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Seismic Analysis of Irregular Builiding on Sloped Terrain with Varying Shear Wall Configuration - A Literature Review

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ABSTRACT— -

Because of the inconsistencies in elevation and plan, structures situated on sloping terrain are extremely susceptible to earthquakes. Because they are often uneven and torsionally linked, structures on hill slopes in earthquake-prone areas are particularly vulnerable to serious damage from ground motion during an earthquake. Additionally, dynamic analysis must be performed in order to ascertain the building's maximal dynamic reaction for this kind of structure. The mass and stiffness of the building at each level determine the modal periods and frequency of the building in any mode. When a building is built on sloping terrain, the mass of the structure will vary at each level since the plan area will not stay the same. Studying the dynamic behavior of buildings built on sloping terrain is crucial because, in addition, the length of the column varies at different floor levels, causing the column's stiffness and the building's stiffness to alter at each floor. Taking into account the various shear wall configurations examined by earlier researchers, an effort has been made to investigate the behavior of irregular structures resting on sloping ground in the current work. The findings highlight the criticality of the ground's slope angle on irregular structures. It also becomes clear how important it is to take the shear wall system's location into account. This study demonstrates that irregular buildings provide a vulnerable reaction to earthquakes on leveled and sloping terrain.

Keywords: Irregular RC Building, Sloping Ground, Shear wall, Drift, Displacement, Time Period, Base Shear.

1. Introduction -

Building on sloping terrain has become more common in hilly regions due to the lack of plain land. The mass and rigidity of the buildings in both the horizontal and vertical planes determine how they behave during an earthquake. Step-back and set-back construction methods result in the majority of buildings built on hill slopes being asymmetrical and uneven. Shear, torsion, and uneven column heights within a storey are among the unique structural and constructional issues that these buildings are likely to encounter. These issues cause a significant variance in the stiffness of columns within the same storey. The short column is more likely to sustain damage and is subject to significantly greater lateral stresses. A parametric analysis has been carried out on several buildings using Etabs to highlight the behavioral differences, which may also be influenced by the properties of the locally accessible foundation material. Current building codes, such as IS:1893 (Part 1):2002 and IS:1893 (Part 1):2016, recommend a thorough dynamic analysis of these kinds of structures on various types of soil, including soft, medium, and hard soil. It is crucial to use static or dynamic analysis to forecast the force and deformation demands that severe earth motions will place on structures and their components in order to evaluate the design's acceptability.

Real estate development has intensified in the hilly region due to economic prosperity and growing urbanization. As a result, the hilly region's population density has significantly expanded. Therefore, the development of multi-story structures on hill slopes in and around the cities is in high demand. In hilly areas, buildings with adobe burnt brick, stone masonry, and dressed stone masonry are typically constructed on level ground. There is an urgent need to build on hill slopes because there is relatively little level ground in hilly areas. The only practical option to meet the growing demand for residential and commercial activity is to construct multi-story R.C. Frame structures on a hillside. It has been noted from previous earthquakes that, despite being built to protect residents from natural dangers, buildings in hilly areas have collapsed due to high demand. Therefore, the greatest care should be made to make these buildings earthquake resistant while implementing the practice of multi-story buildings in these mountainous and seismically active places.

The purpose of this study is to compare the positioning of shear walls in multi-story reinforced concrete buildings on sloping terrain. Because seismic stresses are distributed more uniformly in buildings on level ground, design optimizations are comparatively easier. On the other hand, because of the differing heights, constructions on sloping ground experience torsional irregularities, uneven settling, and asymmetrical load distribution. Because of these special circumstances, the location and design of the shear walls must be carefully considered in order to improve the building's seismic performance.

Engineers and designers will be guided toward techniques that improve earthquake resistance by the study's findings, which will offer a substantial grasp of the optimal way to build shear walls in structures with sloping terrain [8]. In order to make buildings stronger and safer and reduce the chance of catastrophic collapses, this research attempts to enhance building standards and design methods in seismically active areas. Critical performance metrics, including as base shear, narrative drift, torsional anomalies, and overall structural response, were analyzed. Finding shear wall sites that reduce torsional impacts and improve earthquake resilience is the aim. The results will help structural engineers create safer structures and help strengthen design standards and guidelines for areas that are vulnerable to earthquakes [9].

