International Journal of Research Publication and Reviews

Journal homepage: www.ijrpr.com ISSN 2582-7421

A Review on Investigate How Story Displacement Changes with Varying Slope Angles and Story Heights

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ABSTRACT

By comparing these results, the study aims to identify the most effective configuration that minimizes seismic risks while accommodating the constraints of sloped terrain. This analysis will contribute to the development of design guidelines for buildings in hill regions, ensuring better earthquake resistance and overall structural integrity. The study you're outlining addresses the challenges associated with designing buildings on hill slopes, particularly in regions prone to seismic activity, such as in northern India. The uneven column heights on sloped sites lead to variations in seismic forces acting on different parts of the structure, which can cause damage to shorter columns that attract more forces during earthquakes. To analyze this, the response spectrum method is employed, which is well-suited for evaluating the dynamic response of structures subjected to earthquake loads. By analyzing two types of building frames—step back and step back-setback frames—the study compares how different configurations perform under varying conditions like slope and building height.

Key words:- Sloped terrain, Response spectrum, Seismic forces, Displacement, Story Drift

Introduction

Slopes are indeed more susceptible to failure during earthquakes due to both seismic forces and the additional stresses from earth pressures imposed by the sloped terrain. These failures can be exacerbated by a combination of factors such as soil stability, slope angle, and the type of foundation.

Contribute to the vulnerability of structures on slopes include:

Seismic Forces: Earthquakes generate horizontal and vertical ground movements. These forces can cause differential settlement, lateral sliding, and tilting of the structure, especially if the slope is steep or the soil is loose and poorly compacted.

Earth Pressures: The weight of the soil on the slope, combined with the dynamic loads from an earthquake, can result in increased earth pressure against the foundation of the structure. This can lead to sliding or overturning, particularly if the foundation is not adequately designed to withstand these forces.

Soil Liquefaction: In areas with loose, water-saturated soils, an earthquake can induce soil liquefaction, where the soil temporarily loses its strength and behaves like a liquid. This can cause severe ground deformation, leading to the collapse of structures.

Landslides and Slope Failure: Earthquakes can trigger landslides, particularly in steep areas, as the shaking destabilizes the soil and rock. The movement of the soil can cause significant structural damage or even complete collapse.

To mitigate these risks, areas are classified into different earthquake zones based on the intensity and magnitude of past earthquake data. These zones help in designing structures that can withstand seismic forces by ensuring that foundations, materials, and construction methods are appropriate for the seismic risk in the area.

Literature Review

These studies provide foundational insights into the behavior of buildings on slopes and under varying wind conditions, emphasizing the interplay of slope angles, dynamic loads, and structural stability. If you need additional information or specific methodologies.

Nandini Naresh Raut et al (2024) the study you are describing seems to focus on the seismic behavior of reinforced concrete structures located on sloping terrains. This type of terrain can significantly affect a building's response to earthquake forces due to factors such as mass distribution, irregular shape, and torsional behavior, which may lead to greater vulnerability during seismic events. The study emphasizes using ETABS 16 to model both level and sloping surfaces, assessing the dynamic response of buildings subjected to seismic forces. Seismic analysis in this context helps determine the building's ability to withstand earthquake-induced forces, with a focus on key parameters such as story displacement, overturning moments, story drift, and story shear. The study considers five distinct building shapes, including ordinary (rectangular or symmetrical) buildings and asymmetrical buildings commonly found on sloping terrains. Asymmetry and irregularity in shape can create torsional effects, where different parts of the building experience different amounts of movement, leading to non-uniform responses. The time taken for a building to complete one cycle of vibration. For irregular buildings on slopes, this value may differ from structures on level ground. This measures how much each story moves due to seismic forces. The displacement tends to be larger in structures on sloping terrains due to irregular mass distribution. The total horizontal force that the building experiences due to seismic activity. This force is critical for understanding how the building transfers the earthquake load to its foundation. These represent the lateral displacements in the horizontal plane, with X typically corresponding to one direction (e.g., along the slope) and Z corresponding to another (e.g., perpendicular to the slope or in the vertical plane).

Darshan Ramachandra Todkar et al (2024) 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 torsion ally 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.

