiffness Regular and Stiffness Irregular Building Subjected to Seismic Load using Pushover Analysis

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***Abstract*—Earthquake is the one of the most dangerous natural hazards to damage the building structures and life. About 60% of the land area of our country is likely to damaging levels of seismic hazard. Now a days a space available for constructing the buildings are limited hence the building with irregularity is occur more, due to this irregularities in the building damages are more during earthquake. In high seismic zone areas building with irregularity become more vulnerable. To overcome this problem a study has been made to evaluate the seismic performance of vertically irregular buildings. In this study is to evaluate the seismic performance of G+5 RC L shaped building with stiffness regular and stiffness irregular subjected to earthquake forces. The modeling and analysis of the building is done by using ETABS 2015 software and evaluated by considering non-linear static analysis called pushover analysis. Different seismic responses like lateral displacement for the column at the end of projection (C1) and at the re-entrant corner (C2) and storey shear force are obtained. By using these responses a comparative study has been made between vertical regular and irregular buildings. The result remarks the conclusion that, a building with stiffness irregularity provides instability during seismic loading. Therefore to control the instability, a proportionate amount of stiffness is beneficial in RC building**

Keywords— Stiffness Irregularity, Pushover Analysis, Lateral Displacement, Storey Shear, ETABS 2015 (V 15.2.2)

I. INTRODUCTION

Earthquake is the most devastating and destructive of all the natural calamities. During an earthquake the damage in a structure generally initiated at location of the structural weakness in the building. A building is said to be a regular when the building configuration are almost symmetrical about the axis and it said to be the irregular when it lacks of symmetry and discontinuity in geometry, mass or load resisting elements. In the urban areas space available for constructing the building is limited hence the building with irregularity is occur more in that region. Therefore the structural engineer needs to have a thorough understanding of the seismic response of irregular structures.

The irregularity in the building structures may be due to irregular distributions in their mass, strength and stiffness along the height of building. When such buildings are constructed in high seismic zones, the analysis and design becomes more complicated.

There are two types of irregularities,
1. Plan Irregularities
2. Vertical Irregularities

Vertical irregularity is the irregular distribution in their mass, stiffness and geometry in vertical direction. Mass irregularity results from a sudden change in mass between adjacent floors, such as mechanical plant on the roof of a building or party hall on top floor etc. stiffness irregularity results from a sudden change in stiffness between adjacent floors, such as setback in the elevation of a building.
There are five types of vertical irregularities,

1) *Stiffness Irregularity*
a) Soft storey- A soft storey is one in which the lateral stiffness is less than 70% of the storey above or less than 80% of the average lateral stiffness of the three storey's above.
b) Extreme soft storey- An extreme soft storey is one in which the lateral stiffness is less than 60% of that in the storey above or less than 70% of the average stiffness of the three storey's above.(Fig 1)

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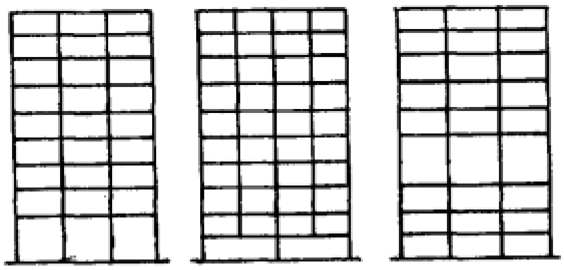

Fig. 1. Stiffness Irregularities

2) *Mass Irregularity*

Mass irregularity shall be considered to exist where the effective mass of any storey is more than 150% of effective mass of an adjacent storey. The effective mass is the real mass consisting of the dead weight of the floor plus the actual weight of partition and equipment. In case of roofs irregularity need not be considered. (Fig 2)

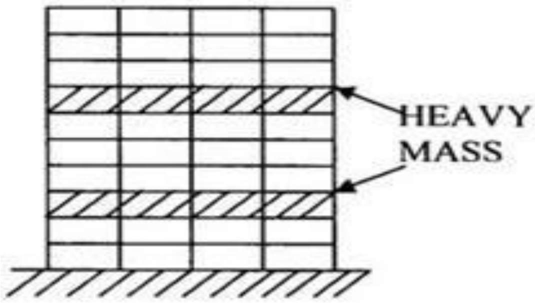

Fig. 2. Mass Irregularity

3) *Vertical Geometric Irregularity*

A structure is considered to be vertical geometric irregular when the horizontal dimension of the lateral force resisting system in any storey is more than 150% of that in an adjacent storey. (Fig 3)