2. OBJECTIVES OF THE STUDY

One helpful metric that is in charge of correlating the seismic elastic response of reinforced concrete structures is structural stability. The current study's goal is to assess earlier studies and ascertain how different R.C. frames built on sloping terrain are affected by slope. The impact of these characteristics on the seismic performance of building frames is also investigated. Additionally, an effort is made to comprehend the usefulness and efficacy of this study as well as how it affects the structure.

3. Literature Review –

The static and dynamic study of such structures with varying soil effects and sloping configurations has been the subject of numerous studies. The studies also indicate that when such a condition arises, the seismic design of such a building faces challenges. The methods used, findings, and a few of the data from earlier investigations have all been covered here. The application of the set-back and step-back systems in multi-story buildings has been the subject of numerous research studies. This review explains the features of the constructions caused by the sloping terrain and the change in the best locations for the shear wall.

"B.G. Birajdar1, S.S. Nalawade SEISMIC ANALYSIS OF BUILDINGS RESTING ON SLOPING GROUND", 13th World Conference on Earthquake Engineering, Vancouver, B.C., Canada, August 1-6, 2004, Paper No. 1472" assumed that the materials were homogeneous and isotropic. It is assumed that floor diaphragms are rigid.P-delta creep and shrinkage effects were not taken into account when using M25 concrete. For columns, axial deformation was taken into account. According to IS-1893:2002, the torsional effect was taken into account.According to IS 1893:2002, seismic analysis was carried out using the Response Spectra Method.In seismic zone III, the standard moment-resisting frame was used for all of these kinds of buildings. The importance factor was set at one, and the response reduction factor at three.Damping of 5% was taken into account.

"Pandey A.D et.al (2011) "Seismic Soil -Structure Interaction of Buildings on Hill Slopes", Vol 2 No 2, International Journal of Civil and Structural Engineering" : Five structures with various configurations and soil conditions have undergone reaction spectrum analysis (RSA) and static pushover study. These structures were examined using equivalent springs for hard, medium, and soft soil types. The response correction factor was calculated by taking into account the displacement from both pushover analysis and RSA. The pushover analysis's displacement was higher than the RSA's displacement. As the correction factor decreases, the value of T rises.

"Y.Singh et.al(2012) - Seismic Behavior of Buildings Located on Slopes-An Analytical Study and Some Observations from Sikkim Earthquake of September 18,2011", 15WCEE LISBOA 2012" : In terms of interstory drift, fundamental period of vibration, plastic hinge creation, and column shear, dynamic analysis of hill structures with various configurations and sloping angles of 45 degrees was contrasted with regular structures on a plain ground. Analysis of both linear and non-linear time histories was done. Compared to buildings on level ground, buildings on hills have distinct dynamic personalities. Torsional irregularity was seen as a result of the center of mass and center of stiffness shifting with floor level due to the vertical and horizontal irregularities on a sloping ground. On a hillside, story shear was greater, leading to shear collapse.

"S.M.Nagargoje and K.S.Sable Seismic performance of multi-storeyed building on sloping ground", Elixir International Journal, 7 December 2012" Using the Seismic Coefficient Method in accordance with IS 1893:2002, the seismic behavior of these buildings situated in seismic zone III was examined.The importance factor was set at one, and the response reduction factor at five. Every kind of building has at least six modes examined.

"Babu et al. (2013) "*Pushover analysis of unsymmetrical framed structures on sloping ground*" International Journal of Civil, Structural, Environmental and Infrastructure Engineering Research and Development (IJCSEIERD) ISSN 2249-6866 Vol. 2 Issue 4 Dec - 2012 45-54" carried out pushover analyses of a variety of symmetric and asymmetric structures built on both level and sloping terrain. They used structures with various plan symmetry and asymmetry combinations with varying bay sizes to perform their analysis. They took into consideration a four-story structure with one story above ground level and built at a thirty-degree slope. According to pushover study, they found that the short column was subjected to the highest degree of severity and lay outside of collapse prevention (CP). They calculated base shear to be 2.77*103 kN and displacement to be 104 mm. They created pushover curves using the X-axis for displacement and the Y-axis for base shear based on these findings, and they provided a number of comparisons for the scenarios they looked at. They discovered that the symmetric structure's maximum displacement up to failure limit is 70%, while the asymmetric building's is 24% greater than the structure on plain ground. They came to the conclusion that elevation irregularity is more significant for construction than plan irregularity.

