IJRESM
International Journal of Research in Engineering, Science and Management
Volume-2, Issue-1, January-2019
www.ijresm.com | ISSN (Online): 2581-5792

Study of Seismic Response of Multi-Storied Vertical Irregular Building Due to Stiffness Irregularity

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***Abstract*: There are various types of irregularities in the buildings depending upon their location and scope, but mainly they are divided into two groups plan irregularities and vertical irregularities. Nowadays, as in the urban areas the space available is limited for the construction of buildings. So, in that limited space we have to construct such type of buildings which can be used for the multiple purposes such as parking, lobbies etc. Irregular structures contribute a large portion of urban infrastructure. The attempt is made to investigate the proportional distribution of lateral forces evolved through seismic action in each story level due to changes in stiffness of frame on vertically irregular frame. In This Project Study of Seismic Response of Multi-Storied Vertical Irregular Building due to Stiffness Irregularity was carried. Objective of this project was to study Seismic Response of Multi-Storied Vertical Irregular Building due to Stiffness Irregularity. To evaluate lateral load behavior of special moment resisting frame structure with vertical stiffness irregularities by studying the following parameters Storey Deflection, Storey Drift and Storey Shear under dynamic analysis by using response spectrum method. Comparison between building without stiffness irregularity and building with stiffness irregularity was observed. For the analysis and modelling of the structure Finite element based ETABS 2016 (V 16.0.2) software was used.**

***Keywords*: Stiffness, Storey Deflection, Storey Drift, Storey Shear, ETABS 2016 (V 16.0.2).**

1. Introduction

Irregular buildings constitute a large portion of the modern urban infrastructure. The group of people involved in constructing the building facilities, including owner, architect, structural engineer, contractor and local authorities, contribute to the overall planning, selection of structural system, and to its configuration. This may lead to building structures with irregular distributions in their mass, stiffness and strength along the height of building. When such buildings are located in a high seismic zone, the structural engineer's role becomes more challenging. Therefore, the structural engineer needs to have a thorough understanding of the seismic response of irregular structures. For example structures with soft storey were the most notable structures which collapsed. So, the effect of vertically irregularities in the seismic performance of structures becomes really important. Height-wise changes in stiffness render the dynamic characteristics of these buildings different from the regular building. As per IS 1893(Part1):2002 vertical 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.

2. Methodology

A. Response spectrum analysis

Earthquake is a random and time variant process. During earthquake shaking inertia forces are induced in the structure. These earthquakes induced inertia forces as the net effect in the form of design equivalent static lateral force. This force is called as the seismic design base shear (V_B) and this is primary quantity involved in force based earthquake resistant design of building. This force depends on the seismic region where the building located represented by the seismic zone factor (Z). Also, increasing design forces to increase the elastic range of the building and therefore to reduce the damage in the building, codes tend to adopt the importance factor (I). Further, the net shaking of a building is a combined effect of the energy carried by the earthquake at different frequencies and the natural periods of the building. To form relationship between frequencies and natural period the code introduces an average response acceleration coefficient (Sa/g). Finally, to make normal buildings economical, design codes allow some damage for reducing cost of construction. This philosophy is introduced with the help of response reduction factor(R), which is larger for ductile buildings and smaller for brittle ones. Each of these factors are discussed in below as per IS 1893(Part1):2002.

B. Design of horizontal seismic coefficient (A_h)

The design horizontal seismic coefficient A_h for a structure shall be determined by the following expression:

$$A_h = \frac{Z}{2} \times \frac{I}{R} \times \frac{Sa}{g}$$

Where,

Z= Zone factor for the Maximum Considered Earthquake (MCE) and service life of structure in a zone. The factor 2 in the denominator of Z is used so as to reduce the MCE zone factor to the factor for Design Basis Earthquake (DBE).

Table 1
Zone factor (Z)

Seismic Zone	II	III	IV	V
Seismic Intensity	Low	Moderate	Severe	Very Severe
Z	0.10	0.16	0.24	0.36

I = Importance factor, depending upon the functional use of the structures, characterized by hazardous consequences of its failure, post-earthquake functional needs, historical value, or economic importance.