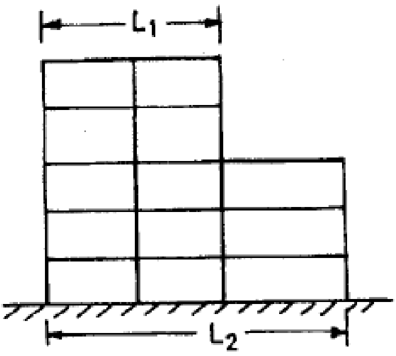

Fig. 3. Vertical Geometric Irregularity

4) *In-Plane Discontinuity in Vertical Elements Resisting Lateral Force*

An in plane offset of the lateral force resisting element greater than length of those elements.

5) *Discontinuity in capacity –weak storey*

A weak storey is one in which the storey lateral strength is less than 80% of that in the storey above.

II. PUSHOVER ANALYSIS

The use of non-linear static analysis, pushover analysis came into practice in 1970's but the potential of pushover analysis has been recognized for last 10 to 15 years. This procedure is mainly used to estimate the strength and drift capacity of existing structure and the seismic demand for this structure subjected to selected earthquake. Pushover analysis is defined as an analysis wearing a mathematical model directly incorporating the normal load deformation, characteristics of individual component and elements of the building.

Federal Emergency Management Agency (FEMA) and Applied Technical Council (ATC) are two agencies which formulated and suggested the non-linear static analysis. This included documents FEMA-356, FEMA-273 and ATC-40.

There are two types of pushover analysis one is Displacement Co-efficient method documented in FEMA-356 and other is Capacity Spectrum method documented in ATC-40. Both methods depend on lateral load deformation variation obtained by non-linear static analysis under the gravity loading and idealized lateral loading due to the seismic action. This analysis is called as pushover analysis.

The analysis involves applying horizontal loads or lateral loads, in a prescribed pattern to the structure incrementally, that is pushing the structure and plotting the total applied shear force and associated lateral displacement at each increment until the collapse condition.

III. METHODOLOGY

In the present study the L shaped stiffness regular and stiffness irregular building is considered, the plan view of the model as shown in Fig 4. The modeling and analysis is done by using ETABS 2015 software. The method of seismic analysis is non linear static analysis also called pushover analysis. Both stiffness regular and stiffness irregular models consist of 6 floors (G+5) with floor height being 3.2m each.

The dimension of the columns being fixed at 230X600mm and that of beams at 230X600mm, thickness of the slab is 150mm for both models as shown in table 1. The column positions have so been fixed that the spans of all the beams in both X and Y directions are kept same and equal to 5m. For stiffness irregular building, the ground floor height is kept it as 4.5m to maintain the vertical irregularity. In this study the results like storey shear force and lateral displacement for the column C1 (at the end of projection) and C2 (at the re-entrant corner) are considered.

The typical beam and column layout out of the L shaped building as shown below.

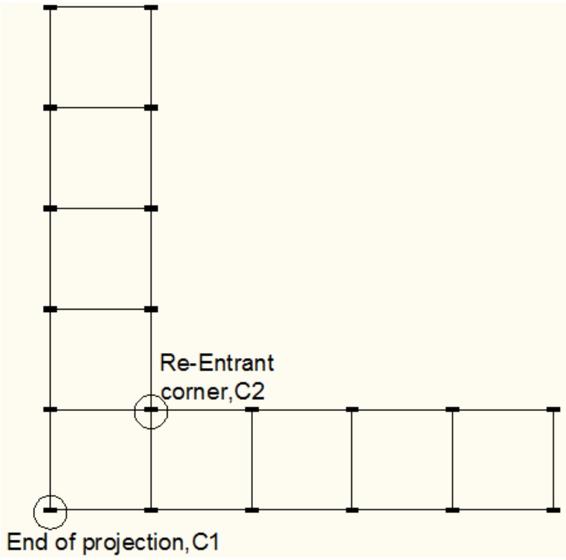

Fig. 4. L shaped model

IV. MODELING AND ANALYSIS

The software ETABS 2015 was used throughout the work for the modeling and analysis of the box shaped building. ETABS 2015 is an integrated structural analysis and design software. The building was modeled in ETABS 2015 software by considering the parameters like beam, column, slab etc. as mentioned in Table 1. Then the model was subjected to dead load and live load as per Indian standards. This is to be done in order to check the capacity of the preliminarily fixed dimensions of the structural members. If all the members are safe with design check, then seismic analysis is carried out. If not revise the member dimensions. The static non linear load patterns and load cases are defined for both along X and Y directions. After that the beam and column members are assigned with auto hinges based on the hinge properties taken from ASCE 41-13 table. After this the model is checked for errors and finally analyzed when subjected to lateral pushover loads as per displacement control method. After the analysis is complete the results like lateral displacement, bending moment, storey shear force and pushover curve are reviewed.

