

Seismic and Wind Performance of Multi-storeyed Building with Plan and Vertical Irregularities

Bilal Ahmad Lone, Jagdish Chand, Mohit Bhandari



Abstract: It is a big challenge that the tall buildings must withstand the various forces acting from different directions and aspects such as seismic and wind forces while designing the tall structures it is mandatory to deeply understand the seismic and wind behaviour of multi-storeyed buildings. In this study we are concerned to determine and analyse the seismic and wind behaviour of high-rise buildings some of which were regular and other had irregularities in them in their plan and elevations. Three G+30 storied buildings were considered which were situated in seismic Zone-V and analysis were carried out using response spectrum method as per IS 1893- 2016 on ETABS software. Each building is subjected to wind load at different terrain categories to examine its effects at different slopes as per IS 875 Part 3 2015. Various parameters like Auto lateral load, maximum storey displacement, maximum storey drift, overturning moment, storey shear and time period were considered in this study. It is concluded that vertical irregular building in terrain category-4 with ground slope less than 3 degree's provides greater resistance against both seismic and wind loading among all buildings.

Keywords: G+30 storied buildings.

I. INTRODUCTION

Earthquake and wind are among the most destructive natural hazards that cause considerable loss of life and livelihood. An earthquake is a tremor of ground shaking generated by rapid release of energy in the lithosphere of earth this energy derives mainly from stress caused by tectonic action and the earth's interior from which there is interaction between the crust and the interior contact of earth. In India high frequency earthquakes have occurred in past with very high magnitude greater than 8. One of the devastating earthquake Indian occasion occurred in Dec 24, 2004 with magnitude 9.1-9.3 having epicentre west coast of Sumatra. Another one Bihar and Nepal occurred in Jan 15, 1993 with magnitude 8.7 having epicentre south of mountain Everest. Kashmir earthquake occurred in October 8, 2005 with magnitude 7.6 having epicentre Muzaffarabad, Pakistan administered Kashmir. Assam earth quake occur in August 15, 1950 with magnitude 8.6 having epicentre Rima, Tibet. Another one of the deadliest earthquakes that India has faced is kanga earthquake occurs in April 4, 1905 with magnitude 7.8. Ground motions which generate the earthquake are the most severe motions by which loss of life and livelihood occurs.

Earthquake damages are not only caused due vibrations or shaking of ground but also with chain effects such as landslide, floods, fires. Therefore, it is mandatory to design the structure with greater stability to withstand extreme and moderate ground motions which is based on location of site and structure importance.

Wind load and seismic load plays an important role while designing tall structures, because remaining all other loads have variations in a very small margin, present study deals with the seismic and wind load effect of regular and irregular multi-storey building. If a building is designed with high resistance towards wind the structure will become more expensive. To keep proper balance between the economy and safety it is compulsory to deeply understand the relation between the behaviour of buildings subjected to wind force acting on the buildings. In general wind plays greater role while designing tall buildings. Forces and moments are generated due to wind and these forces and moments are applied on structure and its cladding and wind pressure is developed around the building

Wind has two important components, static and dynamic. The dynamic character of wind contains mean wind velocity and varying gust velocity. It is important to consider while designing high rise buildings the resistance against wind are not too much, high rise buildings are weak in resistance against wind. Tall structures are the major projects during designing they need valid logistics and well management. Proper arrangement of structure components and the shape of structure minimise the lateral displacement and decreases the overall cost of structures. From the past lot of research work has been done on seismic and wind analysis of high rise regular and irregular structures, containing plan and vertical irregularity same of them are mentioned below.

Ritu Raj, et al. (2019) studied behaviour of plus shaped and square shaped structure on varying wind loads. They studied the effect of lateral loads acting on the plus shaped and square shaped buildings. Wind analysis data for plus shaped building are not available in IS codes. Therefore, two types of analysis were taken into consideration. Experimental in which different stiff models were selected for both type of structures was examined in wind tunnel to determine mean and fluctuating forces on defined surfaces. Second one response study, in which response capacity of both the structures were determined first experimentally and then using staad pro software for analytical work. It has been concluded that for square and plus shaped building when wind acts perpendicular to the windward face, pressure will be generated on structure due to which there will be suction occurrence on all other faces. Also due to increase of wind speed, wind effect increases along height of structure Sumukam Sai et al. (2018) conducted study on high rise buildings subjected to wind loads using SAP 2000. They studied the behaviour of two RCC structures G+5 and G+11

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were analysed on inclined slope i.e., 0° , 15° , 20° to determine storey displacement at different slopes of ground. It has been concluded that G+11 storey building shows greater displacement than G+5 building without providing ground slope. After providing slope of structure storey displacement increases in both structures, also inter storey drift increases after increasing the slope angle.

Oren Lavan, et al. (2016) performed seismic design of reinforced concrete frame structures having irregularity in geometry and also contain vertical setbacks. They studied that to design the irregular buildings with ground motions along different directions. The design process is conducted when seismic members of structures with less moment capacity satisfy the ductility facts and inter-storey drift. It has been concluded that the volume of steel varies in the force based design for primary structure with response modification factor three and four and four and five for secondary structure. The same values have been determined for overturning moment and base shear. In force based design the drift values increases greater than 70 per cent.

Types of wind load forces on buildings.

Shear load, shear load is also named as wind pressure acting along horizontal direction due to which there will be possibility of tilting a building.
Lateral load, lateral load is a pulling and pushing horizontal pressure due which building will shift from its position.
Uplift load, it is a pressure generated from wind flow and acting along upward direction to uplift the building or causes uplifting effects.

Structural Configuration.

The standard method for design of tall buildings in past was in the form of rectangular shape, mostly but now a days much more complex geometries are in practice. Tall structures consider four main important factors such as stiffness, ductility, regular and simple structure, and ample lateral strength. Regular geometry structures in plan and in elevation possess less damage than the irregular configuration.

