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Seismic Performance Evaluation of RCC Building Resting on Slopping Land

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Abstract- Sloping terrain is a prevalent feature in many regions of Nepal, often necessitating the construction of buildings on uneven ground. These geographical conditions present unique challenges regarding seismic vulnerability and structural integrity. Buildings on sloping terrain are more challenging to design and construct due to the presence of powerful earthquake loads combined with the forces of the sliding slope itself. This conference paper presents a comprehensive study on the seismic performance of Reinforced Concrete (RCC) buildings situated on sloping land. The main objective of this study was to evaluate the seismic performance of RCC buildings resting on sloping ground. To achieve this objective, a Static Non-Linear Analysis, commonly known as Pushover Analysis, was carried out for building models with different ground slopes. Pushover Analysis is a method used to determine the potential seismic performance of a structure by subjecting it to a gradually increasing lateral load until it reaches a target displacement. This analysis helps in understanding the inelastic behaviour and collapse mechanisms of the structures under seismic loads. In addition to analysing buildings on sloping terrain, a comparative study was conducted between buildings on plain ground and those on sloping ground. The findings of this study indicate that the performance of buildings on plain surfaces is superior to those on sloping ground. The primary reason for this is the uniform distribution of forces and the absence of additional stresses caused by the slope. Among the various configurations of buildings on sloping ground, the study found that buildings constructed in a step-by-step back arrangement exhibit better consistency in seismic performance compared to other configurations. This arrangement helps in distributing the forces more evenly and reduces the occurrence of short columns, which are prone to early hinge mechanisms. As the slope angle increases, the formation of hinge mechanisms occurs earlier in short columns due to the increased stress and force concentration. This early hinge formation can lead to a significant reduction in the structural integrity and seismic performance of the building. In conclusion, the study underscores the importance of careful consideration of slope angles and building configurations in the design of RCC buildings on sloping terrain. By employing appropriate design strategies and conducting thorough seismic performance evaluations, the resilience of buildings in earthquake-prone regions like Nepal can be significantly enhanced.

Index Terms- Building in hill sides, Performance of slope structures, Pushover analysis, Slope land

I. INTRODUCTION

1. Background

Nepal lies in a highly active seismic zone; earthquakes are a frequent phenomenon and cause significant loss of lives and property[1]. In addition to their direct impact, earthquakes also induce additional geo-hazards such as landslides, which further contribute to the loss of lives and property[2] [3][4]. Due to its location in one of the most seismically active regions of the world, Nepal has a long history of earthquakes, Nepal experienced a major earthquake on 25 April 2015 with a magnitude of 7.8, which devastated large parts of the country[5]. Scientists with the Open University say that Nepal's location makes it more susceptible to earthquakes, according to geoscientists[6].[7], [8] They state that moving thrust faults caused the 7.8 magnitude earthquake that occurred on April 25. The Himalayas are a result of the Indian tectonic plate sliding under the Eurasian tectonic plate. As the mountain range continues to grow taller due to this tectonic activity, scientists predict that tremors will continue to occur [9], [10].

Earthquakes cause serious damage to buildings, leading to failure of structural members and potentially the collapse of the structure if the earthquake's intensity is high [11], [12], [13] [14] [15]. In recent years, population growth has increased drastically, leading to the expansion of cities and towns. Consequently, many buildings are being constructed in hilly areas. Nepal's landscape, characterized by a large number of mountains and hills, includes the Himalayan range, which has many towns spread across it. Numerous resorts are also being constructed in these hilly areas to accommodate tourists. Buildings in these areas are often constructed on sloping grounds [16]

