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Seismic Vulnerability of Irregular Buildings

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Abstract—*The performance of buildings subjected to earthquake forces have shown that asymmetric structures cause more extensive damages as compared with symmetric structures and failure of these structures can be held responsible for most of the human fatalities. This paper aims to study the vulnerability characteristics of irregular structures subjected to seismic excitation. For this, 5 different models have been compared with that of regular one by using Finite Element Method based software SAP 2000 (v18). Regular RCC frame building having G+9 storey is considered with varied discontinuity at different floors are analyzed using Response Spectrum Method (Linear Dynamic) as per IS 1893 (Part 1). The influence of various structural parameters i.e. Natural Time Period, Base Shear, Inter-Storey Drift Ratio, Beam Moment and Column Moments, effect of variation in angle of incidence of earthquake are compared with that of regular building. Pushover Analysis (Non –Linear Static) is also carried out to compare the base shear –roof displacement curves i.e. pushover curve and hinge displacement. From this study, it is concluded that the irregular buildings are more vulnerable under earthquake forces as compared with the regular building. The results also show that the effect of angle of incidence of earthquake should be considered in the assessment of irregular multi-storey building.*

Keywords*: Response Spectrum Method, Pushover Analysis, Vulnerability, Angle of incidence, Asymmetric Structures.*

1. INTRODUCTION

Importance of irregular buildings has increased tremendously due to functional demands such as public buildings (e.g. hospitals, hotels, shopping complex,).These buildings are higher seismic vulnerable as compared with regular buildings due to irregularity in their shape. The seismic performance of a structure during an earthquake depends on its seismic responses and its capacity .The earthquake forces developed at different floor levels in a building need to be brought down along the height to the ground by the shortest path and if any there is any discontinuity in the load transfer path results in increase in the concentration of stresses gets developed in certain portion within the structure and can cause serious damages .Buildings with vertical setbacks causes a sudden jump in earthquake forces at the level of discontinuity hence it is imperative to study the structural behavior of the buildings with irregularities. Many buildings with an open ground storey intended for parking collapsed or were severely damaged in Gujarat during the 2001 earthquake.

The response of irregular building is studied in past and large number of literature is available. Influence of bi-directional seismic excitations on the inelastic behavior of in-plan irregular systems having one symmetric axis, one storey building with orthogonal resisting elements, seismic design procedures of base isolated system, high rise building with vertical irregular in nature, irregular structures by nonlinear response history analysis , seismic codes still allow the use of static analysis and supply formulations of equivalent static eccentricities, which should provide a safe estimate of the elastic design, Non-linear pushover analysis of irregular building. Further in most of engineers are using computer software for analysis, it will also create some problem in analysis. Thus various factors of the structure which contributes causes of the failure.

The analysis of the seismic response of irregular structures is complex due to nonlinear and inelastic response and more difficult than that of regular structures. Accordingly, the nonlinear dynamic analysis method is the best choice for solving these problems since they provide more realistic models of structural response to strong ground shaking and, thereby provide more reliable assessment of earthquake performance than other methods of analysis.

2. ANALYSIS PERFORMED

In this paper, building with vertical irregularities is considered. For this six types of building are studies. The first type is a regular building with perfect symmetry second, third, fourth, fifth and sixth building having setback irregularities where percentage of floor area is different at different height.

These six types of buildings are analyzed using Response spectrum analysis and Push Over analysis. This comparison helps in assessing the effect of vertical irregular building over regular one on the seismic response of building.

2.1 Response Spectrum Analysis

In the response spectrum method the peak response of a structure during an earthquake is obtained directly from the earthquake response spectrum. Often a response spectrum is presented as a plot of maximum response of a set of SDOF systems subjected to a support (ground) motion as ordinate and corresponding natural frequencies of the SDOF system as abscissa. Idealized single degree freedom systems having certain time period and damping, during earthquake ground motion. The maximum response is plotted against the undamped natural period and for various damping values and can be expressed in terms of maximum absolute acceleration, maximum relative velocity or maximum relative displacement. IS 1893 2002 has been considered here.

This procedure gives an approximate peak response, which is quite accurate for structural design purposes. The RSA is performed with SAP for all six building models. The response spectrum obtained from IS 1893 (part 1):2002.

