Study of wind loads on RC building resting on sloping ground

Darshan Ramachandra Todkar [1], U.R. Awari [2],

[1]*P.G. Student, Dept. of Civil Engineering, AISSMS College of Engineering, Pune, Maharashtra State, India*
[2]*Professor, Dept. of Civil Engineering, AISSMS College of Engineering, Pune, Maharashtra State, India*

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Abstract - As the wind blows against a building, the resulting force acting on the elevations is called the 'wind load'. The building's structural design must absorb wind forces safely and efficiently and transfer them to the foundations in order to avoid structural collapse. Wind loads will typically depend on the wind velocity and the shape (and surface) of the building, and is why they can be difficult to predict accurately. The building shape may exacerbate any over- or under-pressure effects. On the windward side (facing the wind), wind overpressures may blow windows in, while on the leeward side (sheltered from the wind) under-pressure (suction) may blow windows out. Hill buildings differ from plains buildings in that they are highly uneven and asymmetrical in horizontal and vertical planes, as well as torsionally linked. Because very few plain grounds are available in hilly locations, structures must be built on slopes. R.C.C structures with columns of varying heights at same story have sustained more harm in the columns with lesser height than in the columns with greater height in the same floor. A case study B+S+18 building has been considered in this research work. Step back and step back set back configurations are included to the actual plan of the building in our research. Building is considered resting sloping ground with varying angle of 0°, 15°, 20° and 25°. After the analysis we can conclude that Slope of building is maintained by increasing the height of columns from one side as compared to other side which creates additional torsional effect on the building. There is significant increase in maximum story drift of the structure due to sloping ground. Also there is reduction in maximum story drift for step back set back configuration as compared to step back configuration.

Key words: *Wind load analysis, step back, step back set back, ETABS, story drift*

1. INTRODUCTION

Every building's structure is susceptible to many loads, the first of which is gravity's pull on the structure. In a similar vein, the "live load"—the weight of the people, furnishings, fixtures, etc.—must be supported by the building. In addition to bearing its own weight, the structure must withstand loads from the wind, an earthquake, etc. Always design and build buildings, other structures, components, and cladding to withstand wind loads.

The force that results from wind blowing against a building and acting on its heights is referred to as the "wind load." To prevent structural collapse, wind forces must be safely and effectively absorbed by the building's structural design and sent to the foundations. Wind loads can be challenging to anticipate with accuracy since they usually depend on the wind velocity and the form (and surface) of the building. Any consequences of over- or under-pressure may be exacerbated by the design of the building. Wind overpressures on the windward side (facing the wind) can force windows in, while under pressure (suction) on the leeward side (sheltered from the wind) can force windows out. A glass-clad building with a very smooth profile will tend to deflect the wind far more effectively than a sculpted or textured profile, as will a circular building compared to a square shape.

Mechanism of Wind Loads on Structures

Any kind of structure's design must take wind load into account. The load exerted by wind on a structure's exterior is measured in kN per square meter. This is contingent upon:

- The angle at which the wind strikes the structure
- The shape of the structure (height, width, etc.)

Strengthening vulnerable building areas is necessary to prevent wind damage. The foundation, roof, and walls all need to be sturdy, as do the fasteners that hold them together. A continuous load path from the roof to the foundation—connections that hold all structural components together and are capable of withstanding various wind loads that could push and pull on the building during a storm—is necessary for a structure to withstand hurricanes and light tornadic winds.

Wind exerts three types of forces on a structure:

- Uplift load - Wind flow pressures that create a strong lifting effect, much like the effect on airplane wings. Wind flow under a roof pushes upward; wind flow over a roof pulls upward.
- Shear load – Horizontal wind pressure that could cause racking of walls, making a building tilt.
- Lateral load – Horizontal pushing and pulling pressure on walls that could make a structure slide off the foundation or overturn.

Elevated wind pressure has the potential to bring down doors and windows, tear off roof decking and roofing, and demolish gable-end walls. Particularly vulnerable to damage are roof overhangs and other elements that have a tendency to trap air beneath them, creating strong uplift forces. Broken windows and doors put the building's contents at risk of significant harm from water intrusion and internal wind pressure.