Constructing buildings on hillside slopes poses a significant challenge to structural engineers, especially under seismic loads. Given the population growth and limited availability of land, people are increasingly building houses on hillside slopes. One of the main sources of seismic vulnerability is the instability of slopes; therefore, this is a subject of great significance, particularly in light of the growing attention dedicated to reducing seismic hazards. Using alternative light weight material may be beneficial in this case[17]. But due to the country's geographical terrain, with its mountainous regions and lack of developed infrastructure, makes it difficult to transport materials efficiently. This leads to increased costs and logistical complications, making alternative materials less practical. Buildings constructed on sloping grounds are highly vulnerable to earthquakes[11], [18], [19], [20] [21]. This paper evaluates the seismic performance of buildings constructed on slopes, focusing on base shear, acceleration, and displacements. The stability of the slope was first evaluated under seismic loads, and then the stability of the buildings constructed on the slope was assessed

Historical earthquakes, such as Kangra (1905), Bihar-Nepal (1934 & 1980), Assam (1950), Tokachi-Oki-Japan (1968), and Uttarkashi-India (1991), Petrinja earthquake (2020), Yogyakarta (2006) and Padang (2009) earthquakes have demonstrated that buildings located near the edges of hills or sloping terrain are particularly susceptible to severe damage. These buildings often have varying mass and stiffness along both vertical and horizontal planes [22] [23] [24][25].

[26]Step back frames generally produce higher base shear, top storey displacement, and time periods compared to step back-set back frames. This is particularly evident in step back frames on sloping ground, where shorter columns on the higher side are most affected, necessity acting special design considerations. The performance of step back frames under seismic excitation can be detrimental, making them less desirable unless systems to control large displacements are implemented. In contrast, step back-set back frames experience less torsional effects. Therefore, if step back frames are used, they should be designed to accommodate higher seismic-induced moments in columns.

[20]Saurav Kumar Verma and Hrishikesh Dubey's study on the seismic performance of buildings with various configurations in hilly regions highlights key findings regarding different frame designs. The research demonstrates that step back frames generally experience higher base shear and top storey displacements compared to step back-set back frames. The latter configuration performs better in terms of torsional effects and overall seismic response. In hilly regions, step back frames are particularly vulnerable due to the increased seismic forces acting on shorter columns positioned on sloping ground. The study emphasizes the need for enhanced design considerations and displacement control systems to mitigate the adverse effects observed in step back frames, advocating for the use of step back-set back frames or equivalent designs to improve seismic resilience.

[27]Birendra Kumar Bohara's study on the seismic response of hillside step-back RC framed buildings with shear wall and bracing systems investigates the impact of these structural enhancements on performance during seismic events. The research finds that incorporating shear walls and bracing systems significantly improves the seismic resilience of step-back RC frames by reducing lateral displacements and base shear. These modifications help in controlling the torsional effects and enhancing the stability of the building on sloping ground. The study highlights the effectiveness of these structural reinforcements in mitigating the adverse seismic impacts typically associated with hillside step-back frames, thereby offering a viable solution for improving the safety and performance of such buildings in earthquake-prone areas.

2. Need of Study

In much of Nepal, the terrain is characterized by hills and mountains, making it challenging to have a flat or even topography for building foundations. Consequently, constructing buildings with foundations at varying levels is a common practice due to the difficulties and increased costs associated with attempting to create level foundations on sloping ground. Past earthquakes have revealed that even though buildings in hilly regions have been designed to withstand seismic loads, they often experience a high level of stress, ultimately leading to structural collapse.

This current study focuses on buildings situated on sloping terrain with foundations at different elevations and aims to assess and analyse the responses of these structures.

3. Scope of Work

An analysis of three-dimensional space frames was carried out for eight different building configurations, which were subjected to seismic loads, on both sloping and flat ground. These buildings were compared in terms of base shear, fundamental time period, storey drift, and top-floor displacement within the considered configuration as well as

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with other configurations. At the end, a suitable configuration of the building to be used in hilly areas is suggested.

4. Objectives of Study

Main Objectives

To study seismic Performance evaluation of RCC Building resting on slopping land.

Specific objectives of the study are as follows.

