# The Influence of Short Column Behavior on the Seismic Performance of a Reinforced Concrete Structure Situated on a Sloping Lot

**Jyoti Yadav**[1], **Ms. Ragini Mishra**[2]

[1]M. Tech Scholar, Dept. Of Civil Engineering, Swami Vivekanand University, Sagar M.P., India
[2]Assistant Professor, Dept. Of Civil Engineering, Swami Vivekanand University, Sagar M.P., India

**Abstract-** The latest earthquakes' extensive destruction pushed researchers to concentrate more on the short column effect. Due to the presence of both short and tall columns on the same storey level, the short column effect is one of the key factors that draws stronger earthquake forces. Compared to the others, short columns often sustain greater damage. A building may exhibit short column behavior in a number of circumstances. The variation in ground level is one of them. The performance of RC structures with short columns in relation to sloping lots is the main topic of the current research. In this work, a five-story reinforced concrete building with a variable slope is analyzed using SAP2000, and the building's performance is contrasted with that of a flat lot structure. The results demonstrate that when the slope angle increases, columns grow shorter, absorb more earthquake forces, and suffer damage before other regular columns.

**Keywords: Sloping lots, Level Difference, Reinforced Concrete, Short Column Effect**

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## 1. Introduction

The main causes of the destruction of structures, engineering infrastructures, and social systems are seismic catastrophes. Structures that are disorganized have a larger risk for damage than other ones, according on knowledge from prior earthquakes. Disorders in structures are mostly caused by technical requirements, architectural, and aesthetic factors. When taking into account general slope, some of these factors may cause a disorder in building height, giving birth to the destabilizing phenomena of a short column at the lowest level. The principal stresses that affect reinforced concrete columns most often result from axial force, flexure, and shear. Secondary stresses, which are usually extremely modest in most columns used in practice, are connected to deformations. Short columns are the name given to this kind of columns. No matter how long the column is, its capacity and the capacity of its section under primary loads are the same. Reinforced Concrete (RC) building frames with columns of varying heights, either horizontally or vertically, have been observed to sustain greater damage in shorter columns than in normal or higher columns in prior earthquakes. Large compressive loads that go beyond the limit state are known to cause the collapse of structures with short columns.

## 2. Case Study

A 5 story RC construction is taken into consideration to assess the performance of an RC building with short column impact on sloping lots. The structure has four bays in each direction. The story height is assumed to be 3 meters, and the spacing in the X and Y axes is 4 meters. Seismic zone IV corresponds to the selected frame zone.

## 3. Methodology

### A. Design data

a) Live load : 3.0 kN/m² at typical floor
: 1.5 kN/m² on terrace
b) Earthquake load: As per IS-1893 (Part 1)2002
c) Type of soil : Type II, Medium as per IS:1893
d) Storey height : 3m

e) Floors : G.F + 4 upper floors.
f) Walls : 230 mm thick brick masonry
g) Seismic zone : Zone IV

**B. Description of building frame**

h) No: of Bays along X axis 4
i) No: of bays along Y axis 4
j) Spacing along X axis : 4m
k) Spacing along Y axis : 4m
l) Height of storey : 3m
m) No. Of floors : G + 4
n) Size of column : 500mm x 500mm
o) Size of beam : 400mm x 230mm
p) Slab :125mm thick

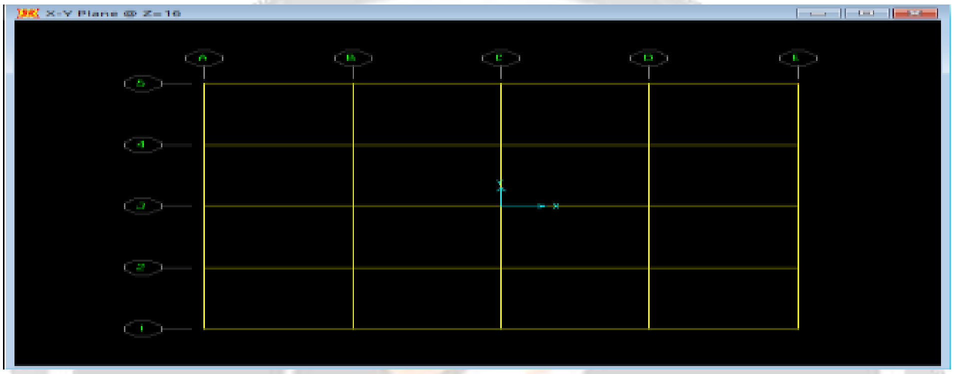

Fig. 1. Plan of building frame

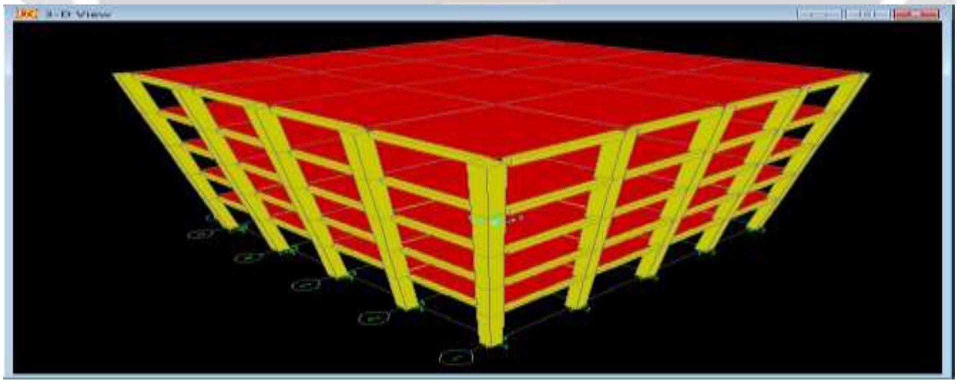

Fig. 2. 3D model of the building frame

| Sr. No. | Model | Percentage of slope |
|---|---|---|
| 1 | M1 | 0% |
| 2 | M2 | 5% |

| | | |
|---|---|---|
| 3 | M3 | 10% |
| 4 | M4 | 15% |
| 5 | M5 | 20% |

Table 1: Details of models with different percentage of slope percentage of slope

## 4.Result

### 4.1 Modal Analysis

From modal analysis the natural time period of the structure and corresponding mode shapes are obtained. Natural period of a structure is its time period of undamped free vibration. It is the first modal time period of vibration. Variation of Fundamental Time Period and corresponding mode shapes for various frames are shown in Table 2.