2.2 Pushover Analysis

Pushover analysis is one of the analysis methods recommended by Euro-code and FEMA 273. Pushover analysis provides valuable insights on many response characteristics like force Demand on Potentially brittle elements, Consequences of strength deterioration of individual elements on structural behavior, Identification of critical regions in which the deformation demands are expected to be high and that have to become the focus of through detailing and identification of strength discontinuities in plan or elevation that will lead to changes in dynamic characteristics in the inelastic region. It is a technique by which a structure is subjected to an incremental lateral load of certain shape. The sequence of cracks, yielding, plastic hinge formation and failure of various structural components are noted. The structural deficiencies are observed and rectified. The iterative analysis and design goes on until the design satisfies pre-established criteria. The performance criteria are generally defined as Target displacement of the structure at roof level. For irregular building, push over analysis is a quantitative approach and here analysis is done for the comparative study Pushover curve is a plot drawn between base shear along vertical axis and roof displacement along horizontal axis. Performance point of the structure in various stages can be obtained from pushover curve. The various performance levels for a building are expressed in terms of a base shear carried versus roof displacement curve. The range AB is elastic range, B to IO is the range of immediate occupancy IO to LS is the range of life safety and LS to CP is the range of collapse prevention. When a hinge reaches point C on its force displacement curve that hinge must begin to drop load. If all the hinges are within the CP limit then the structure is still said to be safe. On the contrary, if the hinges formed are beyond CP limit then it is said that the structure collapses.

3. DETAILS OF BASE MODELS

Other details of this frame are as follows.

Seismic zone V

Zone Factor 0.36

Importance factor 1.00

Type of soil Medium

Analysis and Design parameters

Type of Structure = Residential Building

Materials = M20 grade concrete,

= Fe 415 grade steel

Seismic analysis method = Response Spectrum method

(IS 1893 (Part 1): 2002)

= Push over analysis

Design Philosophy = Limit State Method

(IS 456: 2000)