TABLE 1: PARAMETERS CONSIDERED IN THIS STUDY

Type of building	Stiffness regular
Structure type	Ordinary moment resisting frame
No. of stories	G+5
Typical storey height	3.2m
Type of building use	Public cum office
Foundation type	Isolated footing
Seismic zone	V
Material properties	
Grade of concrete	M20
Grade steel	Fe500
Density concrete	25 kN/m^3
Member properties	
Slab thickness	150 mm
Beam size	230X600 mm
Column size	230X600 mm
Wall size	230 mm
Dead load intensity	
Floor finish	1 kN/m^2
Live load intensities	
Roof	2.5 kN/m^2
Floor	3.5 kN/m^2
Earthquake live load on slab as per clause 7.3.1 and 7.3.2 of IS:1893(part 1)2002	
Roof	0.25X2.5=0.625 kN/m^2
Floor	0.5X3.5=1.75 kN/m^2

V. RESULTS AND DISCUSSION

The L shaped building with stiffness regular and stiffness irregular has been analysed and the results obtained from the analysis with regards to lateral displacement for the column at the end of projection (C1) & at the re-entrant corner (C2) and storey shear with respect to storey number as summarised below. The Fig 5 shows the 3D view of the building model.

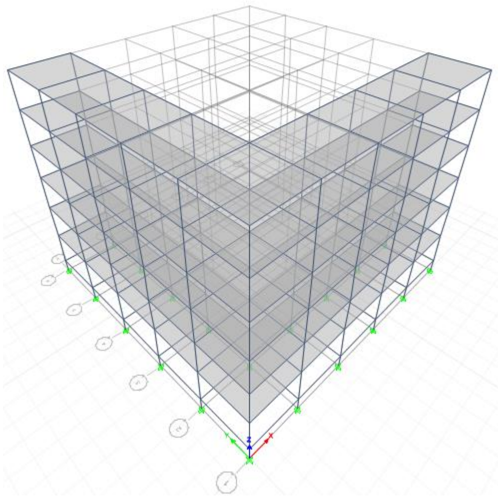

Fig. 5. 3D view of the building

Table 2: variation of lateral displacement at end of projection (C1 Column) of the model

Model type	Storey No.	Push X		Push Y	
		Along X	Along Y	Along X	Along Y
Stiffness regular	6	107.82	3.26	1.00	99.46
	5	105.20	3.03	1.00	96.54
	4	98.12	2.56	1.00	90.53
	3	82.26	1.91	0.00	81.27
	2	56.52	1.22	0.00	66.47
	1	26.19	1.00	0.00	39.48
Stiffness irregular	6	112.90	3.58	1.00	86.84
	5	110.71	3.36	1.00	84.63
	4	105.66	2.89	1.00	80.13
	3	93.58	2.22	0.00	73.31
	2	71.29	1.52	0.00	64.07
	1	41.12	1.00	0.00	49.07

Table 3: variation of lateral displacement at re-entrant corner (C2 column) of the model

Model type	Storey No.	Push X		Push Y	
		Along X	Along Y	Along X	Along Y
Stiffness regular	6	102.19	8.92	2.24	97.94
	5	99.98	8.28	2.14	95.09
	4	93.74	6.96	2.03	89.14
	3	79.10	5.06	1.85	79.95
	2	54.60	3.12	1.32	65.53
	1	25.34	1.42	1.00	39.16
Stiffness irregular	6	106.77	9.73	1.68	83.73
	5	104.96	9.14	1.60	83.57
	4	100.72	7.84	1.51	79.13
	3	89.91	5.89	1.41	72.36
	2	68.94	3.85	1.26	63.18
	1	39.93	2.07	1.00	48.62

Table 2 and Table 3 shows the variation of lateral displacement at the end of projection and at the re-entrant corner with respect to different storeys for push X and push Y loads respectively.

