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Study of Vertical Irregularities in Building Frames under Seismic Loading

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Abstract: Earthquakes are natural disasters that damage both life and property. These disasters cannot be predicted or prevented but the structures can be made to resist them. The failure of a structure begins at points of weakness which may occur due to irregularities in structures. Therefore the study of the various irregularities in structures becomes necessary. In this study, three dimensional reinforced concrete (RC) frame models with vertical irregularities have been compared with models with no irregularity. Displacement, base shear, storey drift and bending moment are the parameters considered.

Keywords: Seismic behaviour, RC frames, vertical irregularity, displacement, storey drift, base shear, bending moment.

I. INTRODUCTION

The world has been facing a threat of natural disasters from time to time. The occurrence of an earthquake cannot be predicted and prevented but the preparedness of the structures to resist earthquake forces becomes more important. Earthquake performance of reinforced concrete bare frame has been well documented in the past. Also, damage patterns in reinforced concrete frames during the past earthquakes have been extensively studied. During an earthquake, failure of structure starts at the points of weakness. The weakness arises due to discontinuity in mass, stiffness and geometry of structure. The structures having this discontinuity are termed as irregular structures. As it is well known, structural regularity is an important issue for a good seismic response. Despite structural regularity is quite easy to obtain through a careful design, it is very common that, in the reality, different irregularities can occur, changing the seismic performance of the building. Nowadays, need and demand of the latest generation and growing population has made the engineers inevitable towards planning of irregular configurations. Structural irregularities are commonly found in constructions and structures. Architectural demands are usually the cause of such irregularities. Many buildings in the present scenario have irregular configurations both in plan and elevation, which in future may be subjected to devastating earthquakes. That is why, it is necessary to identify the performance of the structures to withstand against disaster primarily due to earthquake. Practically, many existing buildings contain irregularity, and some of them have been designed initially to be irregular to fulfil different functions, e.g. basements for commercial purposes created by eliminating central columns, reduction of sizes of beams and columns in the upper stories to fulfil functional requirements, storing heavy mechanical appliances etc. This difference in usage of a specific floor with respect to the adjacent floors results in irregular distribution of mass, stiffness and strength along the building height. In addition, many other buildings are accidently rendered irregular due to a variety of reasons such as non-uniformity in construction practices and material used. However, these irregular structures (designed as per code provisions) exhibit poor seismic performance as shown by the past records.

A. *Regularities and Irregularities in Structures*

A building is said to be a regular when the building configurations are almost symmetrical about the axis and it is said to be irregular when it lacks symmetry and discontinuity in geometry, mass or load resisting elements. A regular structure can be envisaged to have uniformly distributed mass, stiffness, strength and structural form. When one or more of these properties is non-uniformly distributed, either individually or in combination with other properties in any direction, the structure is referred to as being irregular. A structure can be classified as vertically irregular if it contains irregular distributions of mass, strength and stiffness along the building height. Mass irregularity results from a sudden change in mass between adjacent floors, such as mechanical plant on the roof of a

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structure. Stiffness irregularity results from a sudden change in stiffness between adjacent floors. In the present study vertical irregularities have been considered.

STAAD analysis package is useful for the analysis of all structures, to get all nodal displacements. STAAD-PRO can solve typical problems like static analysis and seismic analysis. Therefore, in the present study, STAAD PRO V8i has been used for the analysis of all the models.

II. Review of Literature

A. *IS Code Provisions Related to Vertical Irregularities*

The building configuration has been described as regular or irregular in terms of the size and shape of the building, arrangement of structural elements and mass. IS: 1893 (Part-1) – 2002 has explained building configuration system for better performance of RC buildings during earthquakes. Vertical geometric irregularity shall be considered to exist where the horizontal dimension of the lateral force resisting system in any storey is more than 150 % of that in its adjacent storey (Table 5, Page 18, IS: 1893 (Part-1) – 2002). As per IS: 1893 (Part-1) – 2002, a story in a building is said to contain mass irregularity if its mass exceeds 200% than that of the adjacent storey.