- To identify the variation of base shear with respect to variation in hill slope, step back and step back-set back frames buildings.
- To identify the variation of top storey displacement & Stories drift with respect to hill slope buildings, step back buildings and step back-set back buildings frame.
- To evaluate the seismic Performance of RCC Building resting on slopping land

5. Methodology

To achieve the study's objectives, eight distinct models were selected, each featuring different configurations of step-back and set-back. Utilizing SAP2000 v20, Non-Linear Static (Push-over Analysis) was performed on all models, a widely accepted method for evaluating structural performance. Additionally, various relevant papers and research studies were reviewed to enrich the analysis.

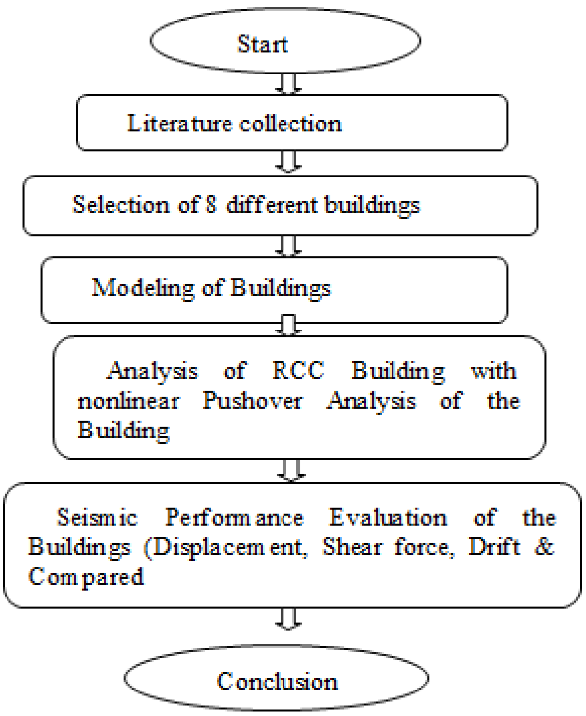

Fig 1: Flow chart of Methodology

The results obtained from these analyses were then compared based on metrics such as base shear, displacement, and storey drift, with performance points identified for each model. Ultimately, conclusions were drawn from these findings to inform the study's outcomes. Figure 1 illustrate the methodology of this research work.

II. MODELING AND ANALYSIS

1. Models Investigated

This Model of building located in vary slopping ground is selected such as the building located in plain ground & hill slope. The soil type of the location is generally not studied and adopted to be II type of soil that is soft soil type.

The material selected for the modeling is considered to be the concrete of grade M20 [28] and steel of grade Fe 500.All the support at the base is considered to be fixed support and each storey height of 3.m. The various linear and nonlinear static pushover analysis was performed for the model. Figure 2, Figure 3 shows the semi basement plan, ground floor plan. Similarly figure 4 shows first, second, third & top floor plan.