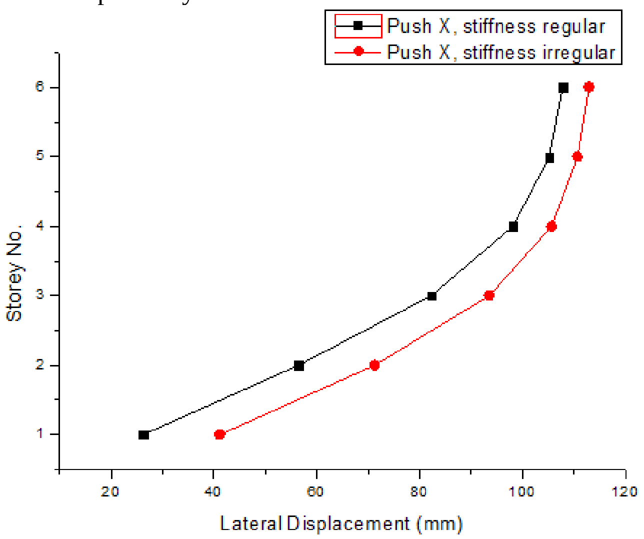

Fig. 6. Variation of lateral displacement at the end of projection (C1) due to PUSH X (X direction)

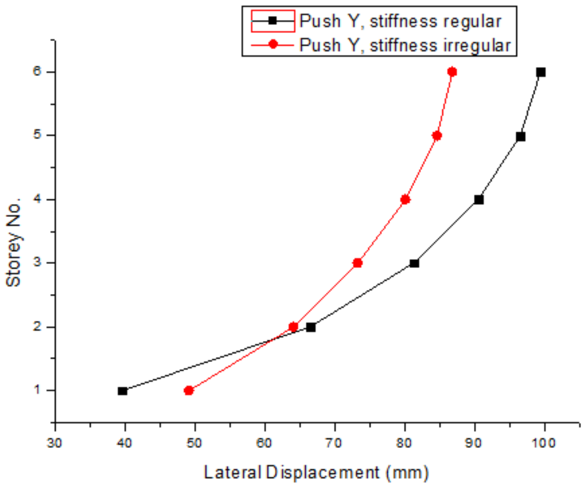

Fig. 7. Variation of lateral displacement at the end of projection (C1) due to PUSH Y (Y direction)

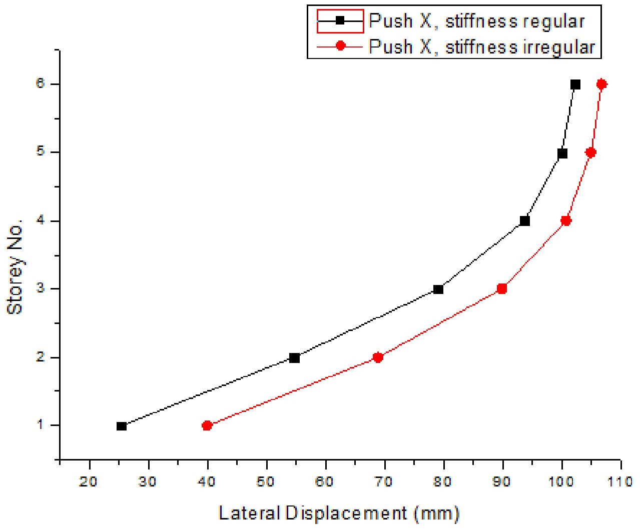

Fig. 8. Variation of lateral displacement at the re-entrant corner (C2) due to PUSH X (X direction)

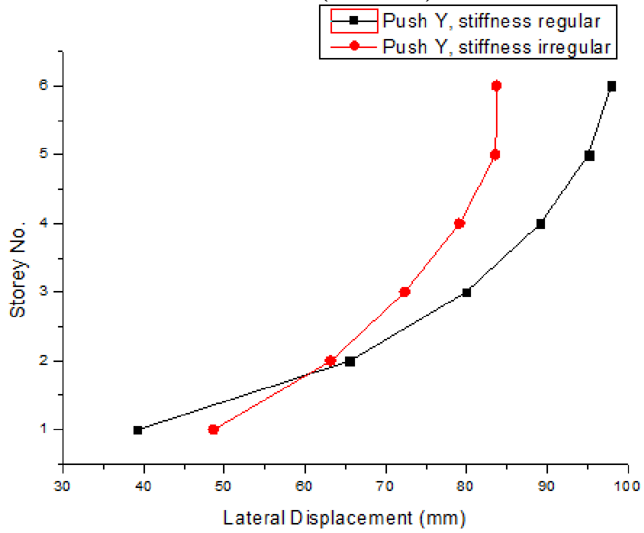

Fig. 9. Variation of lateral displacement at the re-entrant corner (C2) due to PUSH Y (Y direction)