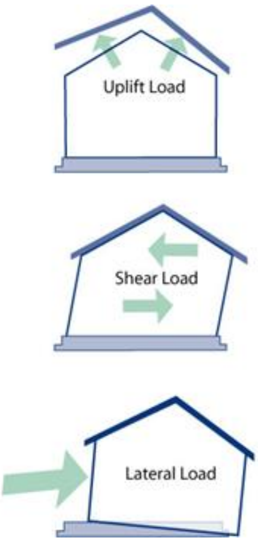

Fig -1: Loads acting on structures due to wind loads

1.1 Behaviour 0f Buildings on Slopes]

India's northeast and north-east contain sizable areas of hill country. The region is experiencing a surge in demand for multi-story RC framed buildings on hill slopes due to its fast urbanization and economic progress. The rise in construction activity is contributing to the growth in population density. In contrast to plain buildings, hill buildings are torsionally linked, very uneven, and asymmetrical in both horizontal and vertical planes. In mountainous areas, there isn't much level ground, therefore buildings have to be constructed on slopes. When lateral loads occur in RC frame buildings with columns that differ in height within a single level, the shorter columns experience greater damage than the taller columns on the same floor.

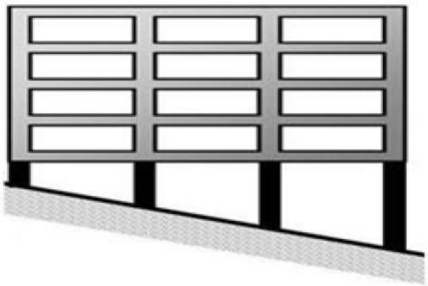

Fig. 2 Building frames with short columns

Short columns have poor behaviour because, during lateral loading like wind/seismic, tall and short columns with the same cross section move horizontally by the same amount, as shown in Figure 2. The short column, on the other hand, is stiffer than the tall column, and so attracts more earthquake force. A column's stiffness indicates its resistance to deformation; the higher the stiffness, the greater the force required to deform it. Due to variations in mass and stiffness distributions on different vertical axes at each floor, these buildings become highly irregular and unbalanced due to the varied designs of buildings in hilly locations. Due to that different configuration has been seen as shown in Figure-3 (a) and (b).

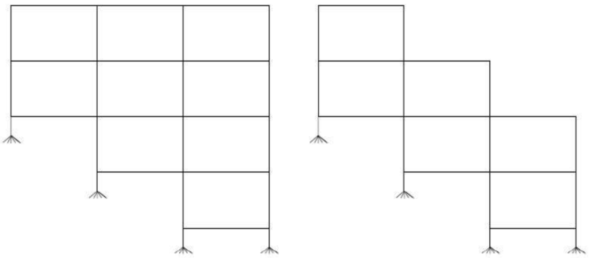

Fig -3: (a) step back building (b) step building set back building

Shreya Manduskar and V. S. Shingade (2023) considered 3D building frames of 25 storied building resting on flat terrain and sloping ground. Slopes of 20°, 30°, and 40° were taken into consideration for sloping ground. They were to be examined at three different wind speeds: 39 m/s, 47 m/s, and 55 m/s. The extended three-dimensional analysis of building systems, or ETABS, software can be used for the modeling and analysis. They came to the conclusion that base shear outcomes for level terrain and all sloping angles were almost comparable. Results of earthquake displacement are found in buildings with varying sloping terrain, including flat terrain, 20-, 30-, and 40-degree slopes, which were nearly equivalent in all sloping-angle structures. Results for wind displacement at basic wind speeds of 39 m/sec were obtained for level ground, 20 m/sec, 30 m/sec, and 40 m/sec sloping ground. Since wind displacement rises with slope angle, it follows that an increase in ground slope will likewise result in an increase in wind displacement. When compared to a building lying on level ground, the displacement rose by 5.6% for a 20-degree slope, 7.5% for a 30-degree slope, and 9.7% for a 40-degree slope. [1]

Ms. Khan Shaima Khan Iftekhar Khan, Mr. Aakash Suthar (2023) prepared 36 models for the interaction between tall buildings and wind on flat and sloping ground, specifically focusing on the northern part of India with high wind flow. An analysis was conducted on reinforced concrete structures with varying heights (G+5, G+10, and G+15) in different wind zones on both level ground and incline surfaces (0°, 10°, 20°, and 30°). Three distinct types of models were used to conduct wind load analyses for each zone using the ETABS software. The results were good when the tale displacement, story drift, and mode period were also examined. Comparisons were also made between software and manual computation results. They came to the conclusion that, in comparison to structures on level ground, those on sloping terrain exhibit a larger maximum displacement, which may result in dangerous circumstances. The 15-story building has the longest period at both the top and bottom storeys, according to the mode shape study. The number of stories and slope both increase story drift, story displacement, and mode period. But as the number of stories increases, the median period gets shorter. [2]

