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COMPARATIVE SEISMIC ANALYSIS OF G+15 RCC BUILDING WITH DIFFERENT PLAN SHAPES ON PLAIN AND SLOPING TERRAIN USING STAAD PRO

Sanskar Sahu[1], Mr. Sumnottam Patel[2]
[1] *M.Tech Scholar, Structural Engineering, Department of Civil Engineering, Madhyanchal Professional University, Bhopal*
[2] *Assistant Professor, Department of Civil Engineering, Madhyanchal Professional University, Bhopal (M.P.), India*

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Corresponding Author:
Mr. Sumnottam Patel

Abstract:

Earthquakes are among the most destructive natural hazards, causing extensive damage to buildings, bridges, and other civil engineering structures. Unlike gravity loads, earthquake forces are dynamic in nature and produce horizontal as well as vertical ground motions that induce inertia forces throughout a structure. The magnitude of these forces depends on several factors, including the mass, stiffness, height, structural configuration, foundation conditions, and characteristics of the supporting soil. Inadequate consideration of these factors during design may result in excessive deformation, structural damage, or complete collapse.

India is located in one of the most seismically active regions of the world. Approximately 58% of the country's land area falls under Seismic Zones III, IV, and V as classified by IS 1893 (Part 1):2016. Rapid urbanization, increasing population, and limited availability of land have led to the construction of multi-storey and high-rise reinforced cement concrete (RCC) buildings in both metropolitan cities and hilly regions. Consequently, the seismic safety of such structures has become a major concern for structural engineers.

Keywords: rcc ,high rice building

1. INTRODUCTION

1.1 General

Earthquakes are among the most destructive natural hazards, causing extensive damage to buildings, bridges, and other civil engineering structures. Unlike gravity loads, earthquake forces are dynamic in nature and produce horizontal as well as vertical ground motions that induce inertia forces throughout a structure. The magnitude of these forces depends on several factors, including the mass, stiffness, height, structural configuration, foundation conditions, and characteristics of the supporting soil. Inadequate consideration of these factors during design may result in excessive deformation, structural damage, or complete collapse.

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High-rise RCC buildings are generally designed to resist gravity loads, wind loads, and earthquake loads. However, earthquake loading governs the design in many regions because seismic forces increase with building mass and height. The response of a tall building depends on its dynamic characteristics, including natural frequency, mode shapes, damping ratio, and lateral stiffness. Therefore, dynamic analysis is essential to evaluate structural behavior accurately.

One of the most important factors influencing seismic performance is the plan configuration of the building. Buildings having regular geometric plans usually possess uniform mass and stiffness distribution, resulting in better lateral load resistance. In contrast, irregular plan configurations such as L-shaped, T-shaped, and U-shaped buildings introduce eccentricity between the centre of mass and the centre of rigidity. This eccentricity produces torsional effects during earthquakes, leading to unequal force distribution among structural members and increased lateral displacement. Consequently, irregular buildings often experience greater seismic demand than regular buildings.

Terrain conditions also play a significant role in determining the seismic response of structures. Buildings constructed on plain terrain generally have uniform foundation levels and equal column heights, resulting in relatively uniform stiffness distribution. Conversely, buildings located on sloping terrain are characterized by unequal column heights, stepped foundations, and varying stiffness along the height of the structure. These features introduce vertical irregularities that significantly alter the dynamic behavior of the building during seismic excitation.

In mountainous regions, step-back buildings are commonly adopted to accommodate the natural slope of the ground while reducing excavation and retaining work. Although such configurations are economical and practical from a construction perspective, they exhibit different seismic characteristics compared with buildings constructed on level ground. The variation in column height and stiffness distribution changes the transfer of earthquake forces and affects important response parameters such as base shear, displacement, natural time period, and member forces.

To evaluate these complex structural responses, advanced numerical analysis software is widely employed. STAAD Pro is one of the most commonly used structural analysis and design programs in professional engineering practice. The software enables three-dimensional modelling, load definition, dynamic analysis, and detailed evaluation of structural behavior under different loading conditions. Response Spectrum Analysis available in STAAD Pro provides a realistic assessment of earthquake response by considering the contribution of multiple vibration modes, making it more suitable than simple static analysis for high-rise buildings.