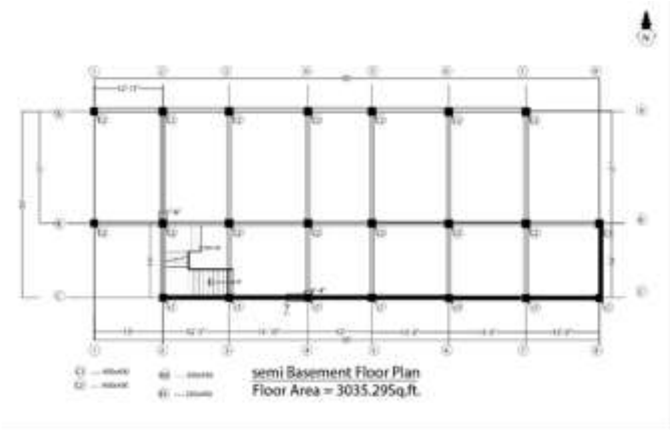

Fig 2: Semi Basement Plan

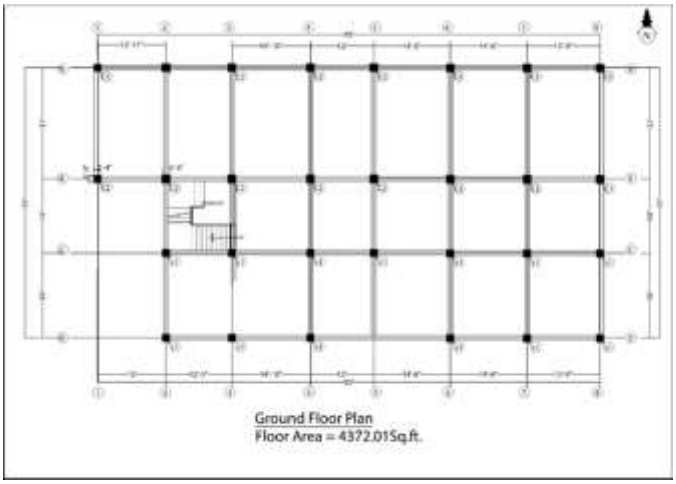

Fig 3: Ground Floor Plan

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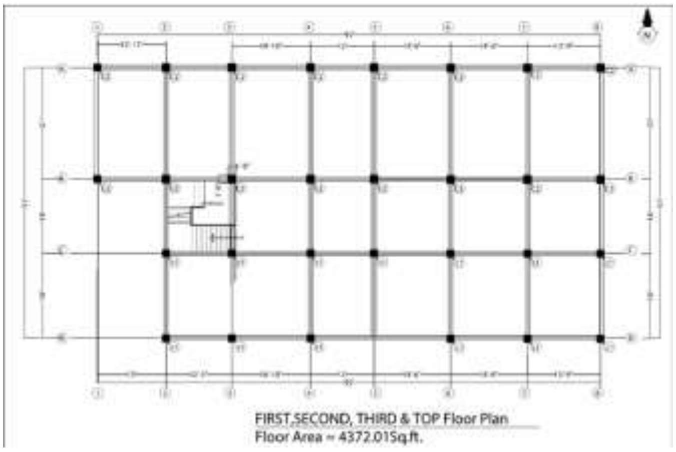


Fig 4: First, Second, Third & Top floor Plan

Table 1 Different 8 Model

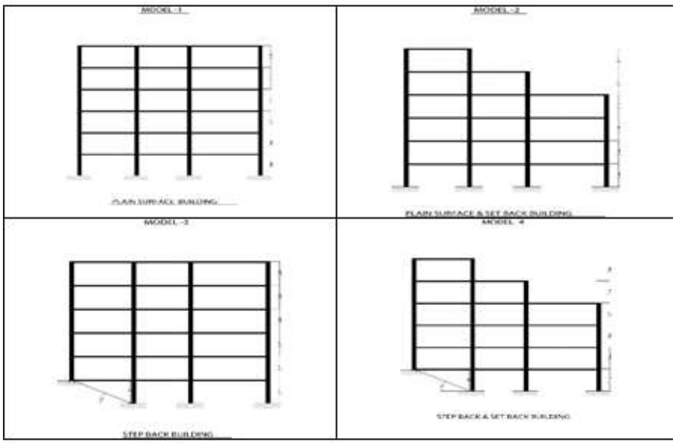
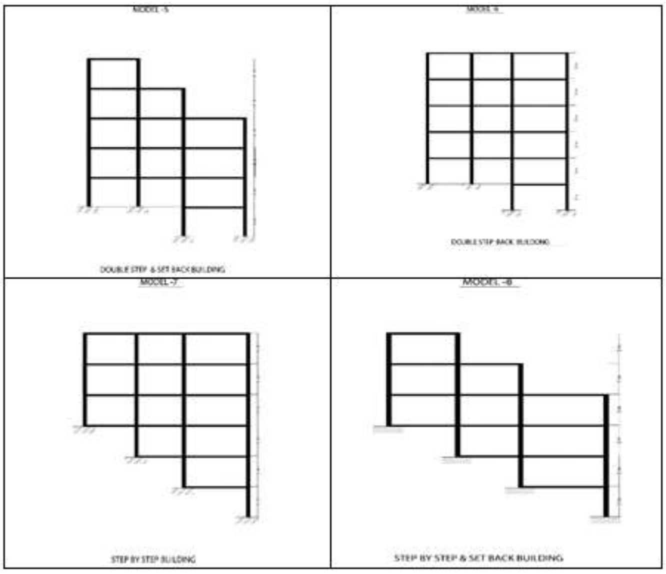


Table 2 shows different 8 model that have been used for research work.