Pradeep Sivanantham et. al. (2023) represented an experimental and analytical investigation of the behaviour of reinforced concrete frames and their response in sloped regions of hills, in which global retrofitting techniques were adopted by providing solid infill in the short column effect zone for the columns in the same storey of different heights. The influence of infill on the short column effect under lateral cyclic loads was studied numerically. It was shown that masonry infill significantly boosted the lateral load-carrying capability by up to 50% as compared to bare reinforced concrete frames. Meanwhile, the energy dissipation capacity of the frame rose linearly. The various behaviors of the reinforced concrete structure, such as ultimate load displacement, crack pattern, energy dissipation, and energy absorption, were studied when infill was added to the frame using the short column effect. The lateral strength and energy dissipation capability of the reinforced concrete structure were enhanced by a factor of 2.45 with the use of a solid infill. In comparison to the reinforced concrete frame without infill, the short column effect and the damage development on the reinforced concrete frame with infill were less affected by lateral stress. [3]

Rayudu Jarapala, Arun Menon (2023) presented a comprehensive review of the classification of sloping ground buildings, their source of irregularity, parameters influencing seismic response, irregularity and storey damage descriptors, and vulnerability methods to quantify their seismic performance. Lastly, various seismic retrofit techniques were also discussed in order to increase seismic performance. In structures with sloping terrain, six main typologies that are commonly found in practice were found. The most important factors influencing earthquake performance were irregular geometry, storey ratio, slope angle, and foundation soil type. Step-back buildings were more vulnerable among these typologies than split foundation and step-back setback buildings. During seismic shaking, the top street-level columns of these buildings are subject to greater shear stresses than the lower street-level columns, which can result in brittle catastrophic failure. For generic RC buildings, there were various storey damage descriptors, vulnerability assessment techniques, and vertical irregularity descriptors available. Seismic modeling and analysis of such typologies may depend critically on the type of structural modeling (2D vs. 3D frames) and the taking into account of soil-structure influences. To enhance the performance of these buildings, various techniques have been proposed, including strengthening ground-floor columns, RC-filled steel tubular columns, earthing tie beams, and RC walls. [4]

Yati Aggarwal, Sandip Kumar Saha (2021) focused on investigating the effect of one or more open stories in reinforced concrete hilly buildings. Two distinct building configurations were examined: (i) stepback and (ii) split-foundation, each having three distinct story ratios. Depending on where the approach road level might eventually be, a building might have open stories at various levels. A set of 22 ground motion data was used to conduct non-linear dynamic studies of these buildings after they were subjected to bi-directional earthquake stimulation. The buildings' maximum story shear, peak inter-story drift ratio, peak floor acceleration, peak roof displacement, and other dynamic features and seismic reactions were examined. A probabilistic evaluation of these buildings' performance was provided, with varying probabilities for the open story's location. The probability analysis shows that these buildings' seismic performance is generally greatly reduced when an open storey is present. Furthermore, it was shown that the structures with open stories at the topmost foundation level were the most susceptible to earthquake excitation. [5]

A Joshua Daniel and S Sivakamasundari (2021) performed an analytical study to compare the behaviour of buildings with irregular structural configuration having foundations at different levels. In terms of fundamental periods of vibration, mode shape, cumulative modal mass participation ratio, forces on member, plastic hinge formation, performance point, and plastic hinge formation with base shear action induced in the corresponding building's columns and beams, the dynamic response of the hill building was compared with that of the corresponding regular building on flat ground. The regular construction on flat ground was clearly more flexible than the corresponding building on a hill slope, according to the analysis, which was based on the time period, modal mass participation ratio, force distribution, and production of plastic hinges in the column. They came to the conclusion that regular buildings on level land are more adaptable than corresponding hill buildings. It is clear from the cumulative modal mass participation ratio that normal flat-ground buildings have a greater potential for energy dissipation than corresponding hill buildings. [6]

Harish Rathod S , Thushar Shetty (2021) analysed the wind response of structures on flat and sloping land with various building configurations such as angel variation of buildings and the usage of X bracing on the wind resistance of structures. Wind loads was applied to flat and inclined structures, and the results were noted. This study finds that by combining slope angle change with SSI consideration, the use of X type bracing in a building constructed on sloping terrain enhanced resistance to top storey displacements, storey drifts, and storey shear in structures. [7]

