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Response of Building Frames with Vertical and Stiffness Irregularity due to Lateral Loads

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Abstract

Irregular buildings constitute a large portion of the modern urban infrastructure. Structures are never perfectly regular and hence the designers routinely need to evaluate the likely degree of irregularity and the effect of this irregularity on a structure during an earthquake. When such buildings are located in a high seismic zone, it becomes more than a concern. Uncertainties involved and behaviour studies are vital for all civil engineering structures. The presence of irregular frame subject to earthquake and other ground shaking calamities is matter of concern. In this paper, response of a 15-storeyed frame to lateral loads is studied for stiffness and vertical irregularities. The proportional distribution of lateral forces evolved through seismic action and wind load also in each storey level due to changes in stiffness of frame on irregular frame is analysed. Analysis output are focused on mainly two basic points – storey drift and displacement under the action of load combination prescribed in Bangladesh National Building Code (BNBC) -1993. In BNBC, different kinds of irregularities are defined. In this paper, definitions according to BNBC are followed and analysis was carried out using CSI-ETABS 9 software. On the basis of analysis, some outlines are mentioned regarding safety and safe construction of irregular structure thus to reduce earthquake hazard.

1. Introduction

Earthquakes are the most unpredictable and devastating of all natural disasters, which are very difficult to save over engineering properties and life, against it. The behaviour of a building during an earthquake depends on several factors, stiffness, adequate lateral strength and ductility, simple and regular configurations. The buildings with regular geometry and uniformly distributed mass and stiffness in plan as well as in elevation suffer much less damage compared to irregular configurations. But nowadays need and demand of the latest generation and growing population has made the architects or engineers inevitable towards planning of irregular configurations.
Most recent earthquakes have shown that the irregular distribution of mass, stiffness and strengths may cause serious damage in structural systems. Structural design of buildings for seismic loads is primarily concerned with structural safety during major ground motions. 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.

Regular structure:
Regular structures have no significant physical discontinuities in plan or vertical configuration or in their lateral force resisting systems.

Irregular structure:
Irregular structures have significant physical discontinuities in configuration or in their lateral force resisting systems. Irregular structures have either vertical irregularity or plan irregularity or both in their structural configurations.

Table 1. Different types of plan and vertical irregularity

Plan Irregularity	Vertical Irregularity
1. Torsion irregularity 2. Re-entrant corners 3. Diaphragm discontinuity 4. Out of plane offsets 5. Non parallel systems	1. Stiffness Irregularity (soft storey) 2. Mass Irregularity 3. Vertical Geometric Irregularity 4. In-plane discontinuity in vertical elements resisting lateral force 5. Discontinuity in capacity-weak storey

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2. Definitions

There are several vertical irregularities defined in BNBC 1993.

Stiffness irregularity (soft storey):
A soft storey is one in which the lateral stiffness is less than 70 percent of that in the storey above, or less than 80 percent of the average stiffness of the three storeys above.

Mass irregularity:
Mass irregularity shall be considered to exist where the effective mass of any storey is more than 150 percent of the effective mass of an adjacent storey. A roof which is lighter than the floor below need not to be considered.

Vertical geometric irregularity:
Vertical geometric irregularity shall be considered to exist where horizontal dimension of the lateral force resisting system in any storey is more than 130 percent of that in an adjacent storey, one storey penthouses need not to be considered.

In-plane discontinuity in vertical lateral force resisting element:
An in-plane offset of the lateral load resisting elements greater than the length of those elements.

Discontinuity in capacity (weak storey):
A weak storey is one in which the storey strength is less than 80 percent of that in the storey above. The storey strength of all seismic resisting elements sharing the storey shear for the direction under consideration.

3. Problem Formulation

A 15 storey building was considered in our analysis. Three combinations of loads were considered here.

Combination 1: 0.75(1.4DL+1.7LL+1.7WL)

Combination 2: 1.4 (DL+LL+QL)

Analysis was carried out using CSI-ETABS 9 program.