Table 2
Importance factor (I)

Structure	Importance Factor
Important service and community buildings, such as hospitals; schools; monumental structures; emergency buildings like telephone exchange, television stations, radio stations, railway stations, fire station buildings; large community halls like cinemas, assembly halls and subway stations, power stations etc.	1.5
All other buildings	1.0

R = Response reduction factor, depending on the perceived seismic damage performance of the structure, characterized by ductile or brittle deformations. However, the ratio (I/R) shall not be greater than 1.

Table 3
Response reduction factor(R) for building systems

Building Frame Systems	R
Ordinary RC moment-resisting frame(OMRF)	3
Special RC moment-resisting frame (SMRF)	5

S_a/g = Average response acceleration coefficient
For medium soil,
Sa/g = 1+15T when $0.00<T<0.10$
Sa/g = 2.50 when $0.10<T<0.55$
Sa/g = 1.36/T when $0.55<T<4.00$
Where, T = T_a = Fundamental natural period of vibration in seconds,

$T_a = 0.075h^{0.75}$ for R.C frame building without brick infill panels, and
$T_a = \frac{0.09h}{\sqrt{d}}$ for all building with brick infill panels.
Where, h = Height of building in m, and
d= Base dimensions of the building at the plinth level, in m.

C. Design seismic base shear (V_B)

The total design lateral force or design seismic base shear (V_B) along any principle direction shall be determined by the following expression:

$$V_B = A_h \times W$$

Where, A_h = Design horizontal acceleration spectrum value, and W = Seismic weight of the building.

D. Distribution of design force

The vertical distribution of the base shear to different floor levels along the height of the building is given by:

$$Qi = V_B \times \frac{Wihi^2}{\sum_{j=1}^{n} Wjhj^2}$$

Where, Qi= Design lateral force at floor I,
Wi= Seismic weight of floor I,
hi= Height of the i^{th} floor from the base, and
n = Number of storeys in the building.

3. Modelling

Table 4
Preliminary data for building

Length x Width	55 m x 55 m
No. of Storey's	21 (G+20) storey
Beam size	230 mm x 600 mm
Column size	300 mm x 600 mm 300 mm x 800 mm 300 mm x 1000 mm 300 mm x 1200 mm 300 mm x 1500 mm
Slab thickness	150 mm
Thickness of Wall	230 mm
Grade of Concrete and steel	M 30 & Fe 500
Length of each bay	5 m
Floor Finish	1 Kn/m^2
Live Load	2 Kn/m^2 for intermediate floor 1.5 Kn/m^2 for terrace floor
Waterproofing	3.5 Km/m^2
Seismic Zone	III
Zone Factor	0.16
Response Reduction Factor	5
Importance Factor	1
Soil Type	II

A. Modal configuration

1) Frame 1 – base model

The basic model consists of (G+20) vertically geometric irregular structure with stilt at basement. It has 11 bays of 5 m in both X and Y directions. After each four consecutive stories, the size of model is reduced by 5 m in both X and Y directions as shown in Figure. The typical storey height is 3.0 m, ground storey height is 3.5 m, and foundation height below the plinth level is 3.0 m. Preliminary data for building is mentioned in article 3.2.1.

2) Base model with stiffness irregularity at ground storey

The preliminary data for this frame is same as frame 1. The typical storey height is 3.0 m, ground storey height is 5 m and no wall load on beam at ground floor.

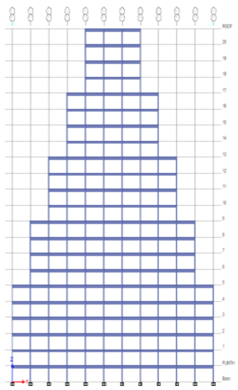

Fig. 1. Frame 1

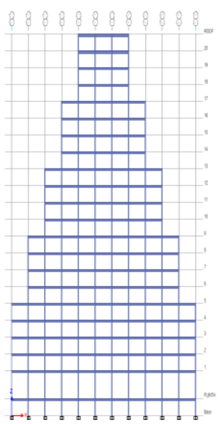

Fig. 2. Frame 2

3) Frame 3 – base model with stiffness irregularity at 10th storey

The preliminary data for this frame is same as frame1. The typical storey height is 3.0 m, tenth storey height is 5 m and wall load on periphery beam only.