Rizwan Khan et al (2023) the design, planning, and analysis of a residential G+8 building using ETABS, focusing on how different slope angles (0°, 5°, 10°, and 15°) influence the building's performance under wind loads. Choose appropriate materials based on local codes and environmental conditions (e.g., concrete, steel). Decide on the type of structural system (e.g., framed structure, shear walls, or a combination). Wind speed, exposure category, and topography (in this case, the slope of the ground) will influence wind load values. As the slope of the ground increases, the wind load distribution on the building may change due to altered wind pressure patterns. The topography factor in the wind load calculation will need adjustment for sloping ground. Create a 3D model of the building in ETABS, incorporating the building layout and structural system. Define the materials, cross-sectional properties, and boundary conditions based on the structural system. Input the wind load parameters in ETABS, adjusting for the slope of the ground at each angle (0°, 5°, 10°, and 15°). Apply the load according to the direction of the wind and the structural components affected. Apply different load combinations to simulate real-world conditions (e.g., dead load + live load + wind load). This project will demonstrate the importance of wind load analysis, especially when dealing with varying topographical conditions, and will highlight the effectiveness of ETABS in modeling and optimizing the structural design.

Pawar et al. (2023) titled "A comparison between a multi-story building resting on level and sloping ground in terms of seismic analysis" presents an analysis of a G+8 story building with a focus on shear wall performance in a setback structural frame. The inclusion of shear walls significantly reduces the base shear compared to other building models. Shear walls play a crucial role in resisting lateral displacement, which is a key factor in seismic performance. Buildings with shear walls exhibit lower absolute displacement, indicating improved structural stability under seismic forces. The building model with shear walls showed the best seismic performance, demonstrating minimal displacement and base shear when compared to other configurations. Among various structural configurations, the inclined-from-front setback building frame provided the best seismic performance, exhibiting minimal displacement and base shear compared to other models. The paper suggests that a combination of shear walls, particularly in an inclined setback frame configuration, offers superior performance in terms of base shear reduction and lateral displacement resistance during seismic events.

Shreya Manduskar et al (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. The base shear values for buildings on flat terrain and sloping grounds with angles of 20°, 30°, and 40° were nearly identical. This suggests that the slope of the ground has little effect on the base shear under earthquake conditions. The overall conclusion is that while the slope of the ground has minimal effect on earthquake displacement and base shear, it significantly influences the wind displacement. As the slope angle increases, the building's displacement due to wind loads also increases, making it crucial to consider ground slope when designing for wind loads, especially at higher wind speeds.

Ms. Khan et al (2023) Buildings on sloping terrains experience greater maximum displacements compared to those on flat ground, which may pose safety risks due to higher lateral movement. Both story drift and displacement increase with the number of stories and slope angle, indicating that taller buildings on sloped ground are more susceptible to wind-induced forces. 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 stores, 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. This kind of analysis is valuable in understanding the dynamic behavior of tall buildings under wind forces, especially on inclined surfaces, and provides insights into potential vulnerabilities for buildings in regions with high wind flow.

Pradeep Sivanantham et. al. (2023) represented an experimental and analytical investigation of the behavior 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 story 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.

Rayudu Jarapala, et al (2023) presented a comprehensive review of the classification of sloping ground buildings, their source of irregularity, parameters influencing seismic response, irregularity and story 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, story 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 story 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, earthling tie beams, and RC walls.

Yati Aggarwal et al (2021) this study highlights the importance of considering the location of open stories in the design of reinforced concrete buildings in seismic zones, particularly in hilly regions. The results suggest that structural adjustments and mitigation measures are necessary for buildings with open stories, especially those with the open story at the uppermost levels, to enhance their seismic resilience. Focused on investigating the effect of one or more open stories in reinforced concrete hilly buildings. Two distinct building configurations were examined: (i) step back 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 story is present. Furthermore, it was shown that the structures with open stories at the topmost foundation level were the most susceptible to earthquake excitation.

A Joshua Daniel et al (2021) performed an analytical study to compare the behavior 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.

Harish Rathod S et al (2021) exploring the impact of wind response on structures, considering both flat and sloping terrains, various building configurations, and the use of X-bracing for wind resistance. Here's a refined summary based on your findings. This study investigates the wind response of structures built on flat and sloping terrains, focusing on the effects of various building configurations, including angular variations, and the implementation of X-bracing systems. Wind loads were applied to structures on both flat and inclined surfaces, and the results were analyzed to assess performance under different conditions. The findings indicate that the combination of slope angle changes with Soil-Structure Interaction (SSI) considerations significantly enhances the wind resistance of buildings. Specifically, the use of X-bracing on buildings situated on sloping terrain improves the building's ability to resist top-story displacements, reduce story drifts, and decrease story shear forces, particularly in the upper floors. This demonstrates that the integration of slope angle and strategic bracing can optimize a building's structural stability against wind forces.