B. *Researches in the Past*

Costa A.G. et al. (1988) studied the seismic behaviour of reinforced concrete buildings exhibiting vertical irregularities. They studied 16 storey-high buildings for three different horizontal layouts and five vertical configurations. Modakwar N.P. et al. (2014) stated that irregularities are not avoidable in construction of buildings. The objective of their study was to understand different irregularities and seismic response due to plan and vertical irregularity and to analyze cross shape and L shape building with earthquake forces acting and to calculate additional shear due to torsion in the columns. They concluded that the corner columns must be stiffened for shear force in the horizontal direction perpendicular to it as significant variation was observed in these forces. Zhou J. et al. (2011) addressed the seismic displacement ductility demand of structures with vertical irregularities when subjected to ground motions. The irregularities were in strength, stiffness, and combined strength-and-stiffness in the first storey of structures. The displacement ductility demand was found to be higher when accounting for vertical irregularities. Colina D.L. (2003) made assessments of several code specified procedures regarding analysis procedures for multi-storey building systems with mass and stiffness irregularity subjected to bidirectional seismic excitation. Singh R. et al. (2014) studied the comparison of the seismic behaviour of regular building frames with vertically irregular building frame at different positions. For analysis STAAD Pro software was used. Observation showed that for all the frames considered, drift values follow a similar path along storey height with maximum value lying somewhere near the thirteenth to fifteenth storey. Das S. and Nau J.M. (2003) evaluated the effects of stiffness, strength and mass irregularity on inelastic seismic response of large number of multi-storey structures.

III. Problem Formulation

A standard building of four-storey has been taken. This model is named as Model 1. The storey height is 3.5 m. The depth of foundation is 1.5 m. The building has 4×4 m bays. Four models have been developed for this basic model for each of the 4 seismic zones, as described in IS: 1893 (Part-1) – 2002. Therefore the 4 models corresponding to Model 1 are Model1 Z2, Model1 Z3, Model1 Z4 and Model1 Z5. The elevation, plan and rendered view of the building are shown below.

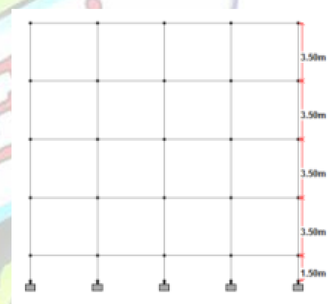

Fig. 1. Model1 Elevation

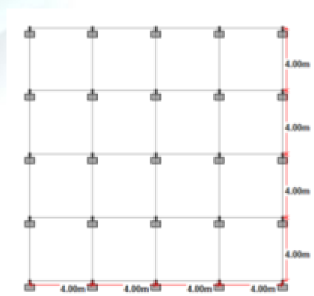

Fig. 2. Model1 Plan

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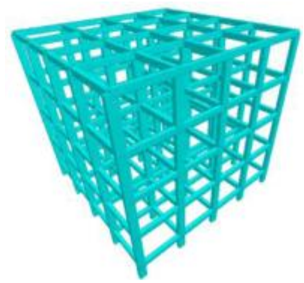

Fig. 3. Model1 Rendered View

The following beam size has been taken:-

Beam size – 450 × 300 mm, Column size – 600 × 300 mm

Seismic load definition:-

Seismic load is as per IS 1893-2002. Following are the parameters:-

Zone factor – For each model 4 different zone factors have been taken. For

Zone II – 0.1, Zone III– 0.16, Zone IV– 0.24, Zone V– 0.36

Ordinary moment resisting reinforced concrete frame has been assumed.

Type II Medium soil has been taken. Response reduction factor – 3

Importance factor – 1, Damping ratio – 5%

The following loading pattern has been taken:-

1. EQ +X – earthquake load acting in the positive X-direction
2. EQ –X – earthquake load acting in the negative X-direction
3. EQ +Z – earthquake load acting in the positive Z-direction
4. EQ –Z – earthquake load acting in the negative Z-direction
5. Dead load-Self weight, Floor load = 5 kN/m^2 ,Load bearing wall load = 15 kN/m^2 , Non-load bearing wall load = 7.5 kN/m^2
6. Live load = 3 kN/m^2
7. 1.5DL +1.5 LL
8. 1.2DL + 1.2 LL
9. 1.2DL + 1.2 LL ±1.2EQ ±X
10. 1.2DL + 1.2LL ±1.2EQ ±Z
11. 1.5DL
12. 1.5DL ±1.5EQ ±X
13. 1.5DL ± 1.5EQ ±Z
14. 0.9DL ± 1.5EQ ±X
15. 0.9DL ± 1.5EQ ±Z

Total number of nodes – 150
Total number of beams - 365

In the present study, models with vertical irregularities have been compared with the standard model i.e. Model1. Models with vertical irregularity are named as V1 and V2. These models have been developed for all the 4 seismic zones. Therefore the models corresponding to vertical irregularities are Model V1 Z2, Model V1 Z3, Model V1 Z4, Model V1 Z5, Model V2 Z2, Model V2 Z3, Model V2 Z4 and Model V2 Z5.