"Halkude et al. (2013) "*Seismic Analysis of Buildings Resting on Sloping Ground With Varying Number of Bays and Hill Slopes*" International Journal of Engineering Research and Technology ISSN:2278-0181,Vol.2 Issue 12, December-2013" carried out seismic analyses of structures with different numbers of bays and slope inclinations that are situated on sloping terrain. They investigated the building's dynamic properties, such as base shear, top storey displacement, and natural time period, in relation to variations in the number of stories and bays along the hillside and slope. They took into consideration a step-back structure with four to eleven stories and three to six bays oriented longitudinally. They have retained the single bay in the

Y-direction since they have not taken into account the variance of bays in the transverse direction. 16.32°, 21.58°, 26.56°, and 31.50° slope angles were measured using the horizontal and seismic zone III. Across all layouts, it was found that base shear rises as the number of stories and bays grows while decreasing when the slope angle increases. Step-back buildings have a larger base shear than step-set-back buildings when compared within different configurations. Additionally, they discovered that the time period grows with the number of stories in both designs increases, whereas the time period reduces in step set back buildings and increases with the number of bays in step back buildings. The time period in all configurations decreases as the slope angle increases because the building becomes more rigid. The displacement of the top storey decreases as the hill slope increases, increases as the number of storeys grows, and decreases as the number of bays increases.

"Prasad Ramesh Vaidya (2014) [4] "Seismic analysis of building with shear wall on sloping ground" ***International Journal of Civil and Structural Engineering Research ISSN 2348-7607 (Online)*****, 2(2), pp: (53-60), (2014)"** – The seismic performance of shear wall structures on sloping terrain is examined in this study. Understanding the behavior of the building on sloping ground for different shear wall positions and researching the efficacy of shear walls on sloping ground are the primary goals. Four mathematical models have been used to study building performance. The first model is a frame-type structural system, while the other three are dual-type (shear wall-frame interaction) systems with three distinct shear wall locations. The response spectrum analysis is performed using SAP 2000, a finite element program. This research presents the building's performance in terms of displacement, story drift, and maximum forces in columns.

"Sujit Kumar et al. (2014)] "The effect of sloping ground on structural performance of RCC building under seismic load" ***International Journal of Science, Engineering and Technology*****, 2(6), (2014)"** – He investigated and compared the seismic analysis of a G+4 story RCC building on several slope angles, such as 7.50 and 150, with the same on level ground. According to IS: 1893-2002, seismic forces are taken into account. STAAD Pro v8i is a structural analysis program used to investigate how sloping land affects a building's performance during an earthquake. The linear static approach has been used for seismic analysis. The purpose of the analysis is to determine how sloping ground affects structural forces. To measure the effects of different sloping terrain, the axial force, bending moment in columns, and the horizontal reaction, bending moment in footings, are thoroughly examined. It has been noted that shorter footing columns draw more forces due to a significant increase in their stiffness, which raises the bending moment and horizontal force (also known as shear) considerably. Because of the influence of sloping land, the section of these columns should be built for modified forces. The current study highlights how important it is to properly construct structures that rest on sloping terrain.

"Prashant and Jagadish (2015) "***Seismic Response of one way slope RC frame building with soft storey*****" International Journal of Emerging Trends in Engineering and Development Issue 3, Vol.5" -** investigated the seismic behavior of a soft-story, one-way slope RC building. Their work has been concentrated on buildings with and without infill walls, or bare frames. In a ten-story building with bare frames and and without infill walls, they performed pushover analysis. The structures had five bays along the slope and were positioned at a 27-degree inclination to the horizontal. Special moment resistant frames (SMRFs) were the frame system under consideration. According to this study, a structure with bare frames takes 1.975 seconds, which is roughly 96–135% longer than a building with infill walls. This is because the bare frame construction is more rigid. They also noted that because of the bare frame's decreased rigidity and lack of an infill wall, the building moves more. Additionally, they discovered that the base shear in infilled frames is almost 250% greater than that of naked frames. As a result, the bare frame model with soft story has greater plastic hinge formation.