The present study investigates the seismic performance of G+15 RCC buildings with Square, Rectangular, L-shaped, T-shaped, and U-shaped plan configurations under plain terrain, sloping terrain, and step-back terrain conditions. The structural models are analysed using the Response Spectrum Method in accordance with IS 1893 (Part 1):2016. The comparative evaluation is carried out using parameters such as design base shear, maximum storey displacement, fundamental natural time period, axial force, shear force, torsion, and bending moment. The results obtained from this investigation are expected to identify the most efficient building configuration and terrain condition for earthquake-resistant design of high-rise RCC buildings.

The outcomes of this research will contribute to the understanding of the influence of plan irregularity and terrain characteristics on seismic behavior. The findings will also provide useful recommendations for structural engineers involved in the planning, analysis, and design of multi-storey RCC buildings in seismic-prone plain and hilly regions.

1.2 Earthquake and Seismic Hazard

An earthquake is a sudden release of energy within the Earth's crust caused by the movement of tectonic plates along geological faults. This energy propagates in the form of seismic waves, producing ground vibrations that generate dynamic forces in structures.

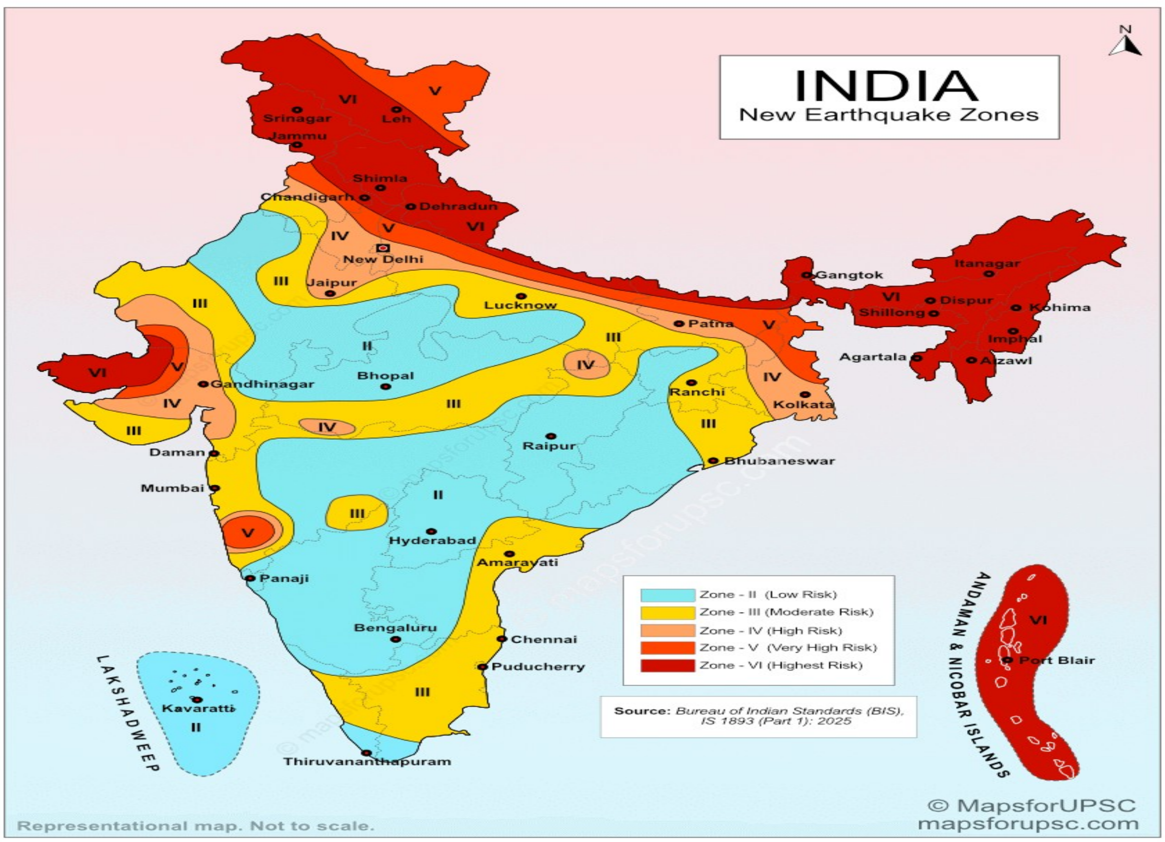

Fig 1.1 Indian Earthquake Zone Map

The intensity of an earthquake depends on several factors, including its magnitude, depth, distance from the epicenter, and local soil conditions. Earthquakes cannot be prevented; therefore, designing structures capable of safely resisting seismic forces is essential.