According to IS1893-2016, structural configuration is defined in terms shape, size and centre of rigidity of mass in structure. A building should be irregular when it is not symmetrical and have discontinuity in geometry, mass, or load, these irregularities creates problems in action of forces and stress distribution. Structure analysis plays a vital role to determine the behaviour of the structures which are subjected to some action. Wind, waves, traffic, earthquake and blasts are dynamic loads, if dynamic loads are applied on a structure, performance of the structure get decreased under severe seismic loading due to structure symmetry, due to asymmetry of structure member forces increased and ultimately structure collapsed.

Types of Irregularities

1. Plan Irregularity; (its types and description)

a) Torsional Irregularity –

To be studied when floor diaphragms are rigid in their own plans which are connected with the vertical structure elements that resist the lateral load action. Torsional irregularity occurs at that point when max storey drift as compared with design eccentricity along one end of structure is more than 1.2 times the average storey drift with two ends of structure.

b) Re-entrant Corners –

A structure is said to have a re-entrant corner in any plan direction when its structural configuration in plan has a projection of size greater than 15% of its overall plan dimension in that direction.

2. Vertical Irregularity; (its types and description)

a) Stiffness Irregularity –Extreme soft storey

Extreme soft storey is defined when lateral stiffness is less than 60% of the above storey or less than the 70% of the average stiffness of the three storeys above

b) Stiffness irregularity - (soft storey)

Soft storey is defined when lateral stiffness is less than 80% of the above three storeys.

Mass irregularity –

When seismic weight of any storey is more than the 200% of its adjacent storey.

Vertical geometric –

This irregularity exists when the horizontal dimension of the lateral force resisting system in any storey is more than 120% to the adjacent storey.

In plane discontinuity in vertical elements resisting lateral force –

In plane discontinuity in vertical elements which are resisting lateral force exists in a structure when in plane offset of the lateral force resisting elements is greater than 20% of its plan length of their structural elements.

Strength irregularity -(weak storey)

Weak story is defined when lateral strength is less than 80 % of the storey above

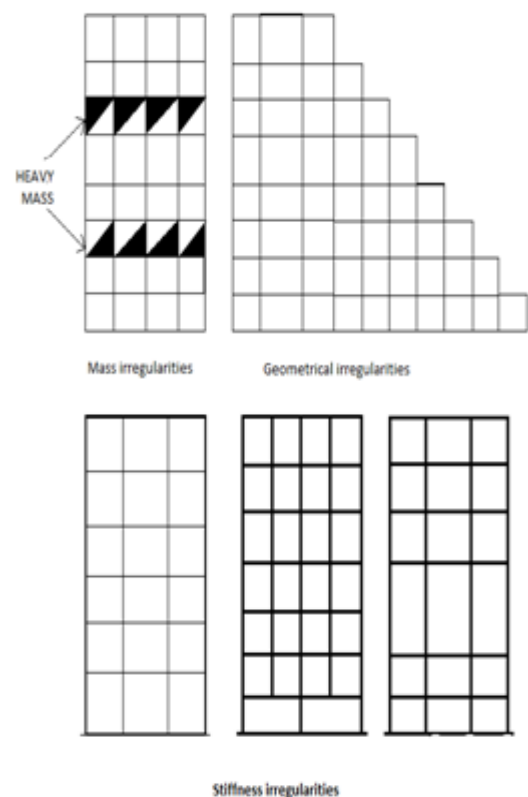


Fig-1 Types of Vertical Irregularities (according to IS 1893-2016)

Terrain Categories

Category 1 - it's exposed to open ground with little or no obstructions where the average height of anybody around the structure is less than 1.5m.

Category 2 - it falls into open terrain with small obstructions usually between 1.5m to 10m high.

Category 3 - Ground in which obstructions are closely spaced and these obstructions have height up to 10m with or without a few isolated elevated structures.

Category 4 - terrain with many wide, spaced, highly closed obstructions.

Objective of the Study

1. To compare seismic capacity moment resisting frame structure with regular plan (rectangular), and irregular plan for the earthquake zone-V.
2. To compare the wind resistance of a regular building, plan irregular building and vertical irregular building.
3. The building models with regular and irregular structures will be compared by changing type of terrain category, and topography factor to provide better information about the response of the system.
4. To find out which building type will be more effective against lateral loads on each terrain category.
5. To develop a most suitable model out of wind and seismic analysis, each for regular and irregular type of structures will perform well in Zone V.

II. MODELLING AND ANALYSIS.

In fact, several problems still exist despite the developments in earthquake engineering over the last three decades. A building design plan plays an important role to resist the lateral forces and distribution of earthquake forces. Past research shows that unsymmetrical plan buildings are more vulnerable to earthquake than those with symmetrical plans. Therefore, it is necessary to consider symmetry about both axes not only for buildings but also for the elements of structures. In this research three $G + 30$ storeyed buildings of same plan dimensions $52m \times 44m$ were considered regular building, plan irregular building and vertical irregular buildings. These buildings are modelled and analysed in different terrains using ETABS software. All the MRF elements are designed as per IS 456-2000. Wind and earthquake loads are defined as per IS 875 part-3, and IS 1893-2016 respectively. Table (1) shows building description and Table (2) shows terrain details for modelling and analysis of buildings

Building Description

Table-1 Geometrical Specifications and Material Properties of Buildings.

| Type of structure | Moment Resisting Frame Structure |
|-----------------------|----------------------------------|
| Plan size | $52m \times 44m$ |
| No. of storey | $(G + 30)$ |
| Floor to floor height | $3.5m$ |
| Grade of concrete | M35 for columns, M30 for beams |
| Grade of steel | Fe500 |

| | |
|---------------------------|--------------------------------------|
| Beam size | $650\text{ mm} \times 400\text{ mm}$ |
| Column size | $900\text{ mm} \times 700\text{ mm}$ |
| Slab thickness | 150 mm |
| Spacing in x-dir. | $4m$ |
| Spacing in y-dir. | $4m$ |
| Dead load | $2kN/m^2$ |
| Live load | $3kN/m^2$ |
| Wall load | $15kN/m^2$ |
| Seismic zone | V |
| Importance factor | 1.2 |
| Response reduction factor | 5 |
| Type of soil | Medium |

Topography Factor k_3 - (according to IS 875 part-3)

The effect of topography factor is varying from 1 to 1.36 basically it depends upon slope of ground. If slope is less than 3° the value of topography factor k_3 are directly taken as 1, according to IS 875 part-3. If slope is greater than 17° the value of topography factor is directly taken as 1.36 as per IS 875 part-3. The values in between 1 and 1.36 are calculated from appendix C in IS 875 part 3.