"**Sripriya Arjun and Arathi S. (2015) "Dynamic Characteristics of RC Buildings on Hill slopes"** ***International Journal of Science and Research (IJSR)*** **ISSN (Online): 2319-7064 Index Copernicus Value 6.14, pp. 1116-1119, (2015)"** – This study uses the structural analysis tool STAAD Pro to perform Response Spectrum analysis in accordance with IS:1893 (part 1): 2002 in order to analyze the behavior of a G+3 story sloped frame building with a step back set back configuration for sinusoidal ground motion with different slope angles, namely 16.7°, 21.8°, 26.57°, and 30.96°. The displacement of the top story and the base shear were the outcomes. Short columns are found to be more impacted during earthquakes. The step-back setback building configuration is appropriate for building construction on sloppy ground, according to the assessments.

"Nilesh B.Mevawala1, Dr. Atul K.Desai2, Free Vibrating Analysis of Building Resting on Sloping Ground with Different Mode Shapes International Journal of Civil and Structural Engineering Research ISSN 2348-7607 (Online) Vol. 4, Issue 1, pp: (26-31), Month: April 2016 - September 2016" - The dynamic characteristics of the buildings located in the hilly environment are examined in this study. The way a building reacts to lateral forces like wind and earthquakes depends on its dynamic qualities when it is built in a hilly terrain. The reaction of buildings built on sloping terrain differs from that of buildings built on level terrain. The mass and stiffness of the building at each level determine the modal periods and frequency of the building in any mode. When a building is built on sloping terrain, the mass of the structure will vary at each level since the plan area will not stay the same.

"S.P. Pawar et al. (2016) "Effect of positioning of RC shear wall of different shapes on seismic performance of building resistance on sloping ground" ***International Journal of Civil Engineering and Technology (IJCIET)*****, 7(3), pp. 373–384, (2016)"** – This study is centered on the seismic behavior of structures with shear walls that are situated on sloping terrain. It has been noted that structures on sloping terrain behave differently seismically than other types of buildings. These structures' different storeys slant back toward the hillside. The majority of research concur that buildings situated on sloping terrain experience greater displacement and base shear than buildings situated on level terrain, and that shorter columns are more likely to attract forces and sustain damage during an earthquake. Buildings with a step back may be more susceptible to seismic stimulation. They come to the conclusion that the shortest columns of buildings on sloping terrain are most rigid. Compared to other transverse directions, the base shear and displacement are greater along the slope. Out of all the layouts, the straight form (or rectangular) shear walls configuration is the most effective at preventing lateral displacement.

"Anjeet Singh Chauhan, Rajiv Banerjee - SEISMIC RESPONSE OF IRREGULAR BUILDING ON SLOPING GROUND, International Journal of Advanced Research in Engineering and Technology (IJARET) 4Volume 12, Issue 5, May 2021, pp. 181-202, Article ID: IJARET_12_05_017 "- The purpose of this paper is to analyze a G+10 RCC Stepback building with 3.6-meter-tall stories and horizontal angles of inclination of 20°, 30°, 40º, and 45° on sloping ground in seismic zone V. Two of the top stories will be used for the setup of machinery equipment, which creates mass irregularities, and the ground to the top of the storey at the edge of the planned building will be used as an opening for natural lighting and a staircase, which creates diaphragm irregularities. In order to compare the buildings based on their dynamic response properties, such as mode Period, Base Shear, Story deflection, Story drift, and Story shear, as well as determine the frame vulnerability in irregularities of structure on the sloping ground, the Stepback building is analyzed and modeled using Etabs software in accordance with IS 1893:2016.

"Poorna chandra B1 Abhishek M,2 Rohith M 3 Rahul V H, Seismic Analysis of RCC Buildings Resting on Sloping Ground with Varying Number of Bays and Hill Slopes, International Journal of Advances in Engineering and Management (IJAEM) Volume 4, Issue 7 July 2022, pp: 1342-1349" - The current study aims to investigate the impact of slope angle changes for structures situated on sloping terrain, taking into account both fixed and flexible (SSI) bases. The study is carried out using the nonlinear static method (NLSM), time history method (THM), response spectrum method (RSM), equivalent static force method (ESFM), and nonlinear time history method (NLTHM). The findings highlight the need of increasing the slope angle both with and without taking SSI into account. It also becomes clear how important it is to take SSI into account while doing seismic analysis.