The following are the models with vertical irregularities (elevation has been shown):-

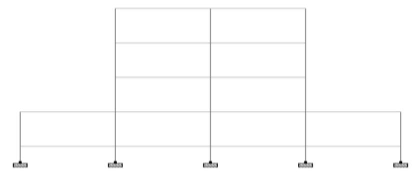

Fig. 4. ModelV1 Elevation

Total number of nodes – 120
Total number of beams – 269

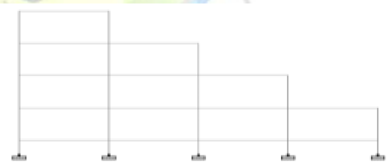

Fig. 5. ModelV2 Elevation

Total number of nodes – 120
Total number of beams – 267

In the observation part, the parameters namely displacement, storey drift, base shear and bending moment of Node No.128 and Column No. 76 has been studied. The location of the Node No.128 and Column No. 76 is given below. The values for the above parameters have been tabulated and plotted graphically for the comparative study.

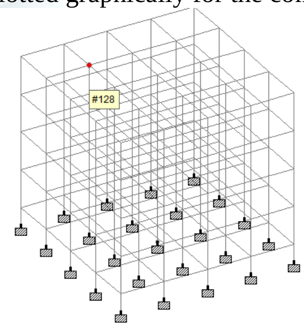

Fig. 6. Location of Node 128 considered

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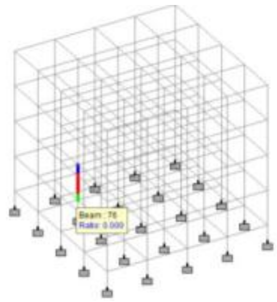

Fig. 7. Location of Column 76 considered

IV. Results and Discussions

As described in the previous chapter, one standard structure (for all 4 zones gives 4 models) & two structures with vertical irregularities have been analysed. All the above mentioned 12 models have been analysed on the software STAAD PRO. These models were analysed for various load cases. In the observations, displacement, base shear and bending moment for two load cases have been taken. The two load cases used are 1) Load case 1 in which earthquake load is acting in +X direction and 2) Load case 3 in which earthquake load is acting in +Z direction. The displacement observed for all the models, with vertical irregularity, for all the four seismic zones, have been then tabulated with the displacement observed for the standard model. Then the base shear observed for all the models, with vertical irregularity, for all the 4 seismic zones have been tabulated with the base shear observed for the standard model. After that the bending moment observed for all the models, vertical irregularity, for all the 4 seismic zones have been tabulated with the bending moment observed for the standard model. After each table, all the values have been compared by representing them graphically.

The numerical values of the displacements of the frame having Node no. 128 have been given in Table 1. As per IS 456, the allowable lateral displacement is H/500, where H is building height. Here the height of building is 15.5 m. Therefore the allowable lateral displacement is 31mm. According to IS-1893:2002 (part I), maximum limit for storey drift with partial load factor 1.0 is 0.004 times of storey height. Therefore the allowable limit is 14mm.

The values of the displacement for the standard model and models with vertical irregularities have been tabulated below. Graph representing these values is drawn below.

TABLE I
EFFECT OF VERTICAL IRREGULARITY IN BUILDING FRAMES ON DISPLACEMENT

NODE 128						
Zone	Standard Model1		Vertical Irregularity V1		Vertical Irregularity V2	
	X (mm)	Z (mm)	X (mm)	Z (mm)	X (mm)	Z (mm)
II	5.70	11.79	5.68	11.45	4.81	10.93
III	9.12	18.87	9.09	18.31	7.69	17.48
IV	13.68	28.30	13.63	27.47	11.54	26.22
V	20.52	42.45	20.45	41.20	17.31	39.33

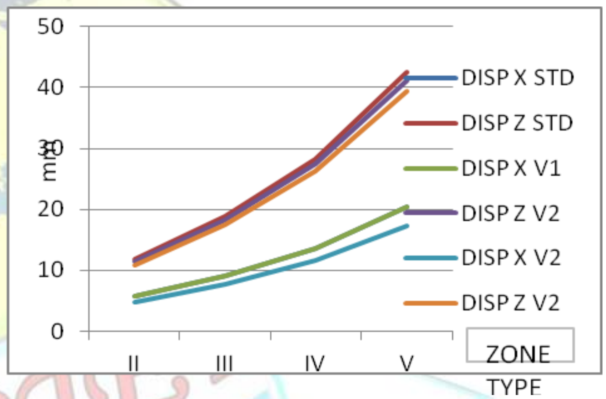

Fig. 8 Effect of vertical irregularity in building frames on displacement

The values of the base shear for the standard model and models with vertical irregularities for column no. 76 have been tabulated below.

TABLE III
EFFECT OF VERTICAL IRREGULARITY IN BUILDING FRAMES ON BASE SHEAR

COLUMN 76						
Zone	Standard Model1		Vertical Irregularity V1		Vertical Irregularity V2	
	X (kN)	Z (kN)	X (kN)	Z (kN)	X (kN)	Z(kN)
II	15.56	17.49	32.94	14.02	10.15	15.88
III	24.89	27.98	52.70	22.43	16.25	25.41
IV	37.33	41.97	79.05	33.64	24.37	38.12
V	56.00	62.95	118.6	50.46	36.55	57.18

Graph representing these values is drawn below.