Seung Yong Jeong, Hamidreza Alinejad, and Thomas H.-K. Kang (2021) carried out preliminary PBWD of the case study RC building using time-history wind load generated from PSD functions. Throughout the initial elastic design, inelastic behavior was introduced by reducing the resonant component by the RW factor. After conducting performance testing, it was shown that the RW factor can be used to successfully lower torsional and across-wind loads. Design forces on horizontal members—particularly coupling beams—were thereby greatly decreased. In order for the along-wind load lowered by RW to be greater than the seismic load reduced by RE, the RW factor was calculated. This was the case for all RW factors of 1, 2, and 3 in the design building case study, partly because of the relatively low requirement of seismic load. PSD functions can be used to generate a time-history wind load for preliminary PBWD. Time-history wind loads for an NTHA must be generated with gradual loading and unloading, vertical distribution of mean and background rather than the mode form of the resonant component, and maximum load occurrence in mind.. [8]

Ted Stathopoulos, Hatem Alrawashdeh (2020) reviewed the wind loading of buildings from a code perspective. Because to Alan G. Davenport's inventiveness, the Canadian wind load provisions for structures have garnered widespread respect from scholars and practitioners worldwide for their unique and pioneering nature. The establishment and growth of numerous national and international wind load standards, such as ASCE 7, ISO, Eurocode, China standard for wind loads on roof structures, and others, have been influenced by these rules in this regard. To get a sense of how much topography, exposure concerns, internal and external forces, and ASCE 7 (USA), NBCC (Canada), and GB 50009 (China) are now being handled by these provisions, the article first gives a review of these three standards. The present wind load allowances for structures were compared and contrasted, and efforts were made to address some of the apparent differences that seemed to be producing findings that might not be conservative. Finally, cutting-edge trends and methods to codification that are presently being developed, discussed, and taken into consideration were also showcased. [9]

D.N. Kakde et. al. (2020) evaluated the structures resting on sloping ground additionally subjected to heavy wind. The SAP-2000 software was used to run each simulation. Based on factors like Base response, Time Period, and the overall displacements of the structure during strong winds, the structural performance was assessed. [10]

Narendra tak et. al. (2020) analyzed the seismic loading applied by Multi-Storied RC structure on a sloping ground with specific angle 29 degree. The multi-story skyscraper is photographed at several tower positions with varying slope angles. The results were assessed using a structure that was taken without any slope and a sloping ground angle of 29 degrees that was on plane ground. Seismic analysis is therefore a component of dynamic analysis. For the investigation along sloping terrain, two different configurations were used: step backset back and set back. The Seismic Analysis Method was used to conduct the analysis. The methodologies and the entire process are executed by IS-1893-2016. Utilizing STAAD pro software, the Response Spectrum Method is investigated. All of the actions taken are a part of the process that leads to the conclusion that step-back set-back construction is a better option than alternative techniques. [11]

P Krishnam Raju et al. (2019) conducted their study to assess the influence of wind on a 17-storey multipurpose Reinforced Concrete Tall Building according to the revised wind code of IS 875 (Part 3): 2015 compared to its previous version i.e., IS 875 (Part 3): 1987. According to Indian regulations, the study includes all basic wind speeds of 33, 39, 44, 47, 50, and 55 m/s. Using the ETABS assessment software, dynamic effects caused by "along wind" and "across wind" were taken into account in the analysis. According to the updated version, it was discovered that the Lateral load, Lateral sway, and Longitudinal Rebar Percentage (LRP) had all increased. There was further reporting of the LRP in the Middle, Edge, and Corner columns. For a base wind speed of 50 m/s, an increase in the overall quantity of Rebar (beams and columns) by roughly 3.7% was noted for the entire structure. [12]

1.3 Objectives of investigation

1. To Study and calculate the wind loading as per IS875 2015 and effect of sloping ground in RC building.
2. To analyze the RC buildings resting on different slope angles with different wind speed.
3. To compare the Global results like base shear, Story drift, time period, overturning moment, maximum lateral displacement for all cases.
4. To suggest the suitable configuration to overcome the effect of sloping ground.

2. MODELLING

Due to complexity in the design of RCC Buildings on scope, lateral load analysis becomes a complex phenomenon. So Modelling of building and analysis needs more advance tool and software so that results can be trusted and implemented uniformly. For this purpose Finite element software which is used worldwide for the analysis of RCC structure ETABS has been used for the analysis in this study.