Table-2 Shows Terrain Specification

| Terrain Category | Slope | Topography factor |
|------------------|---------------------------------------|-------------------|
| 1 | 10° | 1.15 |
| 2 | 15° 20° 3° | 1.24 |
| 3 | | 1.36 |
| 4 | | 1 |

III. BUILDING PLANS AND MODELS

In the present study three building models are considered for analysis (i) Building having symmetrical plan (SB), (ii) Irregular Plan building (IPB), and (iii) Vertical irregular building (VIB)

Fig.2 Shows plan and 3D view of regular building (SB) which is symmetrical about axis, Fig.3 shows plan and 3D view of L shaped building (IPB) which is asymmetrical about its own axis and Fig.4 Shows plan and 3D view of vertical irregular building (VIB) with set-backs at different levels. Each building is provided with 4m column spacing and have same plan dimension $36m \times 44m$. All of these are G+30 storey buildings with a floor height of 3.5m each.

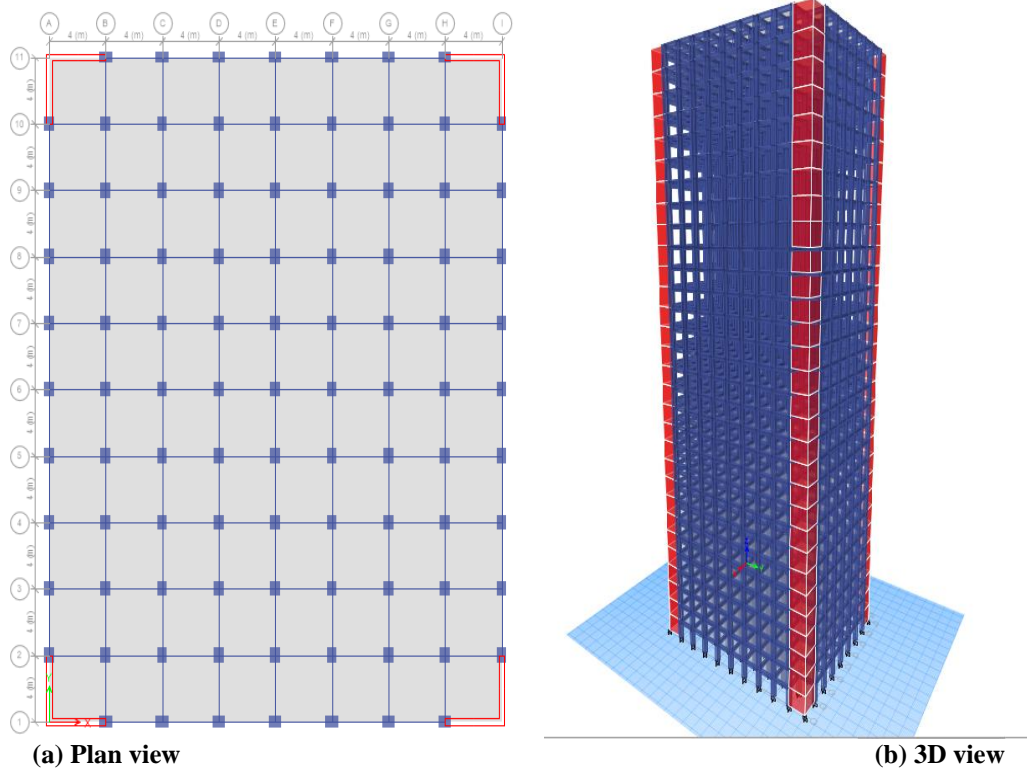


Fig-2 Plan and 3D view of regular building (SB).