Geometric parameters

Foundation level to Ground level = 3 m

Number of bays in X- direction = 5

Number of bays in Y- direction = 4

Spacing of bays in X-direction = 5 m

Spacing of bays in Y-direction = 4 m

Height of each story = 3 m

Number of storey = G+9

Dimensions of structural members

Beam cross -section = 0.35 m*0.30 m

Column cross -section = 0.45 m*0.40 m

Thickness of the slab = 0.150 m

Thickness of external wall = 0.23 m

Loads considered

Unit weight of brick masonry = 18 kN/m3

Unit weight of R.C.C = 25 kN/m3

Self-Weight of external wall (WE) = 0.23 x 18 x (3-0.35) = 10.97 kN/m2

Self-Weight of slab (Ws) = 25 x 2 x 0.15

= 7.5 kN/m

Live load on slab (L.Ls) = 3 kN/m

Self-Weight of floor finish (WFF) = 2 kN/m

Live load on floor = 6 kN/m

Roof Treatment = 3 kN/m

Live roof = 2 kN/m

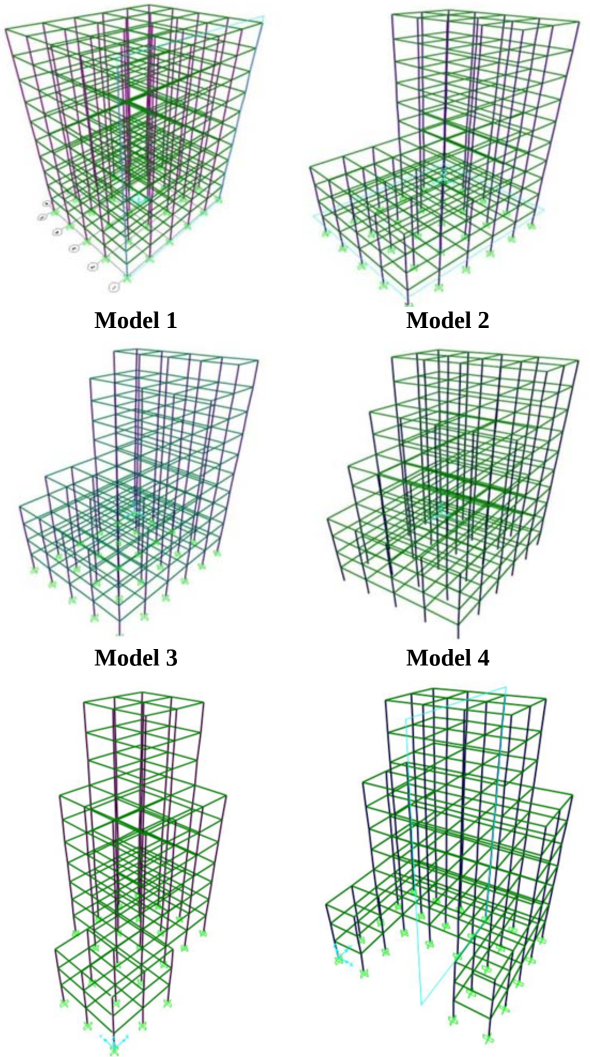


Fig. 1 RC structural models adopted in the analysis

4. RESULTS AND DISCUSSION

4.1 Response spectra analysis

Effect of vertical irregularity on base shear

The base shear for seismic forces in X and Y directions in all six models is shown in Table 1.From the table it can be seen that base shear of irregular structure is less as compared with regular one.

Table 1 Comparison of base shear of different vertical irregular models

Model	Base shear due to	
	EQx	EQy
1	437.727	451.877
2	431.07	385.396
3	461.32	365.942
4	493.954	378.886
5	235.175	217.622
6	146.58	138.916

Effect of vertical irregularity on Time Period

Natural time period is a primary parameter which regulates the seismic lateral response of the building frame. Thus evaluation of natural is necessary and the variations of natural time period in different modes for all six model are shown in Table 2.

Table 2 Time periods of six models

Mode	Time Period (in Seconds)					
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
1	1.810	1.847	1.754	1.899	1.591	0.802
2	1.722	1.657	1.495	1.641	1.406	0.756
3	1.656	1.284	1.100	1.346	0.988	0.590
4	0.585	0.678	0.656	0.698	0.565	0.304
5	0.554	0.665	0.654	0.630	0.543	0.278
6	0.536	0.627	0.615	0.619	0.480	0.264
7	0.331	0.367	0.345	0.545	0.363	0.185
8	0.312	0.366	0.334	0.466	0.345	0.181
9	0.305	0.341	0.298	0.424	0.338	0.167
10	0.223	0.242	0.238	0.396	0.334	0.116
11	0.207	0.232	0.233	0.386	0.319	0.106
12	0.205	0.219	0.224	0.362	0.2286	0.106

Inter Storey Drift

Inter-storey drift is the difference in displacement at roof level and floor level of same storey. According to IS 1893-2002, maximum allowable inter storey drift ratio of the building should not go beyond 0.004. Here various models, inter-storey drift ratio has been obtained in both x and y for response spectra analysis. Figures 2(a) and 2(b) represent the inter-storey drift at each storey level for all six models for seismic force in X and Y directions respectively.

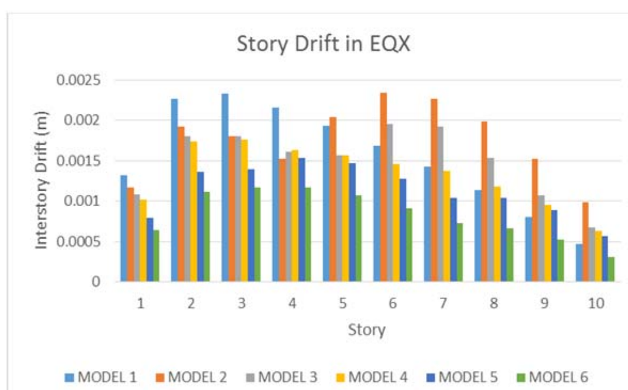


Fig. 2(a) Inter-story drift of six models in EQx

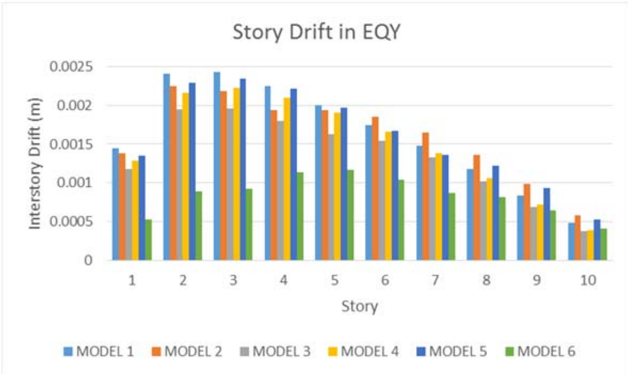


Fig. 2(b) Inter-story drift of six models in EQy

Effect of vertical irregularity on column and beam moments and shear force

Maximum moments and shear forces at ground storey due to earthquake force in X and Y directions using response spectra method are shown in Fig. 3(a) and 3(b) respectively. Moments and shear forces varies with irregularity and seismic force direction.