A case study G+19 building has been considered in this research work, which is currently under construction in Noida, Uttar Pradesh. All members that influence the mass, strength, stiffness, and deformability of the structure are included in the building's analytical models. Beams, columns, slabs, walls, and other structural members of the building. Step back and step back set back configurations are included to the actual plan of the building in our research. Building is considered resting sloping ground with varying angle of 0°, 15°, 20° and 25° as per the calculations shown in fig.2. Floor to floor height of the building is 3m. Response reduction factor is taken as 5 for special moment resisting frame. Static time period of the building is calculated by imperial formula as per IS: 1893:2016. Wind load has been applied as per IS 875 2015. Column and beams sizes are designed in ETABS Software as per the requirement. Wind speed of 44m/s and 47 m/s has been considered and Total 16 models are prepared for the comparison.

The models are prepared in ETABS and initially examined by equivalent static analysis for various slopes, i.e. 0°, 15°, 20° and 25°, and seismic base shear is determined. After this, response spectrum with dynamic scaling, i.e. matching base shear of equivalent static analysis and response spectrum analysis is done as per IS1893:2016. For various slopes, dynamic analysis is performed on step back and step back setback building models. Base shear, story drift, lateral displacement, overturning moment, and building time period are the primary factors considered in this research work. Analysis performed is to check the seismic efficiency of several models with different slopes.

2.1 Structural parameters of the models

The models are prepared in ETABS and initially examined by equivalent static analysis for various slopes, i.e. 0°, 15°, 20° and 25°, and seismic base shear is determined. After this, response spectrum with dynamic scaling, i.e. matching base shear of equivalent static analysis and response spectrum analysis is done as per IS1893:2016. For various slopes, dynamic analysis is performed on step back and step back setback building models. Base shear, story drift, lateral displacement, overturning moment, and building time period are the primary factors considered in this research work. Analysis performed is to check the seismic efficiency of several models with different slopes.