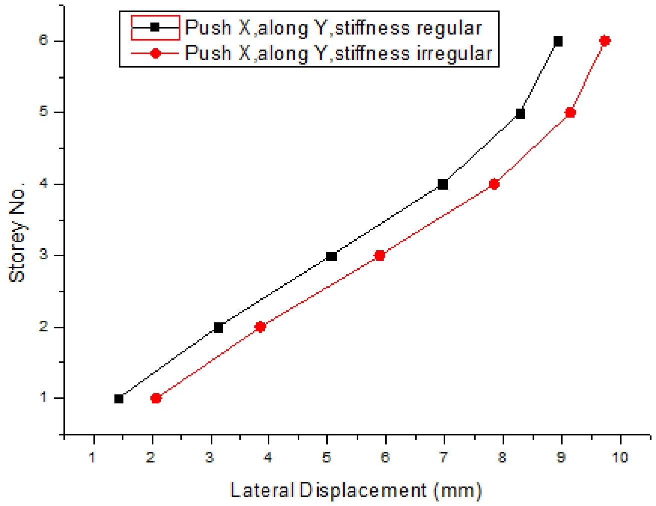

Fig. 10. Variation of lateral displacement at the end of projection (C1) due to PUSH X (Y direction)

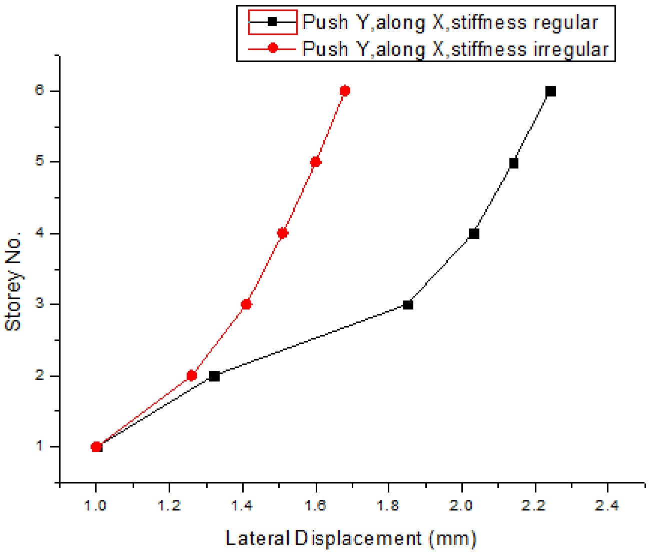

Fig. 11. Variation of lateral displacement at the end of projection (C1) due to PUSH Y (X direction)

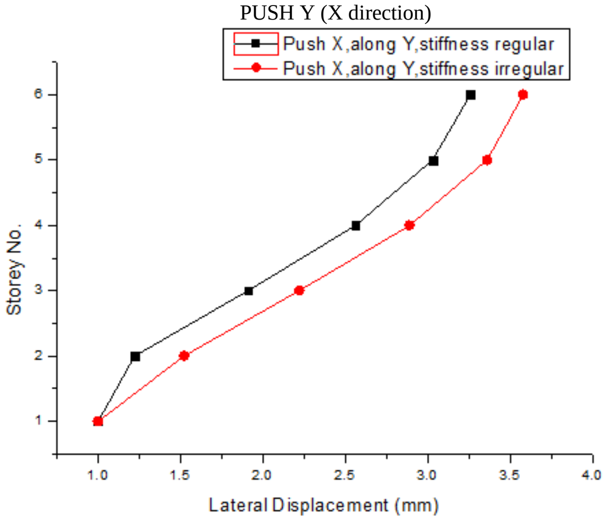

Fig. 12. Variation of lateral displacement at the re-entrant corner (C2) due to PUSH X (Y direction)

From Fig 6 to Fig 9 shows the variation of lateral displacement at different storey for stiffness regular and stiffness irregular building at the re-entrant corner and end of projection due to push X and push Y load respectively. From the chart it can be seen that the lateral displacement goes on decreases from the top storey to bottom story.
From Fig 10 to Fig 12 shows that due to application of push X load in X direction there is a displacement in Y direction occurred and vice versa. Also lateral displacement is more for stiffness irregular building compare with stiffness regular building.