India is one of the most earthquake-prone countries due to its complex tectonic setting. According to IS 1893 (Part 1):2016, the country is divided into four seismic zones—Zone II, Zone III, Zone IV, and Zone V—based on expected seismic intensity. Regions in Zones IV and V are considered highly vulnerable and require enhanced seismic design measures. During an earthquake, buildings are subjected to inertia forces proportional to their mass and dynamic characteristics. Proper seismic analysis enables engineers to estimate these forces and design structures that can withstand earthquake-induced loading without significant damage or collapse.

CHAPTER 2

LITERATURE REVIEW

2.1 Review of High-Rise RCC Buildings

The rapid growth of urbanization and the scarcity of available land have significantly increased the construction of high-rise reinforced cement concrete (RCC) buildings throughout the world. Compared with low-rise structures, high-rise buildings are more susceptible to seismic forces because of their greater height, flexibility, and dynamic characteristics. Consequently, numerous researchers have investigated the seismic behaviour of high-rise RCC buildings using dynamic analysis methods such as Response Spectrum Analysis and Time History Analysis.

2.1.1 Doğan and Erkan (2024) evaluated the nonlinear seismic response of high-rise reinforced concrete buildings considering different structural plans, foundation systems, and soil–structure interaction. The research demonstrated that both foundation conditions and plan configuration significantly influence seismic response parameters, including displacement, drift, and internal member forces. The authors emphasized that realistic modelling of soil–structure interaction should be considered in the seismic assessment of high-rise buildings to improve design accuracy.

2.1.2 Shamim, Fatima, Alam, Khan, and Siddiqui (2023) investigated the seismic behaviour of reinforced concrete frames with mass irregularity using Response Spectrum Analysis. Their results indicated that mass irregularity increased storey displacement, storey drift, and torsional response when compared with regular buildings. The authors concluded that irregularity in mass distribution should be carefully considered during the seismic design of multistorey RCC structures to achieve satisfactory structural performance.

The available literature indicates that the seismic behaviour of high-rise RCC buildings is strongly influenced by building height, structural configuration, stiffness distribution, plan irregularity, and foundation conditions. Most researchers agree that Response Spectrum Analysis is more suitable than the equivalent static approach for evaluating medium-rise and high-rise buildings because it accounts for higher-mode effects and provides a more realistic representation of earthquake response.

2.1.3 Behera and Parhi (2023) conducted a comparative study on the seismic behaviour of a 32-storey conventional RCC framed building and a diagrid structural system using the Response Spectrum Method. Parameters such as storey displacement, storey drift, storey shear, base shear, and storey stiffness were evaluated. The authors reported that the diagrid system reduced lateral displacement and improved overall seismic performance compared with the conventional RCC frame. The study highlighted the importance of structural configuration in controlling the seismic response of high-rise buildings.

2.1.4 Banerjee, Das, Debnath et al. (2022) presented a study on Response Spectrum Analysis of reinforced concrete buildings using the Complete Quadratic Combination (CQC) method. The authors evaluated the influence of modal combination techniques on the seismic response of RCC structures and observed that higher vibration modes considerably affect the dynamic behaviour of multistorey buildings. The study concluded that Response Spectrum Analysis provides reliable estimates of displacement, base shear, and internal member forces and is suitable for seismic evaluation of high-rise RCC buildings.

CHAPTER 3

METHODOLOGY

3. RESEARCH METHODOLOGY

3.1 Introduction

Research methodology is a systematic procedure adopted to achieve the objectives of a research study through scientific investigation, analysis, and interpretation of results. It provides a structured framework for planning the research, developing analytical models, performing numerical analysis, and evaluating the obtained results. In structural engineering, a well-defined methodology ensures that the analysis is carried out consistently and that the conclusions are based on reliable engineering principles.

The present research focuses on the comparative seismic analysis of G+15 reinforced cement concrete (RCC) buildings having different plan configurations constructed on plain terrain, sloping terrain, and step-back terrain. Modern urban development and the increasing demand for infrastructure in hilly regions have resulted in the construction of high-rise buildings on complex topography. Such buildings often possess plan and elevation irregularities that significantly influence their seismic behaviour. Therefore, understanding the combined effects of plan shape and terrain condition is essential for achieving safe and economical earthquake-resistant designs.