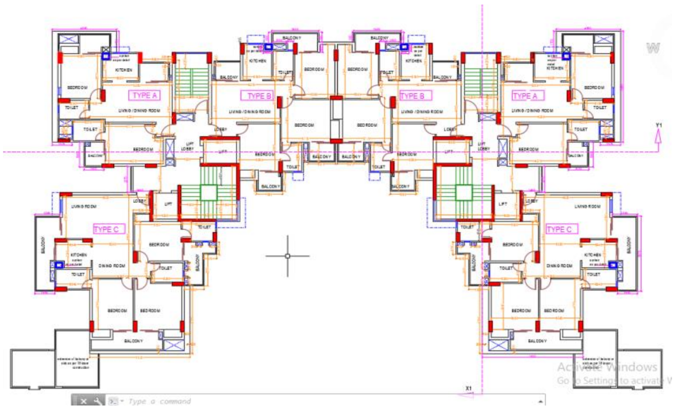

Fig. 4: Plan of the Building in AutoCAD

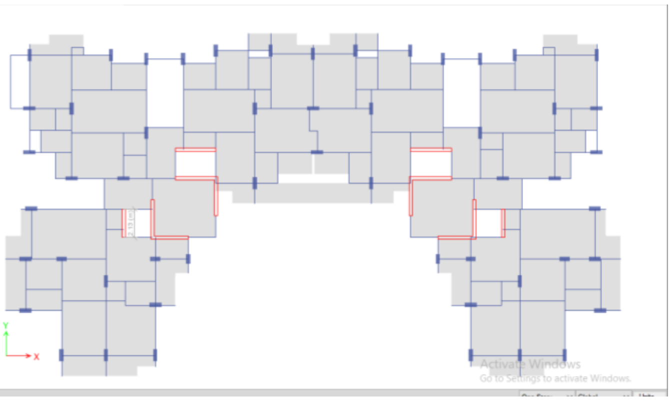

Fig. 5: Plan of the Building in ETABS

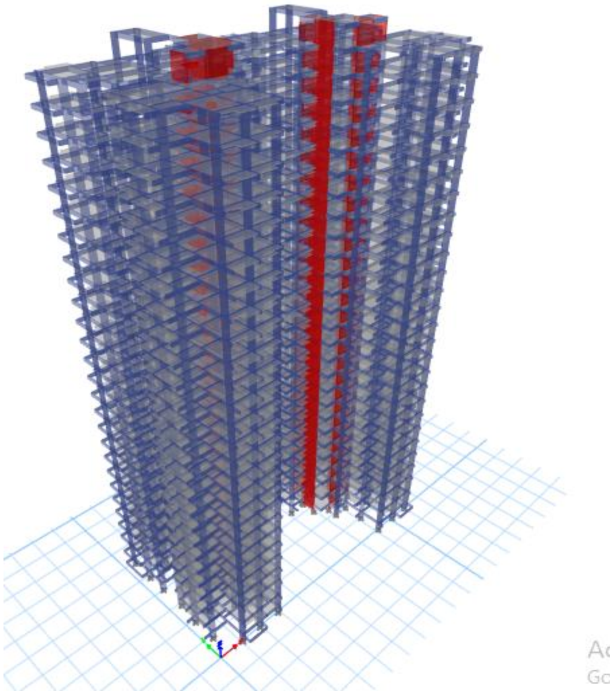

Fig. 6: 3D view of the Building in ETABS

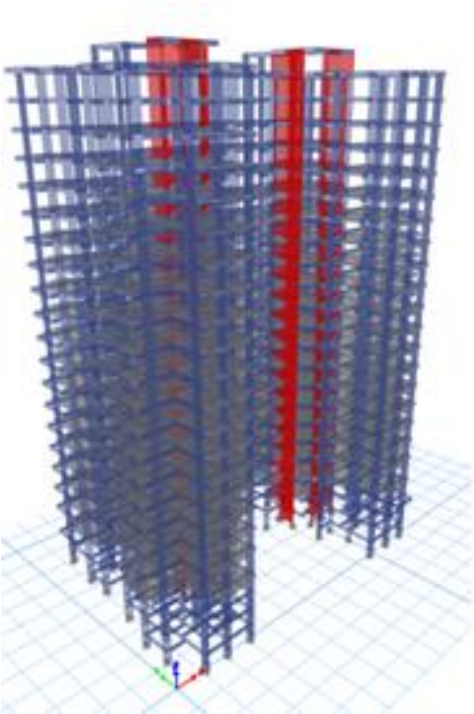

Fig. 7: Building with 15 degree slope step back configuration considered

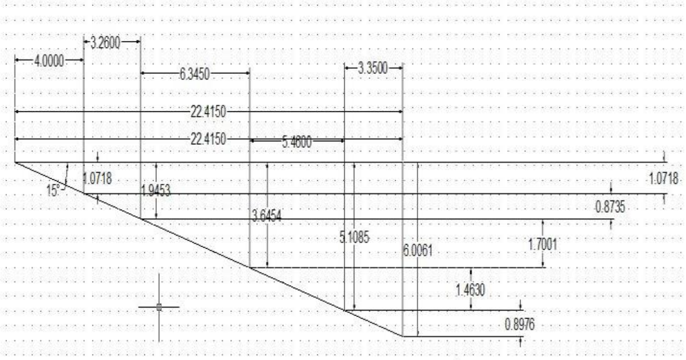

Fig. 6: Building on 15 degree slope

3. RESULTS AND DISCUSSIONS

The evaluation of lateral performance is a complicated process since various elements influence the building's behaviour. The models in Chapter 3 are first examined by equivalent static analysis seismic base shear for various slopes, i.e. 0, 15, 20, and 25, and then by response spectrum with dynamic scaling, i.e. matching base shear of equivalent static analysis and response spectrum analysis. For various slopes, a dynamic analysis of step back and step back setback building models is performed. Base shear, story drift, lateral displacement, overturning moment, and time period of the building are the primary characteristics evaluated in this study to assess the seismic performance of different models with different slopes. The results are also compared across wind speed 44m/s and 47 m/s for seismic zone II for Pune region. In this chapter, the findings of the analysis are discussed.

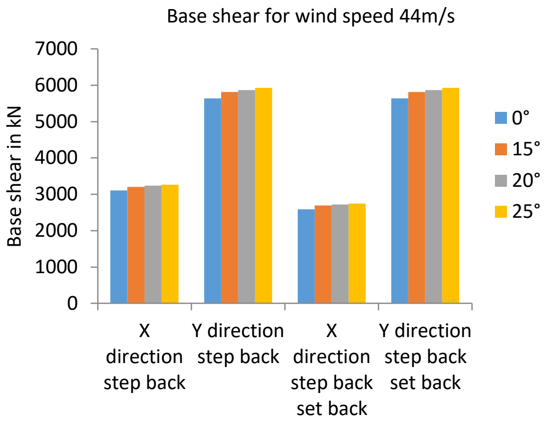

Chart-1: Variation of base shear in X & Y direction for building with varying slope angle for wind speed 44 m/s for step back building and step back set back building