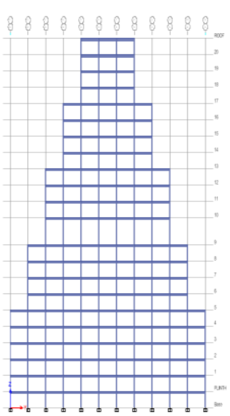

Fig. 3. Frame 3

4) Frame 4 – base model with stiffness irregularity at 20th storey

The preliminary data for this frame is same as frame1. The typical storey height is 3.0 m, 20th storey height is 5 m and wall load on periphery beam only.

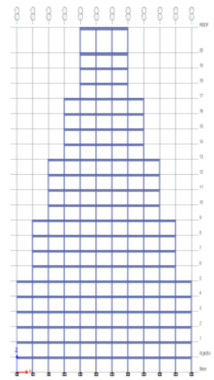

Fig. 4. Frame 4

4. Results and discussion

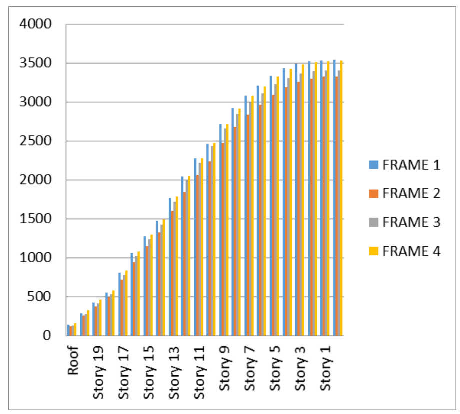

Fig. 5. Story vs Storey Shear

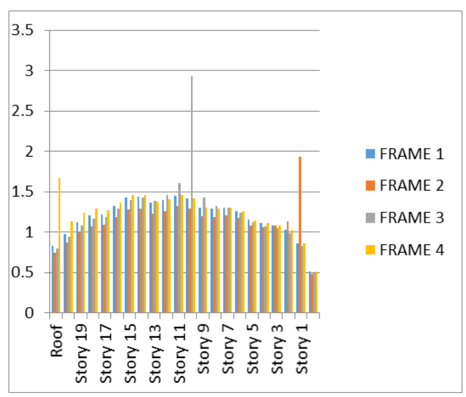

Fig. 6. Story vs Storey Drift

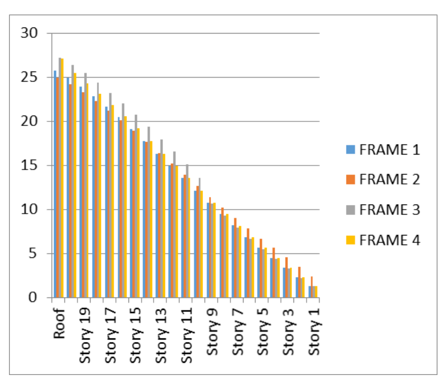

Fig. 7. Story vs Storey Displacement

Table 5
Storey shear (Kn) in X direction

Floor	Frame 1	Frame 2	Frame 3	Frame 4
Roof	139.084	123.190	132.863	162.580
Story 20	290.382	257.575	277.800	326.353
Story 19	427.615	379.841	409.667	461.636
Story 18	551.467	490.561	529.081	583.728
Story 17	810.598	723.091	779.869	839.177
Story 16	1059.021	946.948	1021.300	1084.07
Story 15	1279.073	1146.181	1236.180	1300.999
Story 14	1472.486	1322.223	1426.05	1491.660
Story 13	1771.600	1596.137	1721.47	1786.523
Story 12	2041.828	1845.332	1990.23	2052.912
Story 11	2272.082	2059.393	2221.1	2279.894
Story 10	2465.559	2240.989	2430.00	2470.621
Story 9	2712.594	2475.512	2661.9	2714.146
Story 8	2919.112	2674.303	2847.75	2917.729
Story 7	3082.286	2834.091	2994.59	3078.585
Story 6	3207.217	2959.133	3107.01	3201.741
Story 5	3337.165	3092.994	3223.95	3329.841
Story 4	3429.054	3191.474	3306.65	3420.425
Story 3	3487.864	3258.264	3359.57	3478.399
Story 2	3520.944	3299.497	3389.34	3511.009
Story 1	3535.648	3322.345	3402.57	3525.503
PLINTH	3536.919	3323.554	3403.71	3526.757