In this study, four different plan configurations—Rectangular, T-shaped, L-shaped, and U-shaped—were selected to investigate the influence of geometric irregularity on seismic performance. Each building configuration was analysed under three different terrain conditions, namely plain terrain, sloping terrain with a 20° slope, and step-back terrain. This resulted in twelve analytical models identified as P1–P4, S1–S4, and SB1–SB4. All structural models were developed and analysed using STAAD Pro CONNECT Edition, a widely accepted structural analysis software based on the finite element method.

The seismic analysis was performed using the Response Spectrum Method in accordance with the provisions of IS 1893 (Part 1):2016. The Response Spectrum Method was selected because it provides a realistic representation of the dynamic response of high-rise and irregular buildings by considering the contribution of multiple vibration modes. The analysis incorporated the effects of dead load, live load, and earthquake load through appropriate load combinations specified in the relevant Indian Standards.

After completion of the analysis, important structural response parameters were extracted from each model, including design base shear, fundamental natural time period, maximum nodal (storey) displacement, axial force, shear force, torsional moment, and bending moment. These parameters were then compared among all building models to evaluate the influence of terrain condition and plan configuration on seismic performance.

The methodology adopted in this research was developed to ensure consistency in modelling, loading, analysis, and comparison procedures. By maintaining identical material properties, loading conditions, and design assumptions for all models while varying only the plan configuration and terrain condition, the influence of these parameters on seismic behaviour can be evaluated objectively. The adopted methodology provides a reliable basis for identifying the most suitable structural configuration for high-rise RCC buildings located in earthquake-prone plain and hilly regions.

3.2 Research Design

The research design adopted in the present study is based on a comparative numerical analysis approach. The primary objective is to evaluate the influence of plan shape irregularity and terrain condition on the seismic performance of G+15 RCC buildings. Since experimental testing of full-scale high-rise buildings is economically impractical, numerical modelling using structural analysis software provides an efficient and reliable alternative for evaluating structural behaviour under earthquake loading.

The study begins with an extensive review of published literature related to seismic behaviour of reinforced concrete buildings, high-rise structures, plan irregularity, sloping terrain buildings, step-back buildings, Response Spectrum Analysis, and the application of STAAD.Pro in structural engineering. The literature review was used to identify the research gap and formulate the objectives of the present investigation.

Based on the identified research gap, four representative building plan configurations—Rectangular, T-shaped, L-shaped, and U-shaped—were selected. These configurations represent commonly used regular and irregular building layouts encountered in practical engineering applications. To investigate the influence of terrain conditions, each plan configuration was modelled under three different ground conditions: plain terrain, sloping terrain with a 20° slope, and step-back terrain. Consequently, a total of twelve three-dimensional structural models were developed.

The geometric dimensions, storey height, material properties, loading conditions, and structural system were maintained as identical as possible for all models to ensure a fair comparison. Only the plan configuration and terrain condition were varied so that their individual influence on seismic behaviour could be evaluated without interference from other structural parameters.

All analytical models were developed using STAAD Pro. The software employs the finite element method to analyse the structural response under static and dynamic loading conditions. Dead load, live load, and earthquake load were assigned according to the provisions of IS 875 and IS 1893 (Part 1):2016. Dynamic analysis was performed using the Response Spectrum Method, which is recommended for high-rise and irregular buildings because it considers modal participation and higher-mode effects.

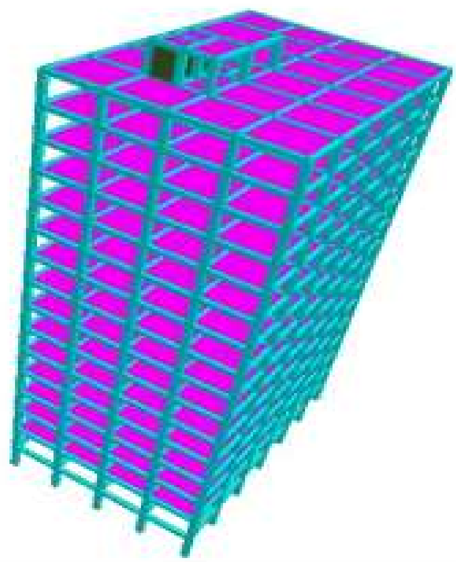

Table 3.1 Twelve three – dimensional Structural model

Model no.	Model Name	Terrain category
1	P1-Rectangular Shape	Plain
2	P2 – T Shape	Plain
3	P3 –L Shape	Plain
4	P4 –U Shape	Plain
5	S1- Rectangular Shape	Sloping
6	S2- T Shape	Sloping
7	S3- L shape	Sloping