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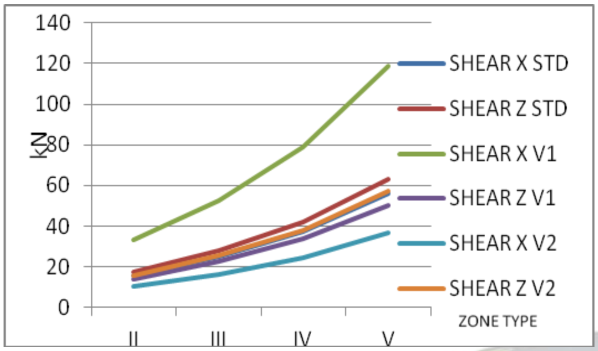

Fig. 9 Effect of vertical irregularity in building frames on base shear

The values of the bending moment for the standard model and models with vertical irregularities for column no. 76 have been tabulated below. Graph representing these values is drawn below.

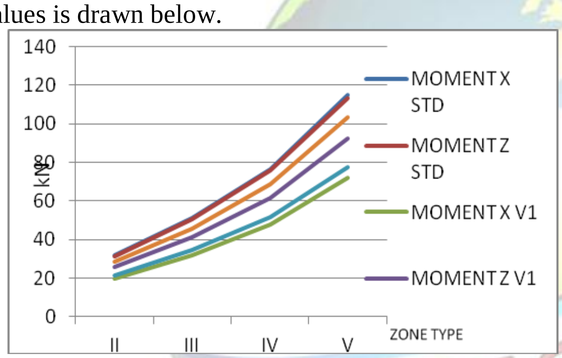

Fig. 10 Effect of vertical irregularity in building frames on bending moment

V. Conclusion

In this study, the effects of vertical irregularities have been compared with standard symmetrical model of a building frame under seismic coefficient method of earthquake loading. On the basis of the observations based on results and discussions of the above said models, following conclusions can be made:-

(i) Lateral Displacement

A. The effect of vertical irregularity in comparison to the standard model do not show any variation in displacement in X and Z direction both, for all the four zones. But there is an appreciable increase in Z direction in comparison to the X direction which is only due to stiffness of the column.

TABLE IIIII
EFFECT OF VERTICAL IRREGULARITY IN BUILDING FRAMES ON BENDING MOMENT

COLUMN 76						
Zone	Standard Model1		Vertical Irregularity V1		Vertical Irregularity V2	
	X kNm	Z kNm	X kNm	Z kNm	X kNm	Z kNm
II	31.94	31.56	20.00	25.69	21.51	28.68
III	51.10	50.50	32.00	41.11	34.41	45.89
IV	76.65	75.75	48.01	61.67	51.62	68.83
V	115.0	113.6	72.01	92.49	77.42	103.3

B. In the standard model, Model V1 and Model V2, when load is applied along Z direction, the lateral displacement exceeds the allowable limit of 31mm.

(ii)Base Shear

A. Though the displacement does not show any appreciable variation of top Node No. 128, but the storey drift in Model V1 increases by 25.2% when load is applied along X direction. Also in Model V2, an increase of 13.93% in storey drift, when load is applied in X direction, in comparison to standard model is observed.

B. In Model V1, when load is applied along Z direction, a small increase of 2% is observed in storey drift. In Model V2, when load is applied along Z direction, a very small increase in storey drift is observed.

C. In the standard model, the storey drift, when load is applied along Z direction, is 88% more than the storey drift, when load is applied along X direction. Maximum storey drift is observed at the middle storeys.

D. In Model V1, the storey drift, when load is applied along Z direction, is 53.5% more than the storey drift, when load is applied along X direction. In Model V2, the storey drift, when load is applied along Z direction, is 65.15% more than the storey drift, when load is applied along X direction.

E. All the models with vertical irregularity and the standard model have the storey drift well within the allowable limit of 14mm.

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F. Therefore, it can be stated that a building with vertical irregularity of first type is quite vulnerable to damage as compared to a building with vertical irregularity of second type.

(iii) Bending Moment

A. It has been observed that the bending moment decreases by 38% in all the 4 zones in Model V1 in X direction as compared to the standard model. The reduction is 32.65 % in Model V2 in X-direction.

B. There is a reduction of 18.6% in bending moment in Z direction for Model V1 whereas 9.13% reduction in Model V2 in Z direction.

C. With the introduction of vertical irregularities, a reduction in bending moment is seen.

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BIOGRAPHY

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