Table 6
Storey drift (mm) in X direction

Floor	Frame 1	Frame 2	Frame 3	Frame 4
Roof	0.829	0.741	0.801	1.667
Story 20	0.973	0.869	0.94	1.131
Story 19	1.12	1.001	1.083	1.243
Story 18	1.202	1.075	1.164	1.29
Story 17	1.218	1.092	1.184	1.273
Story 16	1.32	1.185	1.288	1.361
Story 15	1.425	1.282	1.399	1.457
Story 14	1.435	1.294	1.425	1.458
Story 13	1.363	1.232	1.382	1.377
Story 12	1.395	1.265	1.464	1.405
Story 11	1.449	1.318	1.61	1.456
Story 10	1.416	1.291	2.934	1.42
Story 9	1.302	1.192	1.428	1.304
Story 8	1.287	1.183	1.321	1.287
Story 7	1.304	1.204	1.297	1.303
Story 6	1.261	1.172	1.236	1.26
Story 5	1.151	1.079	1.118	1.149
Story 4	1.112	1.062	1.075	1.109
Story 3	1.083	1.077	1.045	1.081
Story 2	1.029	1.137	0.991	1.026
Story 1	0.865	1.935	0.833	0.863
PLINTH	0.51	0.476	0.491	0.508

Table 7
Storey displacement (mm) in X direction

Floor	Frame 1	Frame 2	Frame 3	Frame 4
Roof	25.746	24.903	27.178	27.122
Story20	24.92	24.165	26.379	25.456
Story19	23.947	23.296	25.44	24.325
Story18	22.831	22.298	24.361	23.088
Story17	21.637	21.229	23.203	21.806
Story16	20.424	20.142	22.024	20.54
Story15	19.105	18.957	20.736	19.179
Story14	17.697	17.691	19.354	17.739
Story13	16.283	16.417	17.95	16.303
Story12	14.933	15.196	16.578	14.939
Story11	13.54	13.932	15.119	13.535
Story10	12.112	12.634	13.52	12.101
Story 9	10.729	11.373	10.655	10.714
Story 8	9.441	10.193	9.251	9.424
Story 7	8.155	9.011	7.931	8.138
Story 6	6.869	7.824	6.65	6.854
Story 5	5.641	6.683	5.448	5.627
Story 4	4.498	5.609	4.339	4.487
Story 3	3.389	4.547	3.266	3.38
Story 2	2.309	3.475	2.224	2.303
Story 1	1.307	2.4	1.259	1.304

5. Conclusion

The behavior of G + 20 storeyed building stiffness irregularity has been studied using four frames. Frame-1 is an irregular vertical building which is considered as the base model. Frame-2 is vertical irregular building having ground storey height 5m and no wall load on beam on that floor. Frame-3 having tenth storey height of 5m and wall load on only periphery beams. Frame-4 having uppermost storey height 5m and wall load on only periphery beams. After analyzed all the frames results in the form of storey displacement, storey drift and storey shear are evaluated and compared. The following conclusions are made from the obtained results.

- Vertical stiffness irregularity at a storey in a building causes increase in storey drift at that storey, while buildings without stiffness irregularity perform well for lateral loads.
- Sudden change in storey height causes change in structure results.
- Storey displacement in particular floor where stiffness irregularity introduced at that floor sudden change in displacement value.
- The analysis proves that irregularities are harmful for the structures and it is important to have simpler and regular shapes of frames as well as uniform load distribution around the building.
- Frame 4 i.e. stiffness irregularity at uppermost floor performs better as compared to the frame 2 and frame 3.

- So, when there is stiffness irregularity in the model of a structure, it should not be provided at ground floor and for the intermediate floor. Stiffness irregularity may be provided in top floor levels.

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