2. Analysis Method

In this study, all the models undergo analysis using both linear static and nonlinear static methods. Specifically, the Equivalent Static Method (ESM) and Pushover analysis are employed. The analysis is conducted using the Sap 2000 software for linear analysis.

The structures are subjected to the assignment of dead and live loads in accordance with IS 875 Part I [29] and II [30]standards. They are designed to comply with the IS 1893 and IS 13920 standards [31], which pertain to seismic design and ductile detailing of reinforced concrete structures.

To evaluate the seismic response of these structures, both the ESM and Pushover analyses are carried out, and their results are subsequently compared.

For each structural instance, the study considers a minimum number of modes to ensure that the cumulative modal masses collectively represent at least 99% of the overall seismic mass. Furthermore, the analysis takes into account various factors, including accidental eccentricity and torsional effects. The estimated damping in the study is set at 5%.

General information of building has been shown in Table II.

3. General Information of Building

Table 3: General Information of Building

General Information of Building	
Type of the building	Hotel Building
Total plinth area of the building (Semi basement)	3035.29Sq. ft.
Total plinth area of the building (Ground Floor)	4372.01Sq. ft.
Total number of storey	Six
Total height of the building, h	18m
Typical storey Height	3 m.
Least lateral Base dimension of the building, d	21’-0”
Type of the soil considered	Type II (medium soft soil)
Bearing capacity of the soil adopted	150KN/m2
Analysis software used for building design	Sap-2000
Code used for seismic analysis	IS :1893
Total number of load combination considered	14
Total no of mode considered	8
Fundamental translational period: $T=0.075h^{0.75}$	0.571sec
Basic seismic coefficient for translational period: C	0.08

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Seismic zoning Factor: Z	1(Kathmandu Valley)
Importance factor: I	1 (Hotel building)
Concrete grade used	M20 (For column)
Total no of mode considered	8
Fundamental translational period: $T=0.075h^{0.75}$	0.571sec
Basic seismic coefficient for translational period: C	0.08
Seismic zoning Factor Z	1(Kathmandu Valley)
Importance factor: I	1 (Hotel building)
Concrete grade used	M20 (For column)
Reinforcing steel yield strength, fy	500 MPa
Size of the column used (C1)	400X400 mm
Size of the column used (C2)	450X450 mm
Size of the Main Beam used (B1)	350X450 mm
Size of the beam used (B2)	350X400 mm
Thickness of the Slab	150 mm
Unit weight of concrete	25 KN/m3
Young's Modulus of Elasticity	5000 √fck
Poisson's Ratio for concrete	0.2
Poisson's Ratio for rebar	0.3
Material Properties	
E value of concrete	25000 M/mm2
Unit weight of RCC	25 KN/ m2

III. RESULTS AND DISCUSSION

Seismic analysis is carried as per IS 1893 (Part 1): 2016 guidelines.[32].Pushover analysis is adopted for the non-linear static analysis of the structure and compared Slope building varying of step back & step back set back models carried out using SAP200 version20 software. After analysis, performances of structures are evaluated with base shear, displacement, storey drift and stages of a number of hinges form

1. Performance Point and Base Shear For Different Models

As stated above seismic performance in terms of base shear and performance point increases with increasing infill percentage

Fig 5: Base Shear

Fig 5 illustrates the base shear of 8 models. The base shear values provide insights into the seismic response of different building configurations. For a building on a plain surface, the base shear is 2405.79 KN, which is the highest among all cases. This suggests a significant seismic force acting on the structure in this configuration. When a setback is introduced, the base shear reduces to 1966.57 KN, demonstrating that setbacks can help decrease seismic loads by modifying the building's dynamic response and mass distribution.