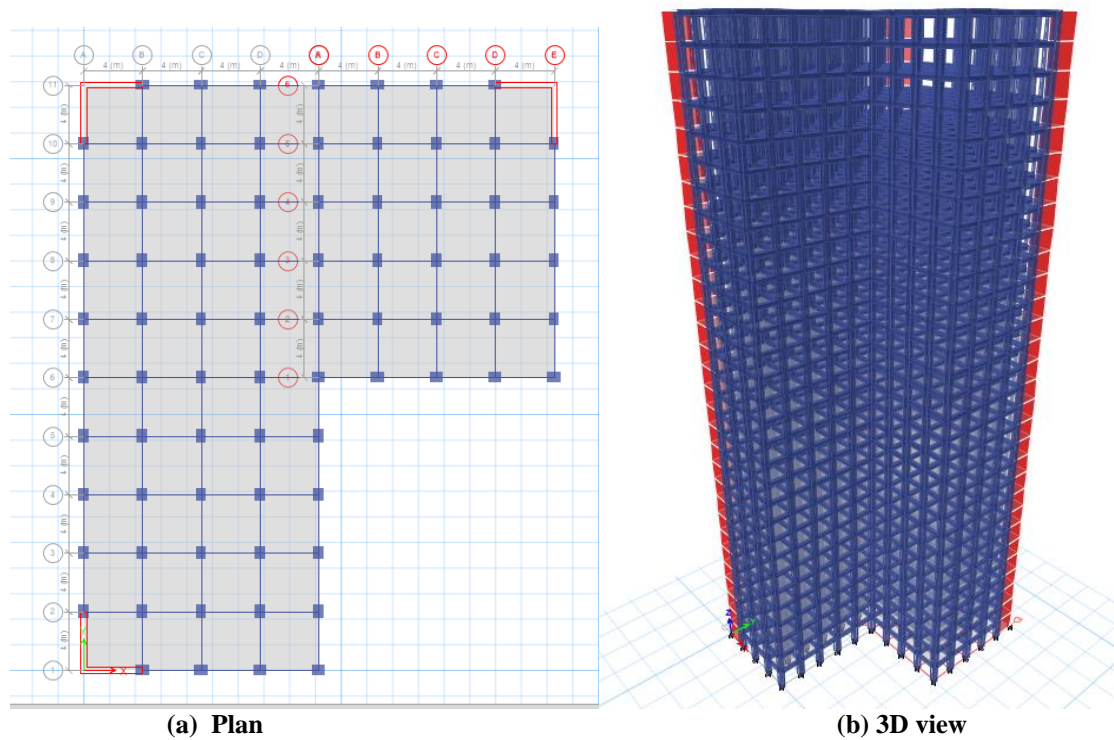
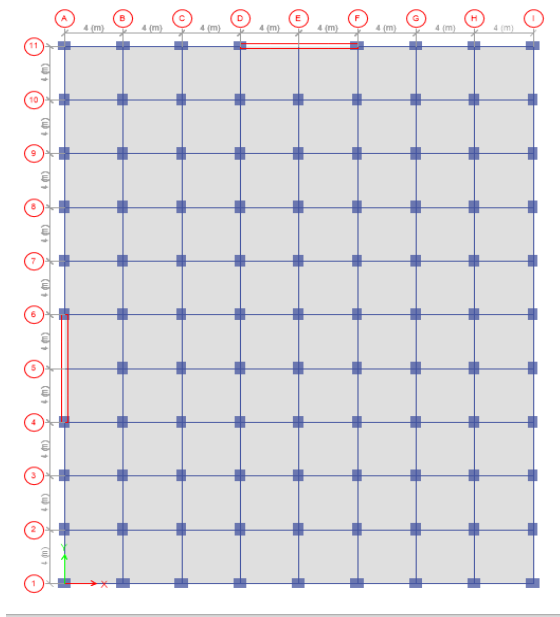
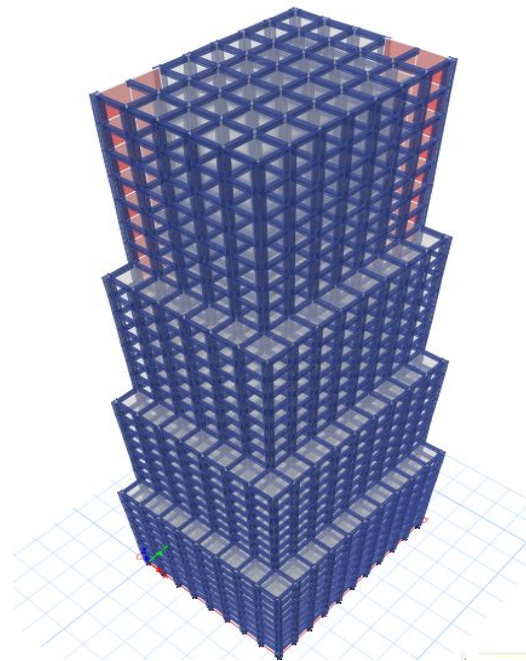


Fig-3 Plan and 3D view of irregular plan building (IPB).



(a) Plan



(b) 3D view

Fig-4 Plan and 3D view of vertical irregular building (VIB).

IV. RESULTS AND DISCUSSIONS

The explanation of results carried out by seismic and wind analysis of regular and irregular buildings are presented in this section. The results of different parameters like displacement, drift, overturning moment, base shear and time period for different terrains of varying slope were presented below.

It is observed that in seismic analysis the buildings in all terrains show same variation of results. Fig-5 shows that the displacement of SB and VIB decreases by 30% and 20% than IPB and the drift of SB and VIB decreases by 27% and 15% than IPB respectively. Overturning moment of IPB and VIB is decreased by 21% and 19% than SB and base shear of IPB and VIB is decreased by 25% and 15% than SB respectively in all terrains.

In terrain category-1 due to wind loading action the Fig-6 shows that displacement is maximum in IPB and minimum in VIB. Displacement of SB and VIB is decreased by 14% and 45% than IPB and storey drift is maximum in IPB and minimum in VIB. Drift of SB and VIB decreases by 14% and 48% than IPB. Overturning moment is maximum in SB and minimum in VIB. Overturning moment in IPB and VIB is decreased by 5% and 26% than SB and also base shear is maximum in SB and minimum in VIB. Base shear in IPB and VIB is decreased by 5% and 19% than SB respectively.

In terrain category-2, due to wind loading action, the Fig-7 show that displacement is maximum in IPB and minimum in

SB. Displacement in SB and VIB is decreased by 45% and 43% than IPB and storey drift is maximum in IPB and minimum in VIB. Drift in SB and VIB is decreased by 43% and 53% than IPB. Overturning moment is maximum in IPB and minimum in VIB. Overturning moment in SB and VIB is decreased by 4% and 22% than IPB and also base shear maximum in IPB and minimum in VIB. Base shear in SB and VIB is decreased by 5% and 16% than IPB respectively. In terrain category-3 due to wind loading action the Fig-8 shows that displacement of SB and VIB decreases by 52% and 43% than PIB and storey drift of SB and VIB decreases by 40% and 48% respectively than IPB. Overturning moment of SB and VIB is decreases by 1% and 22% respectively than IPB and also base shear of SB and VIB decreases by 1% and 16% respectively than IPB.