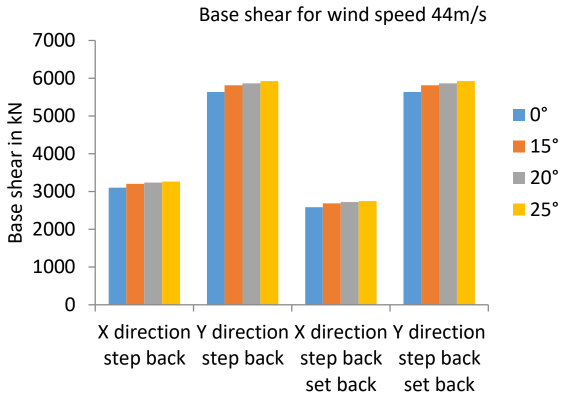

Chart-2: Variation of base shear in X & Y direction for building with varying slope angle for wind speed 47 m/s for step back building and step back set back building

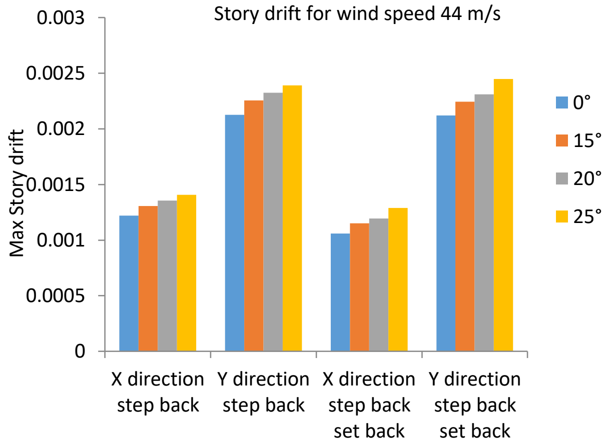

Chart-3: Variation of story drift in X & Y direction for building with varying slope angle for wind speed 44 m/s for step back building and step back set back building

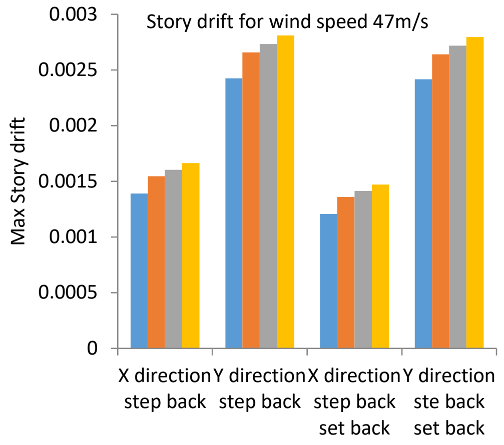

Chart-4: Variation of story drift in X & Y direction for building with varying slope angle for wind speed 47 m/s for step back building and step back set back building

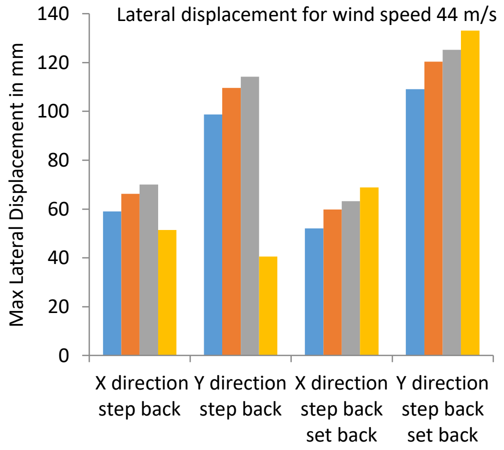

Chart-5: Variation of maximum lateral displacement in X & Y direction for building with varying slope angle for wind speed 44 m/s for step back building and step back set back

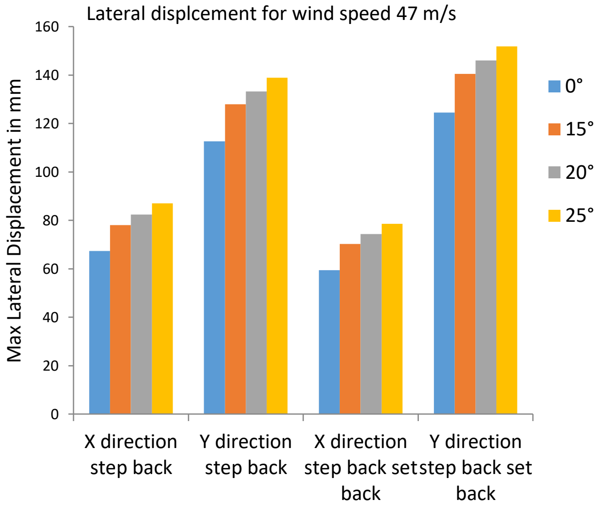

Chart-6: Variation of maximum lateral displacement in X & Y direction for building with varying slope angle for wind speed 47 m/s for step back building and step back set back