"K Veera Babu 1, S Siva Rama Krishna 2, Venu Malagavelli 3 - Seismic analysis of Multi storey Building on Sloping Ground and Flat Ground by using ETABS - IOP Conf. Series: Earth and Environmental Science 1130 (2023) 012004 IOP Publishing doi:10.1088/1755-1315/1130/1/012004" - Investigating the behavior of structures on flat and sloping terrain is the main objective of the current project. Building layouts for hilly terrain differ from those for plain terrain. In contrast to lowland structures, hill structures are asymmetrical in both the horizontal and vertical planes, highly irregular, and torsionally linked. They are therefore susceptible to serious harm in the event of an earthquake. This research aimed to investigate the behavior of a multi-story building with two different slope degrees and compared it to flat ground. by considering Earthquake Zone II. Structures situated on flat and sloping terrain are contrasted. The ETABS structural analysis application is used to help generate the models. Analysis is done using response spectrum analysis. The results of the analysis are tabulated and analyzed, including storey shear, storey drifts, moments, and displacement.

"N. C. Ghangare1* , S. S. Meshram1 and V. U. Wasalwar1 - Optimal placement of shear wall in multistorey buildings on sloping ground, IOP Conf. Series: Earth and Environmental Science 1409 (2024) 012035 IOP Publishing doi:10.1088/1755-1315/1409/1/012035" - Finding the best location for shear walls in multistory buildings with sloping terrain is the primary goal of this research effort. A ten-story RCC structure with slopes and a zone IV seismically active location. The equivalent static technique with IS 1893 (PART–I):2016 is used to compute an earthquake load. STAAD Pro V8i was the program used for these tests. A thorough analysis was conducted to look at a number of elements, such as G+10 story building on sloping terrain, average displacement, period, story shear, story drift, and reinforcement decrease. For multistory buildings to successfully withstand lateral stresses, shear walls are now essential. The shear wall applied structure and the bare frame construction are contrasted.

"Sheshadri G1, Arun Kumar S R2, Bhandary R P1* - Comparative Analysis of Different Locations of the Shear Wall in Multi-storey Rc Building on Sloping Ground With Flat Ground https://doi.org/10.21203/rs.3.rs-4924944/v1 2024" - The seismic behavior of G+15-story reinforced concrete (RC) buildings is examined in this study, with a focus on the effects of shear wall placement on structures located on both level and sloping sites. In high-rise buildings, shear walls provide lateral stability and resistance to seismic forces. The efficiency of several shear wall systems in diverse geological contexts is evaluated in this study. Because of the stiffness and mass distribution in these buildings, there are variations in the centers of mass and rigidity in both vertical and horizontal directions. This discrepancy may lead to increased seismic damage, especially in buildings located on sloping terrain where torsional reactions are more obvious. Shorter columns are more susceptible to stress and damage, and such structures frequently encounter larger displacements and base shear forces. Furthermore, structures that have setbacks—where the floors slope back toward the hillside—may be particularly vulnerable to earthquakes. This study compares the performance of structures on level ground to those on slopes of 10°, 20°, and 30° while analyzing different shear wall positions. With ETABS 19.1.0 software, the Equivalent Static Method and Response Spectrum Method were employed in the analysis. Story displacement, story stiffness, and base shear values were the most important measurements. The results shed light on how to best position shear walls to increase seismic resilience in a variety of terrain types.

4. Conclusion –

According to the aforementioned literature on structural systems with shear walls at various locations built on uneven, sloping terrain, the shorter columns are more likely to be subjected to forces and sustain damage during earthquakes. Additional lateral earth pressure at different elevations, slope instability, and variable soil profiles that result in uneven foundation settling are some of the other issues related to hill constructions. Because the columns of hill structures lie at varying levels on the slope, the analysis of buildings in hilly regions differs slightly from that of buildings on level ground. These buildings require torsion-al analysis in addition to lateral forces under the action of earthquakes because their mass and stiffness vary along the vertical and horizontal planes, causing the center of mass and center of rigidity to not coincide on different floors. The aforementioned factors lead to the conclusion that in earthquake-prone areas, the performance of such structures must be closely monitored.

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