In terrain category-4 due to wind loading action the Fig-8 shows that displacement is maximum in IPB and minimum in SB. Displacement of SB and VIB is decreased by 60% and 43% respectively than IPB and storey drift is maximum in IPB and minimum in VIB. Storey drift of SB and VIB is decreased by 44% and 55% than IPB. Overturning moment is maximum in IPB and minimum in VIB. Overturning moment of SB and VIB is decreased by 5% and 22% respectively than IPB and also base shear is maximum in SB and minimum in VIB. Base shear of IPB and VIB is decreased by 2% and 16% respectively than SB.

Table-3 Results of seismic analysis of 3D models

| Models | Max. displacement in <i>mm</i> | Maximum Drift | Max. Overturning moment <i>kN – m</i> | Base Shear in <i>kN</i> |
|--------|--------------------------------|---------------|---------------------------------------|-------------------------|
| SB | 68.162 | 0.000894 | 451421.8023 | 8136.169 |
| IPB | 96.4 | 0.00124 | 355014.0375 | 6108.059 |

| | | | | |
|-----|--------|----------|-------------|-----------|
| VIB | 77.795 | 0.001049 | 363412.5902 | 6884.5419 |
|-----|--------|----------|-------------|-----------|

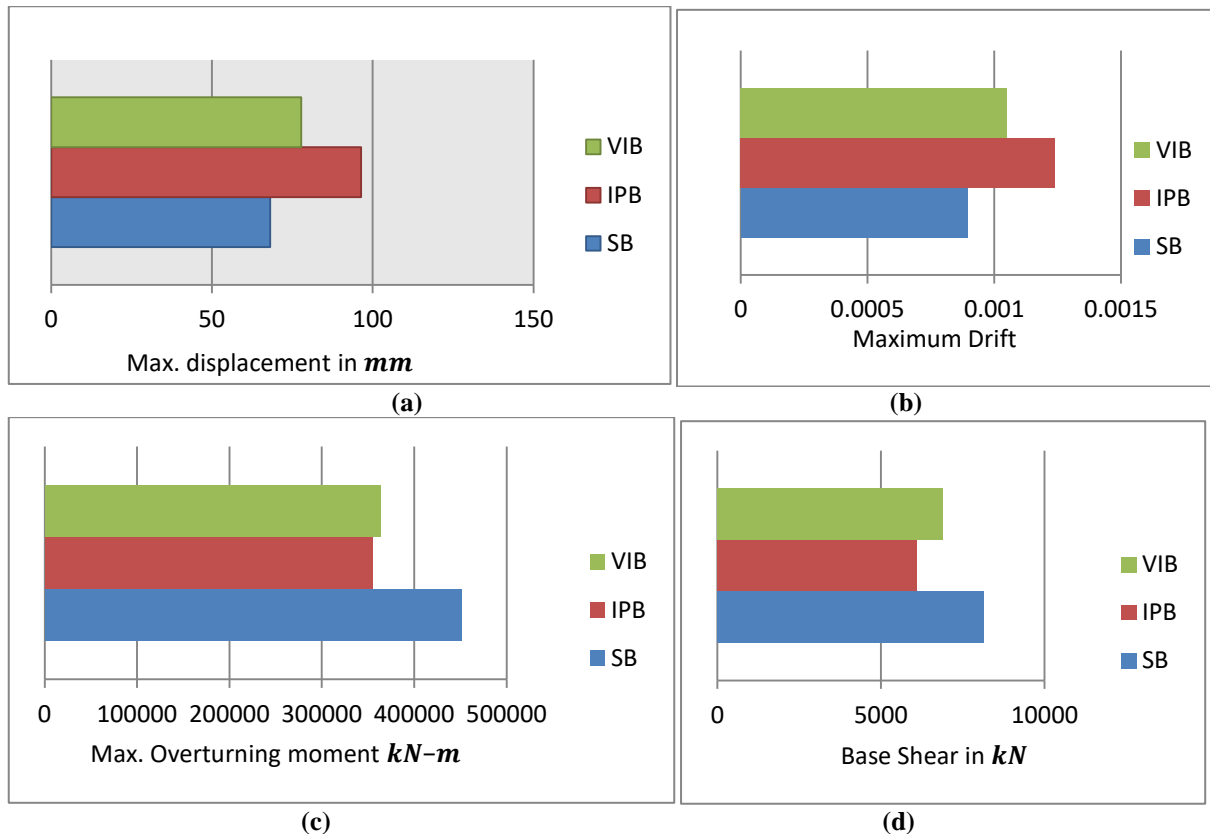
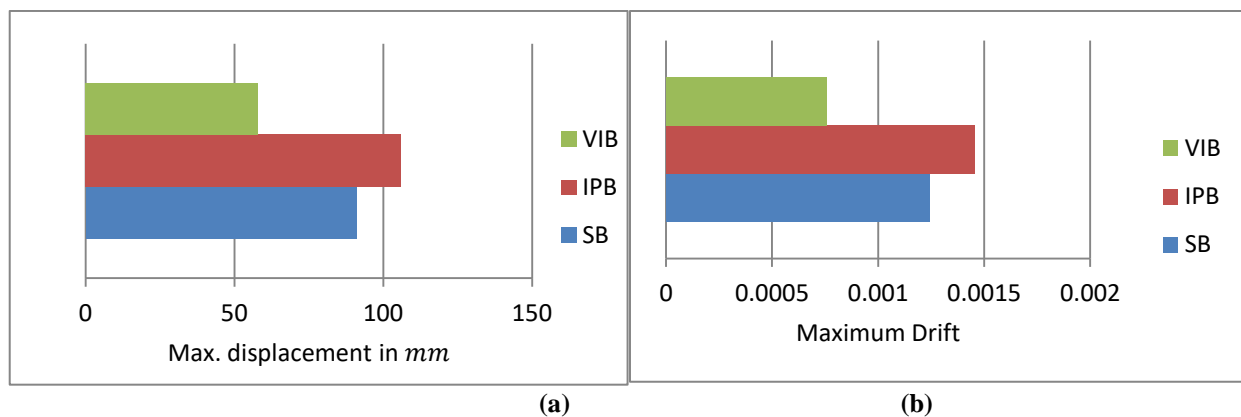


Fig-5 shows variation of (a) Max. Displacement (b) Max. Drift (c) Max. Overturning moment (d) Max. Base shear due to seismic analysis.