In configurations with step backs, the base shear values also decrease compared to the plain surface case. For example, the "Building at Step Back" configuration has a base shear of 2288.11 KN, and the "Building at Double Step Back" configuration shows 1988.84 KN. The "Building at Step by Step Back" configuration further reduces the base shear to 1862.22 KN. These reductions indicate that step backs can enhance a building's seismic performance by altering its stiffness and mass distribution, thereby reducing the seismic forces.

The most significant reductions in base shear occur when setbacks are combined with step backs. The "Building at Step by Step Back & Setback" configuration has the lowest base shear value of 1422.99 KN, while the "Building at Double Step Back & Setback" configuration shows a base shear of 1549.627 KN. These configurations effectively reduce seismic forces by better distributing the forces throughout the structure, demonstrating that the combination of these architectural features is particularly effective in enhancing seismic performance.

2. Storey Displacement Characteristics of Different Cases

Fig 6 shows graph of the displacement behavior of various RCC building configurations across different story heights during seismic events. Each curve represents a distinct design, including Plan Surface, Plan Surface & Set Back, Set Back, Step Back, Step Back & Set Back, Step by Step Back, Step by Step Back & Set Back, Double Step Back, and Double Step Back & Set Back.

The Plan Surface configuration shows a moderate increase in displacement, reaching around 8 mm, suggesting balanced seismic force distribution. The Plan Surface & Set Back configuration exhibits slightly more flexibility, with a maximum displacement of about 9 mm, indicating improved torsion control due to the setback design. The Set Back configuration shows higher displacement, peaking at around 10 mm, indicating potential challenges with lateral movements, especially at higher stories.

The Step Back configuration has a significantly steeper curve, with displacements reaching up to 20 mm, highlighting increased vulnerability to seismic forces. The Step Back & Set Back design mitigates this issue somewhat, reducing the

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maximum displacement to around 15 mm. The Step by Step Back configuration also shows high displacements, up to 17 mm, indicating a highly flexible but potentially unstable structure. However, the Step by Step Back & Set Back configuration displays better control, with displacements peaking at around 12 mm.

The Double Step Back configuration, with the steepest curve, reaches the highest displacement of approximately 25 mm, suggesting significant instability under seismic loading. The Double Step Back & Set Back design reduces this displacement to around 15 mm, indicating improved stability due to the combination of step-back and setback features.

Overall, the analysis highlights that buildings with more complex step-back designs tend to experience higher displacements, particularly at upper stories. Configurations incorporating setbacks generally exhibit reduced displacements, enhancing control over lateral movements and providing better structural stability. These insights are crucial for designing earthquake-resistant buildings on sloping ground, emphasizing the importance of careful configuration selection to mitigate seismic risks.