The values of Storey shear for various storey along push x and push y for stiffness regular and stiffness irregular building is as shown in Table -4.

Table 4: variation of storey shear of the model

Model type	Storey No.	Push X		Push Y	
		Along X	Along Y	Along X	Along Y
Stiffness regular	6	324.50	0	0	200.93
	5	725.64	0	0	449.31
	4	1126.78	0	0	697.69
	3	1527.92	0	0	946.08
	2	1929.06	0	0	1194.46
	1	2330.20	0	0	1442.84
Stiffness irregular	6	284.39	0	0	149.00
	5	635.95	0	0	333.20
	4	987.51	0	0	517.39
	3	1339.67	0	0	701.59
	2	1690.63	0	0	885.79
	1	2050.47	0	0	1074.32

From Fig 13 and Fig 14 shows the variation of storey shear at different storey for stiffness regular and stiffness irregular building due to push X and push Y load respectively. It can be seen that the storey shear will be less in top storey and increasing towards the bottom storey and also storey shear becomes considerably more in stiffness regular building compare with the stiffness irregular building.

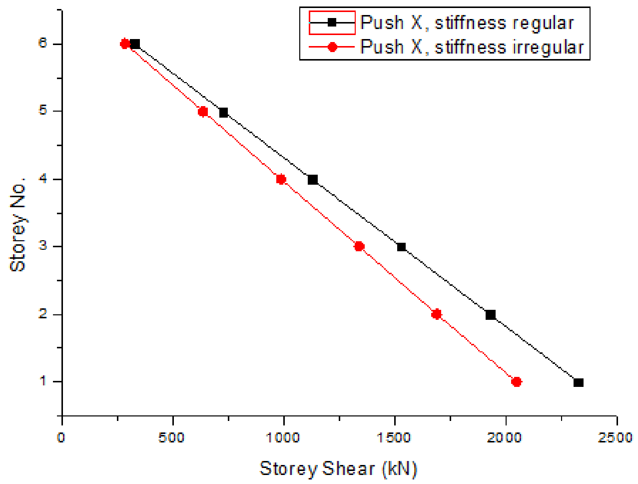

Fig. 13. Variation of storey shear due to PUSH X (X direction)

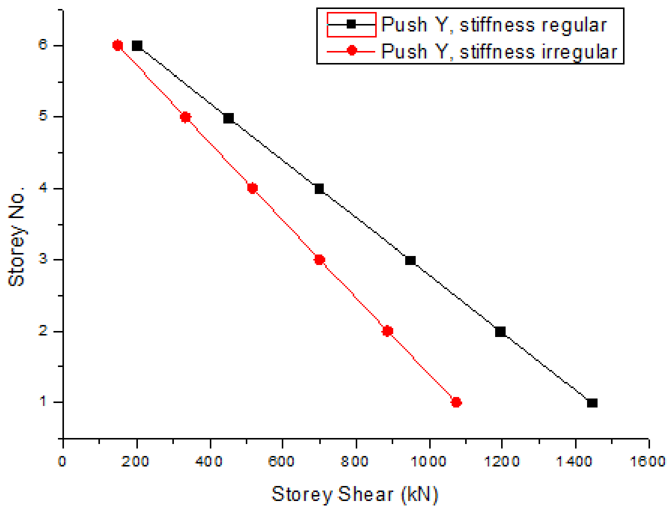

Fig. 14. Variation of storey shear due to PUSH Y (Y direction)

VI. CONCLUSIONS

In the present work, the effect of stiffness irregularities on seismic performance of G+5 RC L shaped building has been carried out. Pushover analysis has been performed using ETABS 2015 software. From the analysis and results it can be concluded that, the lateral displacement value more in the building with stiffness irregularity as compared to building with stiffness regularity. As we noticed that in the ground floor the lateral displacement of stiffness irregular building is 60% more than that of stiffness regular building due to excess height of the ground floor being 4.5m. Also storey shear force is more in the building with stiffness regularity as compared to stiffness irregularity. So that, it proves that vertically irregular buildings are harmful and the effect of stiffness irregularity on the structure is also dangerous in seismic zone. Therefore, as far as possible irregularities in a building must be avoided. If irregularities have to be introduced for any reason such buildings should be designed properly as per IS codes.

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