Table-4 Results of wind analysis in terrain category 1.

| Models | Max. displacement in <i>mm</i> | Max. Drift | Max. Overturning moment <i>kN – m</i> | Base Shear in <i>kN</i> |
|--------|--------------------------------|------------|---------------------------------------|-------------------------|
| SB | 90.996 | 0.00124 | -602179.917 | -11261.6423 |
| IPB | 156.644 | 0.001456 | -570886.1199 | -10773.8735 |
| VIB | 88.193 | 0.000758 | -444833.5067 | -9066.8582 |



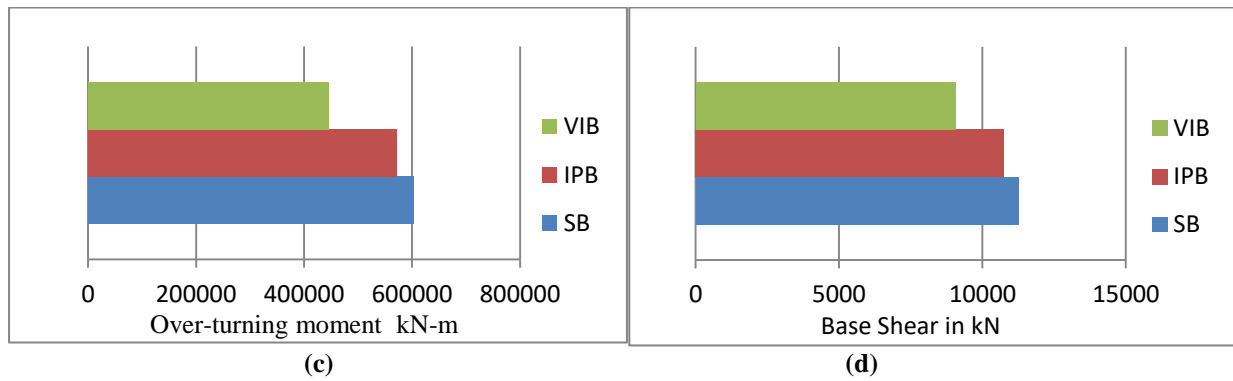


Fig-6 shows variation of (a) Max. Displacement (b) Max. Drift (c) Max. Overturning moment (d) Max. Base shear due to wind analysis in terrain category-1

Table-5 Results of wind analysis in terrain category 2.

| Models | Max. displacement in mm | Maximum Drift | Max. Overturning moment $kN - m$ | Base Shear in kN |
|--------|---------------------------|---------------|----------------------------------|--------------------|
| SB | 95.646 | 0.001304 | 632951.7044 | 11337.12 |
| IPB | 174.697 | 0.002328 | 636016.9352 | 11894.2672 |
| VIB | 98.275 | 0.001088 | 495012.6145 | 9987.2132 |