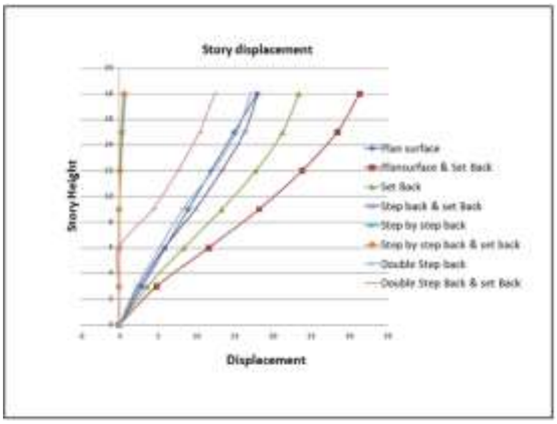

Fig 6: Storey Displacement

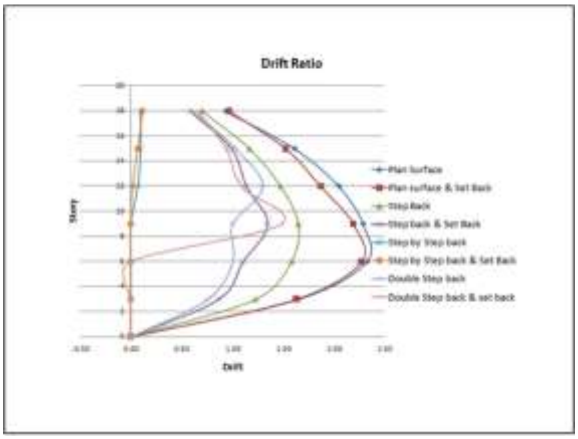

Fig 7: Drift Ratio

Fig 7 graph illustrates the distribution of drift across various story heights for different RCC building configurations, such as Plan Surface, Plan Surface & Set Back, Set Back, Step Back, Step Back & Set Back, Step by Step Back, Step by Step Back & Set Back, Double Step Back, and Double Step Back & Set Back. The Plan Surface configuration exhibits a relatively uniform structural response, with a maximum drift ratio of around 0.50, indicating consistent deformation across all stories. In comparison, the Plan Surface & Set Back design shows a slightly higher maximum drift ratio of 0.60, reflecting a more even distribution of forces due to the setbacks.

The Set Back configuration displays a significant increase in drift ratio, especially at higher stories, reaching around 1.0, suggesting pronounced lateral deformation and potential structural challenges. The Step Back configuration experiences even higher drift ratios, peaking at 2.0, indicating substantial flexibility and susceptibility to lateral displacements, particularly in the upper stories, which may compromise stability during seismic events. The Step Back & Set Back design moderates these effects, with a maximum drift ratio of about 1.50, demonstrating improved control over lateral movements due to the combination of step-back and setback features.

The Step by Step Back configuration also shows significant drift, with a peak ratio of around 1.80, indicating similar challenges to the Step Back design. However, the Step by Step Back & Set Back configuration reduces the drift to a peak of 1.20, showcasing better seismic performance with added setback features. The Double Step Back configuration exhibits the highest drift ratio, reaching approximately 2.50, indicating severe lateral deformation and potential risk to structural integrity. In contrast, the Double Step Back & Set Back design moderates the drift to a maximum of 1.40, demonstrating improved resilience against seismic forces.

Overall, the analysis highlights that more complex step-back configurations tend to exhibit higher drift ratios, indicating greater lateral flexibility and potential instability, especially in the upper stories. Incorporating setbacks generally results in reduced drift ratios, providing better control over lateral deformations and enhancing structural stability. These findings are crucial for assessing the seismic performance of RCC buildings on sloping ground and emphasize the need for careful design choices to mitigate seismic risks.

3. Plastic Hinge Mechanism

Plastic hinges have formed within the building's structural components at various displacement levels. The patterns of these hinges are illustrated at different levels in Table III

In comparing the performance points and hinge formation at pushover capacity curves, the data reveals key insights:

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In the "Plain Surface & Set Back" model, there are 23 hinges formed in the LS to CP (Life Safety to Collapse Prevention) range. This indicates that the structure is particularly vulnerable at these performance points.

In contrast, the "Step by Step Back & Set Back" model shows no hinges forming in the IO to LS (Immediate Occupancy to Life Safety) and LS to CP ranges. This suggests that buildings using the step-by-step back and set-back approach are less vulnerable to damage in these stages compared to other building designs.

Overall, the step-by-step back and set-back method provides enhanced structural resilience, making it less susceptible to damage progression, as indicated by the lack of hinge formation in critical performance ranges.

Table 4: Hinge Formation

Building Type	Steps	A to B	B to IO	IO to LS	LS to CP	CP to C	C to D	D to E	Beyond E	Total Step
Plan Surface	13	593	98	144	3	0	0	0	0	838
Plan Surface Set Back	12	539	108	80	23	0	14	0	0	764
Step Back	10	296	90	159	8	0	23	0	0	576
Step Back & Set Back	7	342	156	77	1	0	0	0	0	576
Step By Step Back	2	705	56	11	0	0	0	0	0	772
Step By Step Back & set Back	2	600	32	0	0	0	0	0	0	632
Double Step back	19	570	79	67	0	0	0	0	0	716
Double Step back & set back	21	827	73	60	0	0	0	0	0	960

