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Structural Behavior of Sloped Buildings Under Seismic Loading: Current Knowledge and Future Directions

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Abstract- This study investigates the seismic response of buildings located on slopes, which are more susceptible to seismic conditions compared to those on level ground. The irregular shapes of sloped buildings, both vertically and horizontally, can lead to torsional coupling and severe damage during seismic events. The study focuses on the dynamic characteristics of G+3 multi-storey reinforced concrete buildings on sloped hills by varying the slope angles, with the main goal of examining how sloped buildings respond to sinusoidal ground movement and earthquake activity. The differences in base shear and displacement based on variations in the sloped building frame are investigated, and the slope angle resulting in less displacement and safer conditions for increasing building height is determined. The study employs various code-based procedures for seismic analysis, including Equivalent Static Analysis, Response Spectrum Analysis, Time History Analysis, and Push Over Analysis. The natural periods of structures are found to depend on the distribution of mass and stiffness throughout the building, with taller buildings having larger central translational natural periods and structures swaying in the directions where they are most flexible. The study highlights the need for thorough examination of structures in seismically active areas, especially in developing countries like India, where there is a significant amount of hilly terrain classified as seismic zones IV and V.

Key Words: Sloped buildings, Seismic loading, Irregular shapes, Ground motion, Torsional coupling, Hill areas, Response spectrum

1. INTRODUCTION

Earthquakes create random motion in the ground, which can occur in any of the three perpendicular directions. This motion causes vibrations in structures. The structure's response to these vibrations depends on several factors, including the soil type under the foundation, the materials used, the shape and size of the building, and the intensity and duration of the ground movement.

Seismic tremors are unpredictable and can be devastating. While a structure may not directly cause loss of life during an earthquake, damage to the building can lead to collapse, resulting in casualties and loss of property. Structures on hills differ from those on flat land because they have irregular shapes. Constructing in seismically active areas exposes buildings to higher shear forces and torsion compared to standard construction. The widespread destruction of both low and tall buildings during tremors highlights the need for thorough examination, especially in developing countries like India. Structures under seismic forces are always at risk for damage, and if an earthquake occurs, sloped structures face an even greater risk due to increased lateral forces acting on shorter columns on the steep side. In northern and northeastern India, there is a significant amount of hilly terrain classified as seismic zones IV and V.

OBJECTIVE:

- This project investigates the dynamic characteristics of G+3 multistory reinforced concrete buildings on sloped hills by varying the slope angles. The main goal is to study how sloped buildings respond to sinusoidal ground movement and earthquake activity. Examine the differences in base shear and displacement based on variations in the sloped building frame.
- Determine which slope angle results in less displacement and is safer for increasing building height.

2. LITERATURE REVIEW

N. Janardhan Reddy (2015) examined the seismic behavior of multi-storey structures with shear walls using ETABS. His work shows that adding shear walls generally reduces displacement because they enhance structural stability and resist lateral forces. Better performance is noted with reduced displacements in both x and y directions when analyzed using the response spectrum method.

Mohit Sharma (2014) studied a G+30 multi-storey building. Both static and dynamic analyses were conducted using computer software STADD-Pro, applying parameters from IS 1893-2002, part 1, for zones 2 and 3.

Kasliwal Sagar K. analyzed two sixteen-story multi-storey buildings using ETABS and SAP2000 for seismic zone V in India. The study incorporates both dynamic linear response spectra and static nonlinear analysis. It finds that multi-storey shear walls are effective in resisting lateral forces during earthquakes. Properly positioned shear walls can minimize damage from seismic tremors and wind.

Sreerama and Ramancharla (2013) observed that varying slope angles of 0°, 15°, 30°, 45°, and 60° resulted in shorter columns attracting greater forces due to increased stiffness. The base response for shorter columns rises with steeper slopes, and the natural period of the structure decreases with an increasing slope angle, as shorter columns resist most story shear while longer columns are more flexible and cannot manage the loads as effectively.

3. MATERIALS AND METHODS

Code-based procedures for seismic analysis:

- Equivalent Static Analysis (Linear Static)
- Response Spectrum Analysis (Linear Dynamic)
- Time History Analysis (Non-Linear Dynamic)
- Push Over Analysis (Non-Linear Static)

Equivalent Static Analysis: All structures must consider the dynamic nature of seismic loads. For typical buildings, analysis using equivalent linear static methods is often sufficient, as allowed by many codes for normal, low- to medium-rise structures. This starts with estimating the peak seismic load based on parameters in the code.

Response Spectrum Analysis: This is a dynamic method of analysis. The structure must be represented by a mathematical or computational model to yield reasonable results, particularly when using response spectrum techniques with modal analysis. At least three modes of the structure's response should be considered unless it can be shown that either the second or third mode has negligible impact.

Time-History Analysis: This method calculates the dynamic response of the structure at each time interval using recorded ground motion data from past earthquakes. This type of linear time-history analysis overcomes the limitations of response spectrum analysis, assuming nonlinear behavior is not included. This approach requires significantly more computational effort than response spectrum analysis and at least three representative seismic motions must be included to account for variability in design motion frequencies.

Push Over Analysis: This is a capacity-based analysis aimed at controlling structural damage. The analysis incorporates several intrinsic properties from FEMA 356 for concrete elements. The study will use nonlinear programming in ETABS 2013 to predict displacement levels and corresponding base shear at which the structure first yields. The primary aim is to develop a displacement versus base shear diagram.

4. CONCLUSION

In summary, the natural periods of structures depend on how mass and stiffness are distributed throughout the building. Some significant trends concerning natural periods of structures with standard geometries are:

- Natural periods decrease with increased stiffness.
- Natural periods increase with greater mass.
- Taller buildings have larger central translational natural periods.
- Structures tend to sway in the directions where they are most flexible and have larger translational natural periods.
- Natural periods are influenced by the amount and distribution of unreinforced masonry infill walls.

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