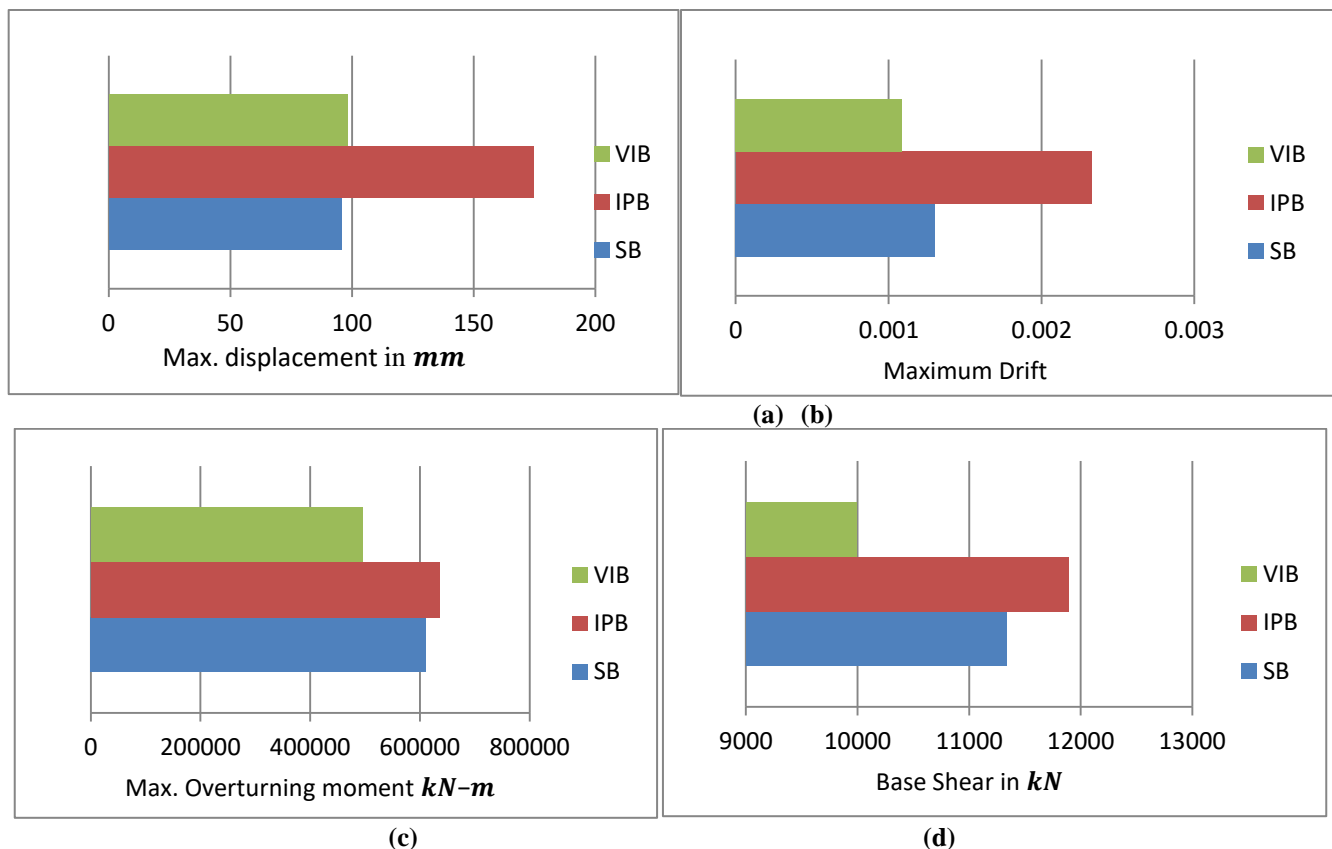


Fig-7 shows variation of (a) Max. Displacement (b) Max. Drift (c) Max. Overturning moment (d) Max. Base shear due to wind analysis in terrain category-2

Table-6 Results of wind analysis in terrain category 3.

| Models | Max. displacement in mm | Maximum Drift | Max. Overturning moment $kN - m$ | Base Shear in kN |
|--------|---------------------------|---------------|----------------------------------|--------------------|
| SB | 96.345 | 0.001088 | 703154.504 | 12953.7158 |
| IPB | 194.374 | 0.001799 | 706558.1662 | 13017.0717 |
| VIB | 109.207 | 0.000936 | 548992.9536 | 10889.9173 |

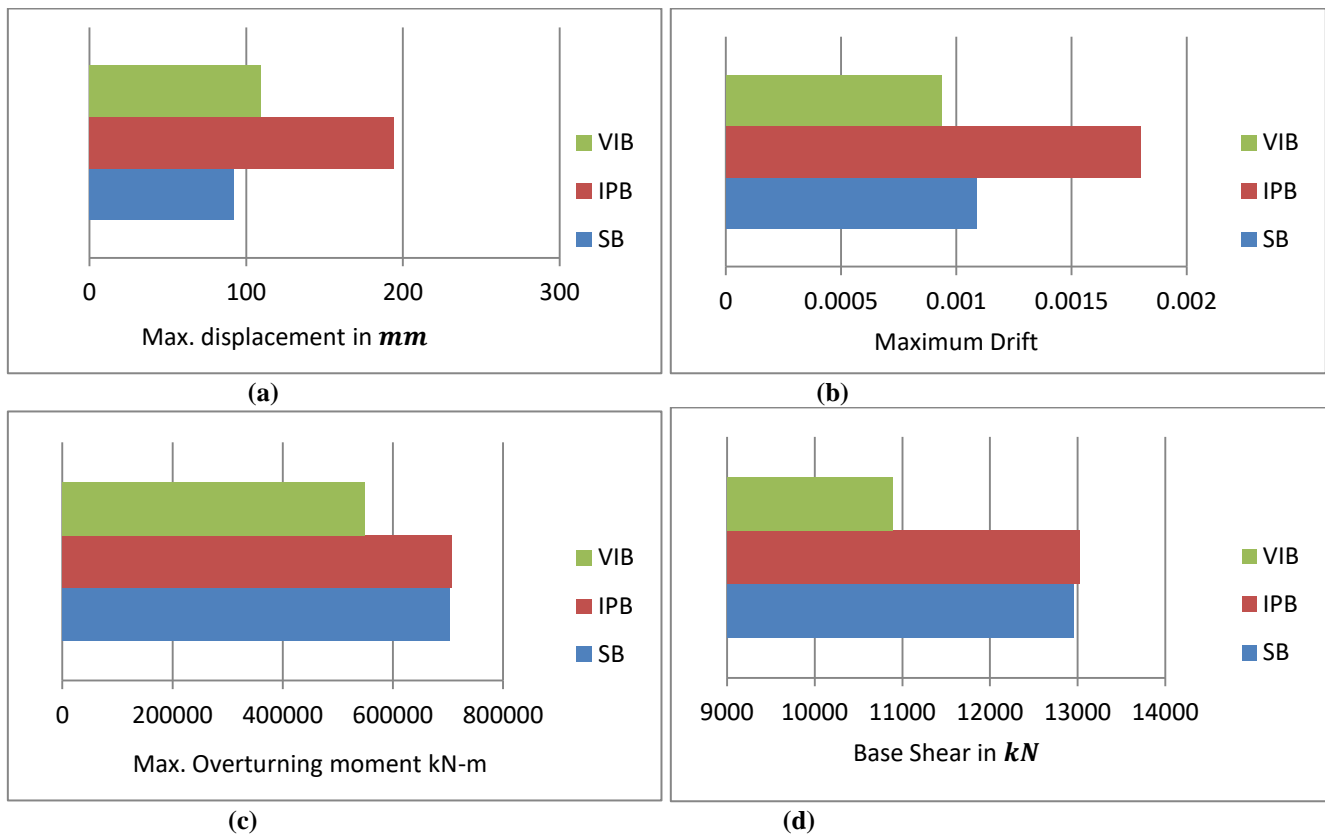


Fig-8 shows variation of (a) Max. Displacement (b) Max. Drift (c) Max. Overturning moment (d) Max. Base shear due to wind analysis in terrain category-3.