8	S4 - U Shape	Sloping
9	SB1-Rectangular	Step Back
10	SB2- T Shape	Step Back
11	SB3- L Shape	Step Back
12	SB3-U Shape	Step Back

Irregular Building	**Story**	**Node**	**Maximum Nodal Displacement (mm)**
Plain Terrain P2	15th Floor	982	69.892
	10th Floor	982	55.509
	1th Floor	672	8.475
Sloping Terrain at 20 Degree S2	15th Floor	1208	68.160
	10th Floor	1168	52.619
	1th Floor	112	16.099
Sloping Terrain with Step Back building SB2	15th Floor	1015	46.739
	10th Floor	705	35.467
	1th Floor	112	9.110

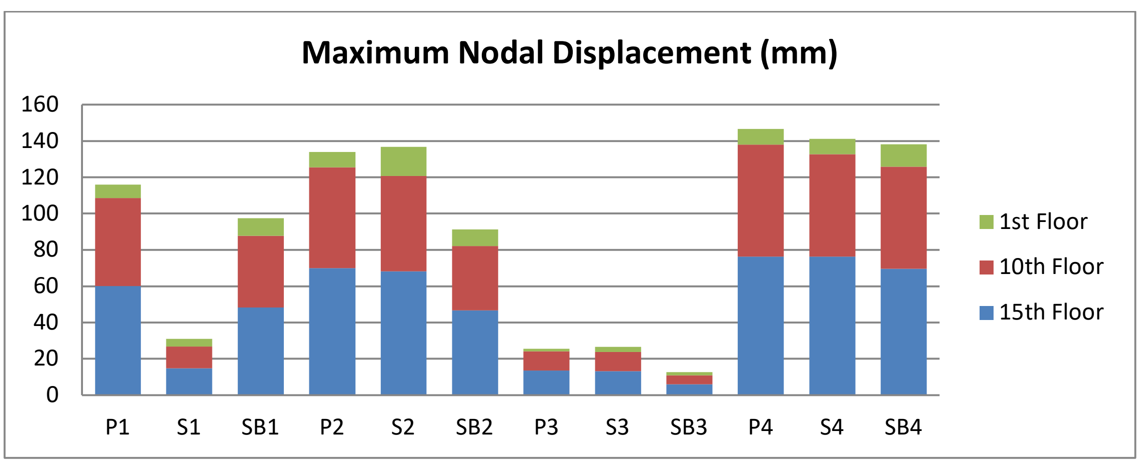

Chart Column Represent Maximum Nodal Displacement for all building cases

CHAPTER 4

RESULTS AND ANALYSIS

RESULTS DISCUSSION

The seismic behavior of G+15 RCC buildings having Rectangular, T, L, and U-shaped configurations was evaluated on plain terrain, sloping terrain, and step-back terrain conditions using Response Spectrum Analysis.

The comparison of base shear indicates that the T-shaped building exhibited the highest base shear values among all configurations in plain, sloping, and step-back conditions, whereas the L-shaped building showed the lowest base shear values. Higher base shear indicates greater seismic force attraction due to structural stiffness and mass distribution.

The comparison of fundamental time period shows that the step-back L-shaped building exhibited the highest natural time period, indicating greater flexibility of the structure. The T-shaped building showed comparatively lower time periods, indicating higher stiffness.

The maximum nodal displacement results reveal that U-shaped and T-shaped buildings experienced the highest displacement values under seismic loading. The L-shaped building demonstrated the lowest displacement values among all building configurations. Buildings located on sloping terrain generally exhibited different displacement patterns due to variation in column heights and irregular stiffness distribution.

The step-back configurations showed improved displacement control in certain cases compared to conventional sloping terrain models. This indicates that proper geometric arrangement on sloping terrain can improve seismicperformance.