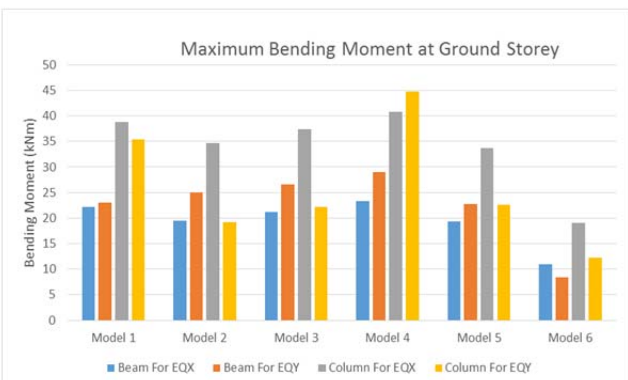


Fig. 3(a) Maximum Bending Moments in Beam and Columns at Ground Storey in both EQx and EQy

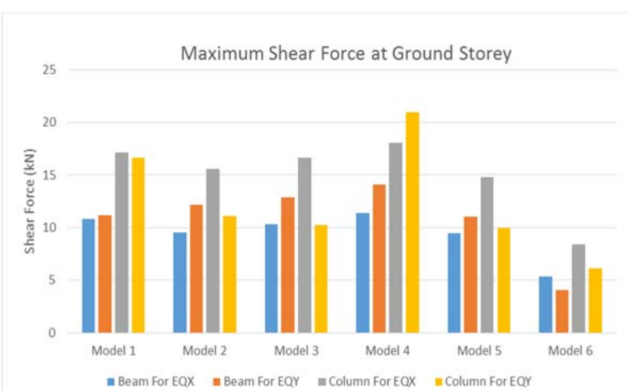


Fig. 3(b) Maximum Shear Force in Beam and Columns at Ground Storey in both EQx and EQy

Effect of angle of incidence of seismic force on base shear of different models

The effect of different angle of incidence i.e. 0^O, 30^O and 45^O of different models are shown in shown in Table 3. It can be seen from the table that 0^O degree angle of incidence results in higher base shear as compared with 30^O and 45^O respectively for all models.

Table 3 Effect of angle of incidence on base shear

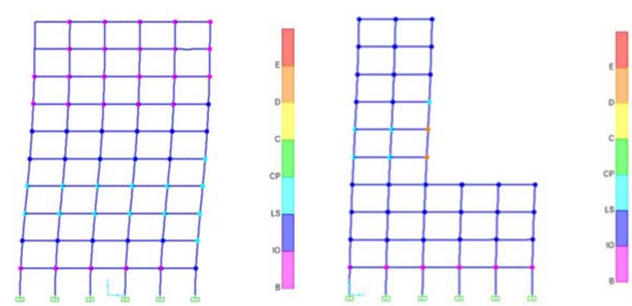
Model	BASE SHEAR(KN) For 0^0 incidence		BASE SHEAR(KN) For 30^0 incidence			
	EQx	EQy	EQx		EQy	
	x	y	x	y	x	y
1	437.7	451.8	410.2	225.0	236.8	391.3
2	431.1	385.3	373.3	192.9	215.5	334.2
3	461.3	365.9	399.5	182.9	230.6	316.9
4	493.9	378.8	427.7	189.4	246.9	328.1
5	235.7	217.6	234.5	148.6	114.1	194.8
6	146.6	138.9	126.9	69.4	73.29	121.3

MODEL	BASE SHEAR(KN) For 45^0 incidence			
	EQx		EQy	
	X	Y	X	Y
1	334.9	319.5	334.9	319.5
2	304.8	272.8	304.8	272.8
3	326.2	258.7	326.2	258.7
4	349.2	267.9	349.2	267.9
5	214.3	175.7	148.5	170.9
6	103.6	98.2	103.6	98.23

4.2 Pushover Analysis

Pattern of Hinge Formation for Various Models in Pushover Analysis

Model 1 is in the range of Life safety under seismic force using Pushover analysis. Model 2 and 3 has two hinges at fifth and sixth storey each in collapse reason. Model 4 to 6 are in range of life safety.