Table-7 Results of wind analysis in terrain category 4.

| Models | Max. displacement in mm | Maximum Drift | Max. Overturning moment $kN - m$ | Base Shear in kN |
|--------|---------------------------|---------------|----------------------------------|--------------------|
| SB | 41.29 | 0.000754 | 350540.46 | 6414.1872 |
| IPB | 101.826 | 0.001347 | 367872.5203 | 6323.9135 |
| VIB | 56.919 | 0.000604 | 284025.4565 | 5319.7721 |

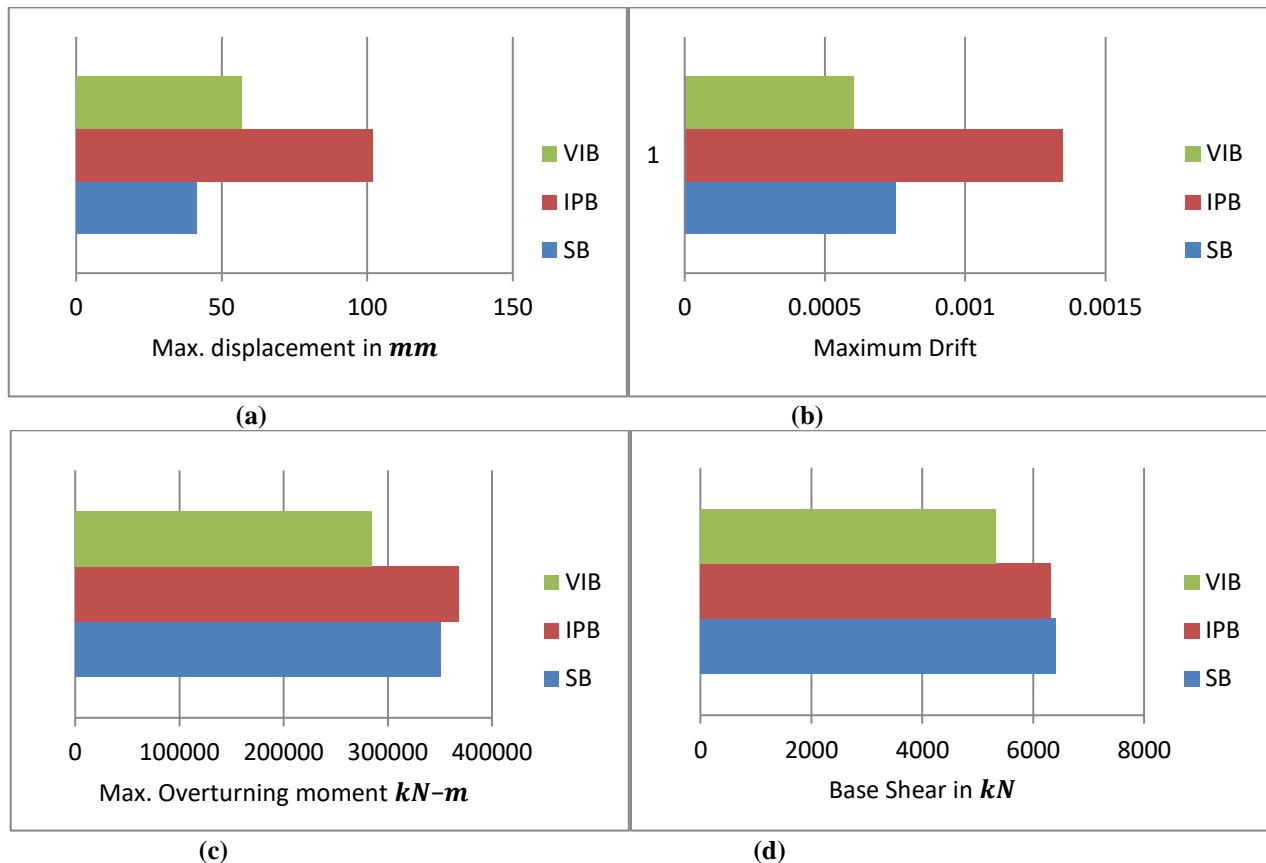


Fig-9 shows variation of (a) Max. Displacement (b) Max. Drift (c) Max. Overturning moment (d) Max. Base shear due to wind analysis in terrain category-4

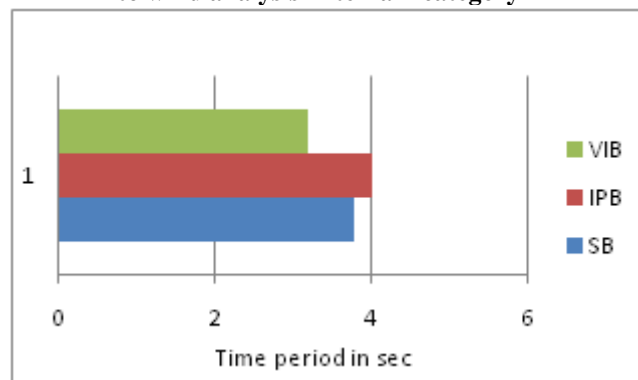


Fig-10 shows that time period of SB and VIB

V. CONCLUSION

Comparison of regular and irregular structures in each terrain category was done on the basis of storey displacement, storey drift, storey shear, overturning moment and time period. Following conclusion points are revealed from seismic and wind analysis of G+30 storey buildings.

- The displacement of plan irregular building increases with increase of slope angle. In Terrain-3 with slope of ground 20 degrees the displacements of SB, IPB and VIB are increased 20%, 11% and 48% as compared to Terrain-1, Terrain2 and Terrain-4.
- Storey drift of SB, IPB and VIB in terrain-2 with slope of ground 15 degrees are increased 37%, 14% and 42% as compared to terrain-1, terrain-3, and terrain-4.
- Over-turning moment also increases with increase of ground slope. In terrain-3 with slope of ground 20 degrees the overturning moment of SB, IPB and VIB are increased 14%, 16% and 50% as compared to terrain-1, terrain-2, and terrain-4.

- Base shear of SB, IPB and VIB, in terrain-3 with ground slope of 20 degrees are increased 17%, 10% and 51% as compared to terrain-1, terrain-2 and terrain-4.
- Time period is maximum in IPB and minimum in VIB. Time period of SB and VIB is decreased by 7% and 20% than IPB respectively.
- From both the analysis (seismic and wind) it is concluded that vertical irregular building in terrain category-4 with ground slope less than 3 degrees provides greater resistance against both seismic and wind loading among all buildings.

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