Details of model (parameters are according to BNBC):

1. Type of structure: Intermediate moment resisting frame (IMRF)
2. Number of storeys: 15
3. Floor Height: 10 ft
4. Column size: 18 inch x 30 inch
5. Beam size: 15 inch x 20 inch
6. Slab thickness: 6 inch
7. Dimension of model: 40 ft x 30 ft
8. Materials used:
    a. f'c for column = 3500psi
    b. f'c for beam and slab = 3000 psi
9. Seismic zone: 2
10. Zone coefficient: 0.15
11. Exposure category: Exposure A
12. Structure importance coefficient: 1
13. Soil profile: S3 (a soil profile 21 meters or more in depth and containing more than 6 meters of soft to medium stiff clay but not more than 12 meters of soft clay)
14. Site coefficient: 1.5
15. Basic wind speed: 210 kph

Frame 1: This was the basic and the regular structure of the building with no irregularities and 15 storeys. Each storey height was 10 ft and the bay width was 10 ft.

Frame 2: This frame consisted of floating column. The three middle columns were left hanging on the third storey and hence not reaching the ground. Rest of the geometry was same as that of frame 1.

Frame 3: This frame had the 1st, 2nd and 3rd storeys soft. No floor slab were been provided which made these three storeys less stiff, i.e., softer. Rest of the geometry was same as that of frame 1.