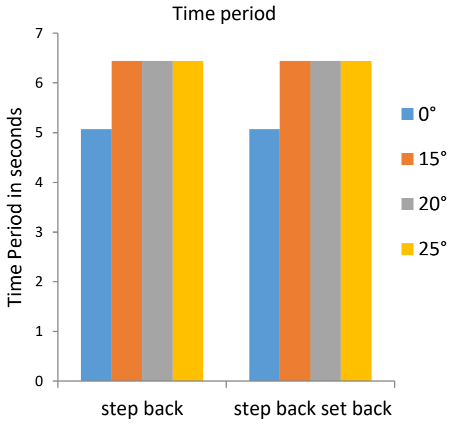

Chart-7: Variation of Time period of building with varying slope angle for step back building and step back set

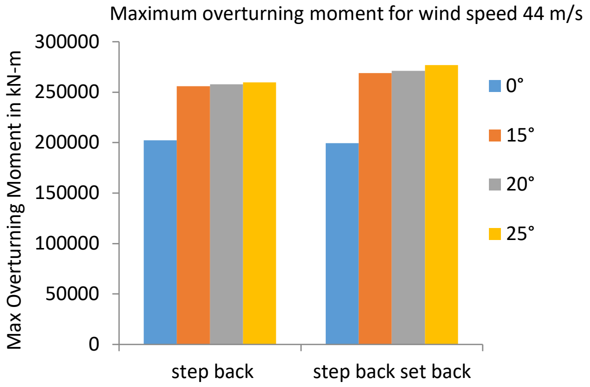

Chart-8: Variation of maximum overturning moment for building with varying slope angle in seismic zone II for step back building and step back set back

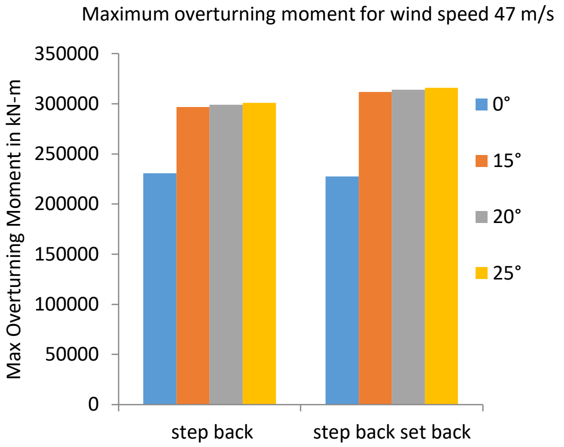

Chart-9: Variation of maximum overturning moment for building with varying slope angle in seismic zone III for step back building and step back set back

4. CONCLUSIONS

Wind loads are calculated as per IS 875 Part 3, which will increase with the slope angle as height of the building increases with increase in slope angle. From results, Slope of building was maintained by increasing the height of columns from one side as compared to other side which creates additional torsional effect on the building. From the results, it was found out that there is not much of change in base shear due to slope of ground as only slight increase of 0.5-1% in base shear is observed due to sloping ground due to increase in wind loading of the building at sloping part of the structure due to wind loading. From the results, it was also found out that there is significant increase in maximum story drift of the structure due to sloping ground i.e. around 10-25%. there is a drastic change of 4-5% is observed when slope angle is increased from 15° to 20° to 20° to 25°. Also there is reduction in maximum story drift for step back set back configuration as compared to step back configuration by around 10-15% in X direction and almost no change in Y direction due to wind loading. It was found out that there is significant increase in Maximum lateral displacement of the structure due to sloping ground i.e. around 12-25% in X direction % 10-21% in Y direction. There is increase of around 5-7% in maximum lateral displacement when slope angle changes from 15-20 & 20-25. Also there is reduction in maximum lateral displacement for step back set back configuration as compared to step back configuration by around 10-12% in X direction and increase by around 8-10% in Y direction for wind loading. From the results, it was found out that that maximum Overturning moment of the building is increase by 5-15% for sloping ground as compared to building on plain ground. Again there is increase only 3-5% in overturning moment when slope angle is changes from 15° to 20° & 20-25. There is 6-8% increase is there in maximum overturning moment for step back set back configuration as compared to step back configuration for wind loading. Thus we can summarize that step back set back configuration performs better as compared to normal step back building resting on sloping ground. Over turning moment as well as lateral displacement & drift is significantly less in step back set back configuration.

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