Overall, plan irregularity and terrain condition significantly influenced the seismic response of G+15 RCC buildings. Regular configurations showed relatively stable behavior, while highly irregular configurations were more susceptible to displacement and torsional effects.

4.1 Max Base Shear For various building cases

Base shear is one of the most important seismic response parameters used in the design and evaluation of earthquake-resistant structures. It represents the total horizontal seismic force acting at the base of a building during an earthquake. This force is generated due to the inertia of the building mass when the ground experiences seismic motion. During an earthquake, the foundation moves with the ground while the superstructure tends to remain in its original position because of inertia. This relative movement induces lateral forces throughout the structure, which are transferred through slabs, beams, columns, and finally to the foundation. The summation of all these lateral forces at the base of the structure is known as the **base shear**.

In structural engineering, base shear serves as a primary indicator of the seismic demand imposed on a building. It determines the magnitude of earthquake forces that must be resisted by the structural system to ensure stability and safety. A building designed to resist the calculated base shear is expected to perform satisfactorily during the design-level earthquake by preventing collapse and minimizing structural damage. Consequently, the accurate estimation of base shear is fundamental in the seismic design of reinforced concrete buildings.

The importance of base shear can be summarized as follows:

- It represents the total design earthquake force acting on the structure.
- It forms the basis for calculating lateral force distribution at each storey.
- It is used to design beams, columns, shear walls, and foundations against seismic loading.
- It assists engineers in comparing the seismic performance of different structural configurations.
- It provides an indication of the overall stiffness and dynamic characteristics of a building.
- It is one of the principal parameters used to assess the seismic safety of high-rise buildings.
- It helps identify structural configurations that are more efficient in resisting earthquake forces.

Table 4.1 Maximum Base Shear in X &Z direction for
P1 to P4 building Case

Plain Terrain	Base Shear X(KN)	Base Shear Z(KN)
P1	1950.71	1950.71
P2	2598.86	2598.86
P3	533.13	533.13
P4	2124.63	2134.43

Table 4.1 Show the **plain terrain models**, the maximum base shear was observed in **Model P2 (T-shaped building)** with a value of **2598.86 kN** in both the X and Z directions. This indicates that the T-shaped configuration attracts the highest seismic force among the four plan configurations considered on level ground. The increased base shear is primarily attributed to the irregular distribution of mass and stiffness, which results in greater lateral force demand during earthquake excitation. Conversely, **Model P3 (L-shaped building)** exhibited the minimum base shear of **533.13 kN**, indicating a comparatively lower seismic force demand. **Model P1 (Rectangular building)** developed a base shear of **1950.71 kN**, while **Model P4 (U-shaped building)** recorded values of **2124.63 kN** in the X direction

and **2134.43 kN** in the Z direction. The slight difference between the X and Z directions for Model P4 may be attributed to its geometric asymmetry.

CHAPTER 5
CONCLUSION

Based on the seismic analysis of G+15 RCC buildings with different plan configurations on plain terrain, sloping terrain, and step-back terrain using STAAD Pro, the following conclusions are drawn:

- Terrain condition has a significant influence on the seismic behaviour of high-rise RCC buildings.
- The T-shaped building attracted the maximum base shear among all building configurations, indicating higher seismic force demand.
- The L-shaped building recorded the minimum base shear values and comparatively lower displacement responses.
- The U-shaped building exhibited the maximum storey displacement, indicating higher flexibility and seismic vulnerability.
- Step-back buildings performed better than conventional sloping terrain buildings in terms of displacement control for several structural configurations.
- The natural time period increased with structural irregularity, and the maximum time period was observed in the step-back L-shaped configuration.
- Buildings constructed on sloping terrain exhibited greater irregularity effects due to unequal column heights and varying stiffness distribution.
- Plan shape irregularity significantly affects the seismic response of structures, and therefore should be carefully considered during the planning stage.
- Regular building configurations are generally more suitable for seismic-prone regions because of their better stiffness distribution and lower torsional effects.
- For the considered G+15 RCC building models, the L-shaped configuration demonstrated comparatively better overall seismic performance, while the U-shaped and T-shaped configurations were found to be more critical under earthquake loading.
- Proper structural planning, use of shear walls, and dynamic analysis are recommended for high-rise buildings located on sloping terrain.