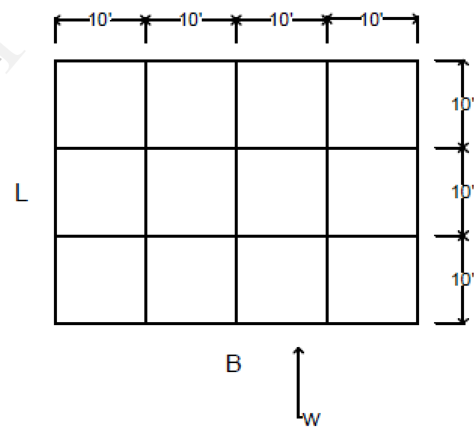

Figure 1. Plan

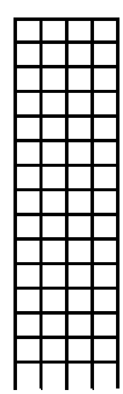

Figure 2. Frame 1

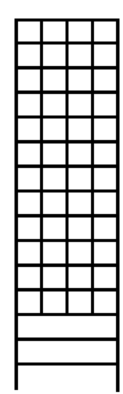

Figure 3. Frame 2

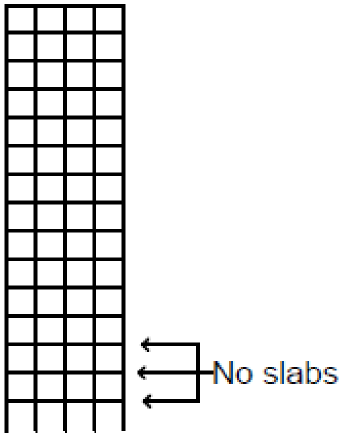

Figure 4. Frame 3

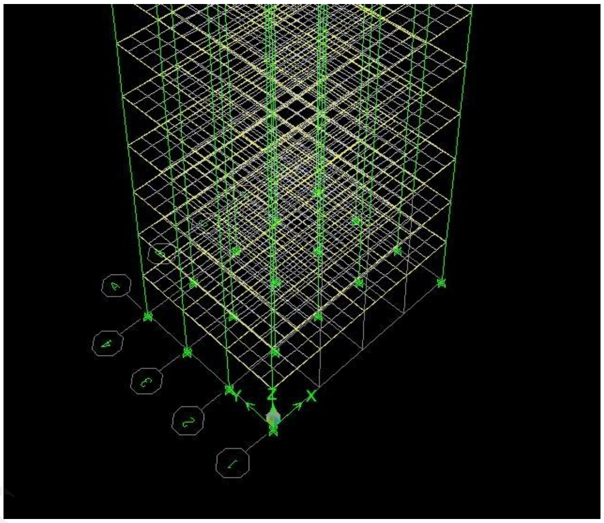

Figure 6. 3D view of Frame 2

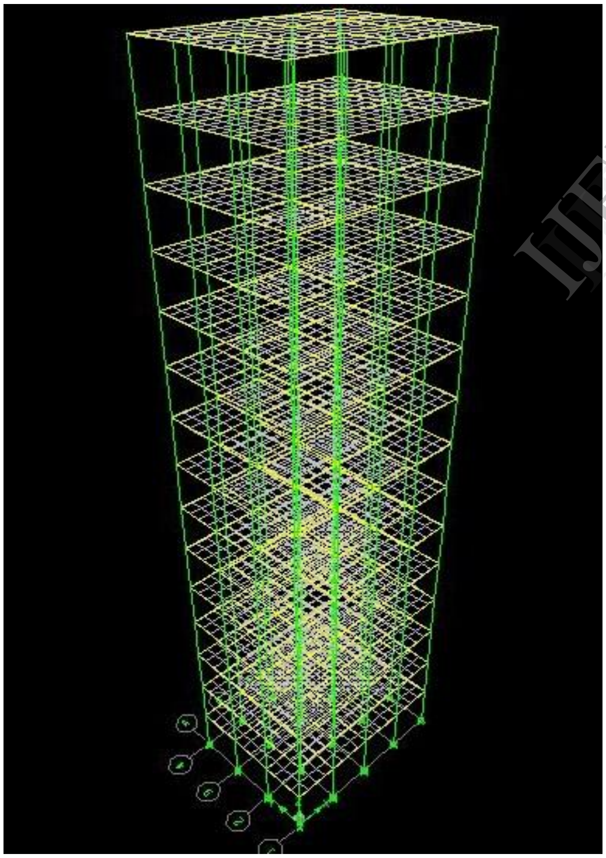

Figure 5. 3D view of Frame 1

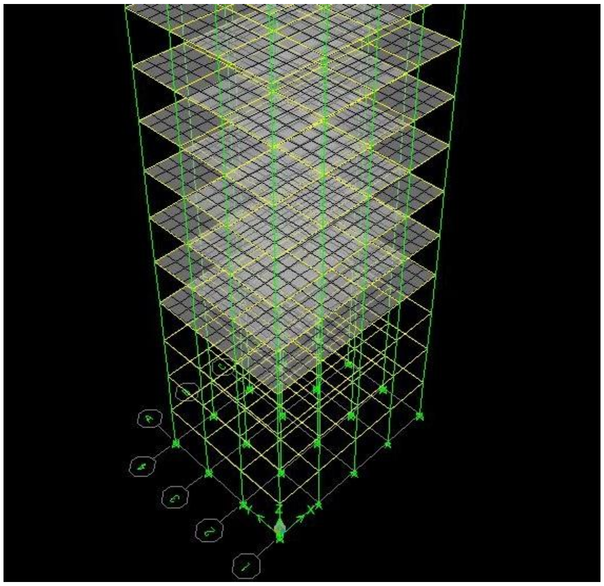

Figure 7. 3D view of Frame 3

The storey displacements for combination 1 as given by ETABS, are tabulated in Table 3.1-

Table 3.1. Displacements in y direction UY (ft)

Storey	Frame 1	Frame 2	Frame 3
Roof	0.2199	0.2070	0.2213
Storey 14	0.2140	0.2025	0.2154
Storey 13	0.2065	0.1964	0.2079
Storey 12	0.1973	0.1886	0.1987
Storey 11	0.1864	0.1791	0.1878
Storey 10	0.1739	0.1681	0.1753
Storey 9	0.1598	0.1555	0.1613
Storey 8	0.1444	0.1415	0.1458
Storey 7	0.1277	0.1262	0.1291
Storey 6	0.1099	0.1099	0.1113
Storey 5	0.0911	0.0926	0.0925
Storey 4	0.0716	0.0746	0.0730
Storey 3	0.0516	0.0561	0.0531
Storey 2	0.0314	0.0350	0.0321
Storey 1	0.0122	0.0138	0.0111

The storey displacements for combination 2 as given by ETABS, are tabulated in Table 3.2-

Table 3.2. Displacements in y direction UY (ft)