Seung Yong Jeong, et al (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.

Supraja Parsa et al (2021) the research you are describing focuses on understanding the seismic behavior of multi-story buildings constructed on sloping ground, particularly in hilly regions, and comparing them to buildings on flat ground. This study is important as buildings on slopes are subject to different forces, and they tend to behave differently in terms of stability and response to earthquake loads compared to buildings on flat terrain. The main aim is to study the seismic behavior of buildings located on sloping grounds at different angles (5° and 10°) and compare them with buildings constructed on flat ground. The analysis focuses on how these buildings behave during earthquakes, specifically in terms of displacement, moments, shear, and story drifts. Buildings on sloping terrain are often irregular and unsymmetrical both horizontally and vertically. This asymmetry increases torsional coupling and can lead to more severe damage during an earthquake. Sloping sites increase the vulnerability of buildings to seismic forces, as the ground itself can amplify ground motion, and the building's irregularity may lead to more significant dynamic effects during an earthquake. The study looks at two different sloping angles of the terrain (5° and 10°). The angle of the slope has a direct influence on how the structure responds to seismic forces, especially in terms of its stiffness and distribution of loads. The study focuses on buildings located in **Zone V,** which is the region with the highest seismic risk according to Indian seismic zone classifications. This makes the study particularly relevant in areas prone to significant earthquake activity.

Anjeet Singh Chauhan et al. (2021) titled *"Seismic response of irregular buildings on sloping ground"*, investigates the seismic performance of a G+10 RCC Step back building with varying degrees of slope inclination (20°, 30°, 40°, and 45°). Four different models of the building frame are analyzed, each with distinct irregularities. As the angle of slope increases, several seismic parameters (mode period, base shear, story displacement, and store drift) increase for all models. However, **story shear** decreases with the increase in slope angle. With mass irregularity, proves to be the most vulnerable in seismic conditions, especially at a 45° slope, due to higher mode periods, displacement, and drift values. With diaphragm irregularity, shows better performance at a 20° slope, where it demonstrates the lowest seismic responses.

Ted Stathopoulos et al (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, Euro code, 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.

D.N. Kakde et. al. (2020) the base response can be assessed in terms of lateral displacements and forces at the base of the structure. SAP-2000 can simulate the wind loads applied to the building and the resulting forces transmitted through the foundation. The effect of the sloping ground should also be accounted for, as it may affect the distribution of forces. 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. The time period of the structure (the natural frequency) is important because it determines how the building will respond to dynamic forces like wind. Structures on sloping ground may have altered vibrational characteristics due to changes in mass distribution, stiffness, and boundary conditions. SAP-2000 can provide a mode shape and the corresponding time period to assess how the structure will resonate under wind loads. The displacements of the structure during strong wind conditions are a crucial factor in determining performance. You can evaluate both lateral and vertical displacements at different levels of the building. Displacements are especially critical in terms of serviceability (ensuring the structure remains functional) and safety. In SAP-2000, wind loads can be defined using various methods, such as the ASCE 7 wind load provisions, or by specifying the load directly through force or pressure coefficients based on the shape and height of the structure. You can simulate a variety of wind conditions (constant or gusty wind) to determine the structure's ability to resist wind-induced forces.

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.

Conclusion:

Earthquakes occur due to ground motion, which is measured by the Richter scale. The shaking of the ground during an earthquake can cause significant damage to building structures. To mitigate these effects, it's crucial to understand the properties of earthquakes and predict the structural response. This involves analyzing seismic forces and their impact on buildings to design more resilient structures. When comparing the story displacement under earthquake forces, it is observed that the displacement in the Y direction, when subjected to EQY forces, is higher than that in the X direction. This can be attributed to the reduced support in the Y direction, which leads to greater flexibility and, consequently, higher displacement. These points align with the importance of considering the directionality of seismic forces, building geometry, and the presence of lateral load-resisting elements like shear walls in earthquake-resistant design.

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