4. Pushover Curve Demand Capacity - ATC40

This is the fig of pushover over curve (figure 8). Where maximum value occurs at step-by-step model and minimum at plain surface & set back model The pushover curves for various RCC building configurations on sloping ground provide critical insights into their seismic performance. The "Plan Surface" configuration, reaching a shear force of approximately 12,000 kN at 0.8 m displacement, indicates moderate stiffness and strength. The "Plan Surface & Set Back" configuration offers slightly higher capacity, achieving around 13,600 kN, due to the added stiffness from the setback design. In contrast, the "Step Back" configuration, with a peak shear force of approximately 15,200 kN, demonstrates higher strength but potentially greater vulnerability due to increased base shear and displacement. The "Step Back & Set Back" configuration, peaking at around 12,800 kN, performs better than the plain step-back design, benefiting from reduced torsion effects and improved force distribution.

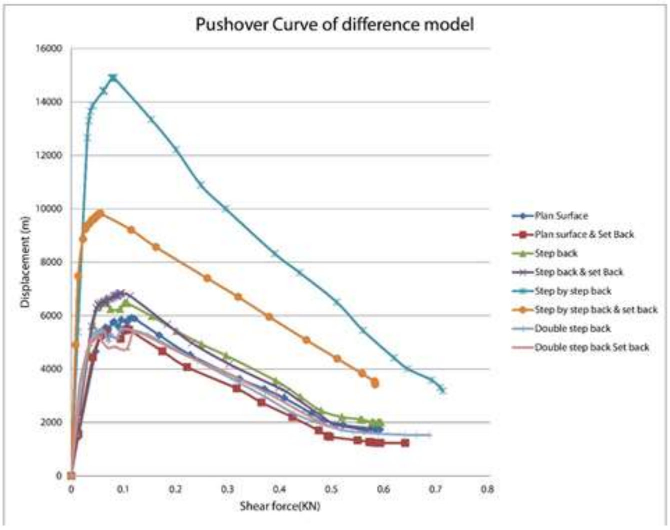

Fig 8: Pushover Curve

The "Step by Step Back" configuration, achieving up to 14,400 kN, shows similar characteristics to the step-back design but with enhanced force distribution. In the "Step by Step Back & Set Back" configuration, the maximum shear force of approximately 11,200 kN indicates reduced torsion effects and less displacement, highlighting its improved seismic performance. The "Double Step Back" configuration exhibits the highest strength among all models, reaching 16,000 kN, suggesting strong resistance but also potential issues with torsion and displacement. Finally, the "Double Step Back & Set Back" configuration, with a shear force of around 10,400 kN, demonstrates a more balanced structural response with reduced lateral forces and displacement, making it a safer option under seismic conditions.

Overall, these analyses emphasize that configurations incorporating setbacks generally exhibit reduced displacement and torsion effects, making them more resilient against earthquakes. The selection of appropriate building configurations is crucial for enhancing seismic resistance, especially on sloping ground where structural stability can be significantly challenged

V. CONCLUSION AND RECOMMENDATION

1. Conclusion

From the above study following conclusion can be drawn

- The Step-by-Step Back & Set-Back building model exhibits a higher shear force in its pushover curve when compared to the other models.,
- The top storey displacement of Step by step back building is less than other models
- As a comparison to performance points & hinges formation at pushover capacity curves. There are 23 hinges formation in LS to CP at plain surface & step back, it shows most vulnerable but there are no hinges formation even at Io to LS & LS to CP at step by step back & set back model, it means step by step back & set back buildings are most vulnerable than other building

These conclusions highlight the importance of considering building configuration in hilly areas and underscore the potential strengths and weaknesses of different design choices in earthquake-prone regions.

2. Further Recommendations

- Further research can be conducted by modeling with shear wall & soil structure interaction too.
- Further research can be further by modeling with nonlinear dynamic &incremental dynamic analysis

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