Storey	Frame 1	Frame 2	Frame 3
Roof	0.0729	0.0085	0.0732
Storey 14	0.0700	0.0105	0.0704
Storey 13	0.0665	0.0119	0.0669
Storey 12	0.0626	0.0128	0.0630
Storey 11	0.0582	0.0133	0.0586
Storey 10	0.0534	0.0135	0.0538
Storey 9	0.0483	0.0133	0.0487
Storey 8	0.0430	0.0129	0.0433
Storey 7	0.0374	0.0123	0.0377
Storey 6	0.0316	0.0116	0.0320
Storey 5	0.0258	0.0108	0.0262
Storey 4	0.0200	0.0101	0.0203
Storey 3	0.0142	0.0094	0.0178
Storey 2	0.0085	0.0067	0..0098
Storey 1	0.0033	0.0029	0.0049

The storey drifts for combination 1 as given by ETABS, are tabulated in Table 3.3-

Table 3.3. Storey drifts in y direction UY (ft)

Storey	Frame 1	Frame 2	Frame 3
Roof	0.000594	0.000452	0.000594
Storey 14	0.000748	0.000607	0.000749
Storey 13	0.000922	0.000780	0.000922
Storey 12	0.001089	0.000947	0.001089
Storey 11	0.001250	0.001107	0.001250
Storey 10	0.001403	0.001259	0.001403
Storey 9	0.001544	0.001400	0.001544
Storey 8	0.001671	0.001525	0.001671
Storey 7	0.001782	0.001635	0.001783
Storey 6	0.001876	0.001727	0.001876
Storey 5	0.001950	0.001801	0.001950
Storey 4	0.002001	0.001851	0.002012
Storey 3	0.002016	0.002108	0.002154
Storey 2	0.001923	0.002119	0.002246
Storey 1	0.001222	0.001381	0.002285

The storey drifts for combination 2 as given by ETABS, are tabulated in Table 3.4-

Table 3.4. Storey drifts in y direction UY (ft)

Storey	Frame 1	Frame 2	Frame 3
Roof	0.000289	0.000199	0.000289
Storey 14	0.000345	0.000143	0.000345
Storey 13	0.000394	0.000094	0.000394
Storey 12	0.000438	0.000051	0.000438
Storey 11	0.000477	0.000014	0.000477
Storey 10	0.000510	0.000018	0.000510
Storey 9	0.000538	0.000042	0.000538
Storey 8	0.000559	0.000060	0.000559
Storey 7	0.000574	0.000071	0.000574
Storey 6	0.000583	0.000075	0.000583
Storey 5	0.000585	0.000073	0.000585
Storey 4	0.000580	0.000066	0.000585
Storey 3	0.000565	0.000275	0..000545
Storey 2	0.000524	0.000375	0.000521
Storey 1	0.000329	0.000292	0.000318

4. Result Analysis

According to the data acquired (shown in the tables), storey displacement of the frame with soft storey (Frame 3) experienced maximum displacement both for wind load and earthquake load. It suffered the considerable displacement in all the floors. Storey drift was also weakest in Frame 3 since having the suddenly extreme change in storey drift. From this it is clear that the frame having stiffness irregularity on vertically irregular frame is susceptible to damage in earthquake prone zone.

In this paper, two frames having different irregularities but with same dimensions have been analysed to study their behaviour when subjected to lateral loads. All the frames have been analysed with the same method as stated in BNBC 1993. It is clearly evident that the frame with less stiffness represents the worse scenario since it faced the maximum displacement and is most prone to damages under lateral loadings. While on the other hand, it can be seen that the base frame had the least displacement and drift, hence least susceptible to the damage.

4. Discussion and conclusion

Frame 3 is the most vulnerable to damages under these kinds of loadings. The other buildings with irregularities also showed unsatisfactory results to some extent. 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. Therefore, regular and symmetrical structures exhibit more favorable and predictable seismic response characteristics than irregular structures.

The use of irregular structures in earthquake-prone areas should be avoided if possible. But, if irregularities have to be introduced for any reason, they must be designed according to the building code.

Now-a-days, complex shaped buildings are getting popular, but they carry a risk of sustaining damages during earthquakes. Therefore, such buildings should be designed properly taking care of their dynamic behaviour.

5. References

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