Model 1 **Model 2**

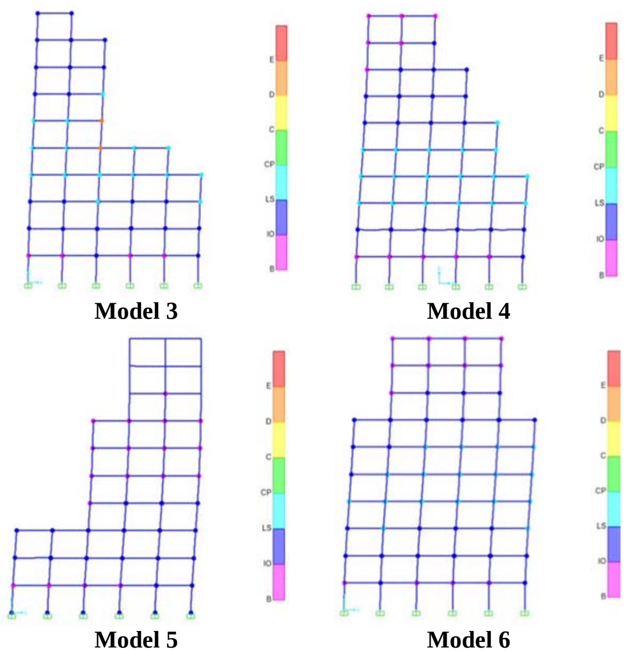


Fig. 4 Plastic Hinge formation in Pushover Analysis in x direction

Pushover Curve

Pushover curve i.e. base shear vs roof displacement curve are plotted for different models. For models 2, 3 and 4 higher base shear as compared to regular model 1 as shown in Fig. below in both X and Y directional seismic forces.

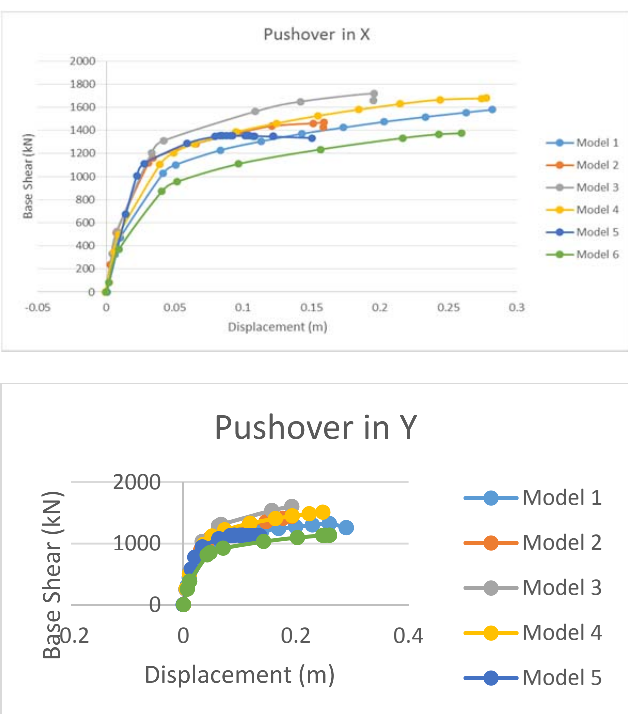


Fig. 5: Shows pushover curve in x and y direction for Models 1, 2, 3, 4, 5&6

5. CONCLUSION

In this paper, the applicability of the 3D response spectrum analysis and pushover analysis for predicting the seismic response of multistoried structures with vertical irregularity has been investigated.

Base shear force using response spectrum analysis is found to be lessor in irregular building as compared with that of regular one.

Zero degree angle of incidence results in higher base shear as compared with 30^O and 45^O respectively for all models

The results of pushover analyses confirm the seismic vulnerability of multistoried structure with vertical irregularity as models 2 and 3 having collapse prone hinges at fifth and sixth floors.

.The results obtained for models 4, 5 and 6 show that pushover techniques still require further refinement in order to provide reliable estimates of the dynamic response of 3D asymmetrical structures.

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