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| **Sr. no** | **Model** | **Time period (s)** | **Mode shape (mode 1)** |
|---|---|---|---|
| 1 | M1 | 0.79198 | Translation |
| 2 | M2 | 0.75521 | Torsion |
| 3 | M3 | 0.73188 | Torsion |
| 4 | M4 | 0.69259 | Torsion |
| 5 | M5 | 0.63761 | Torsion |

Table 2: Time period and mode shapes obtained from modal analysis for various models

### 4.2 Pushover evaluation

Through nonlinear static pushover analysis on the aforementioned building frames, the performance of the building frame is examined in terms of performance point base shear and displacement. Different pushover load situations are taken into account for pushover analysis, including gravity, push X, and push Y. This also makes advantage of the different load combinations. Following the pushover analysis, capacity and demand curves are constructed in order to determine the respective structures' performance point. According to the ATC 40 capacity spectrum approach, the model's performance point is determined. Table 3. below lists the base shear and displacement at the performance point for different slope angle configurations.

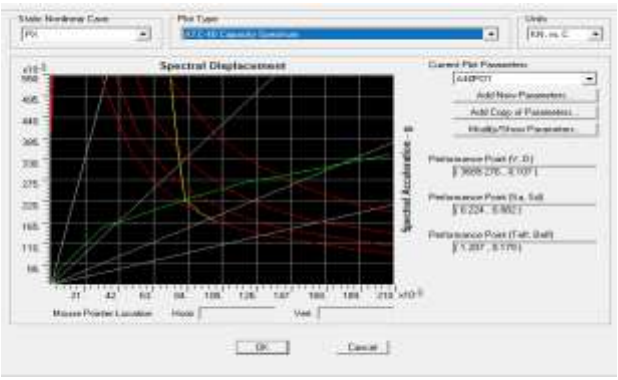


Fig. 3. Pushover curve for the model with 0% slope

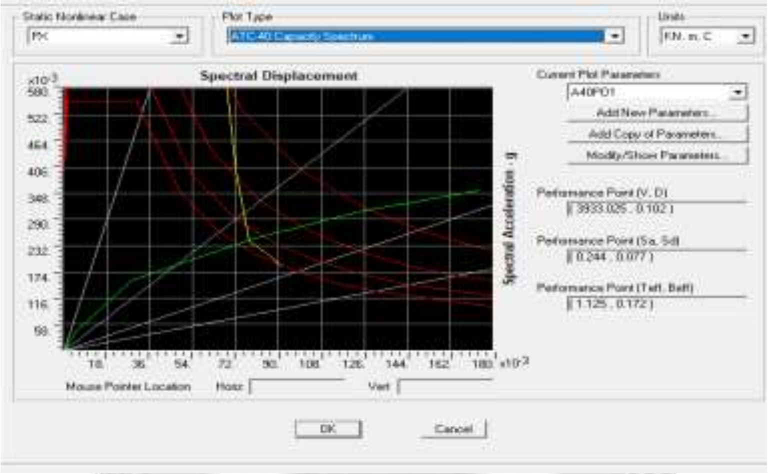

Static Nonlinear Case: PX
Plot Type: ATC-40 Capacity Spectrum
Units: KN, m, C
Current Plot Parameters: A40PO1
Performance Point (V, D): ( 3933.025 , 0.102 )
Performance Point (Sa, Sd): ( 0.244 , 0.077 )
Performance Point (Teff, Beff): ( 1.125 , 0.172 )

Fig. 4. Pushover curve for the model with 5% slope

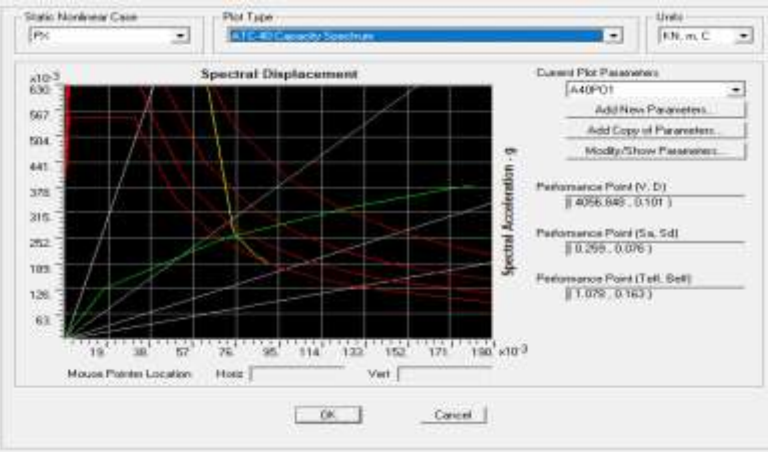

Static Nonlinear Case: PX
Plot Type: ATC-40 Capacity Spectrum
Units: KN, m, C
Current Plot Parameters: A40PO1
Performance Point (V, D): ( 4056.848 , 0.101 )
Performance Point (Sa, Sd): ( 0.259 , 0.076 )
Performance Point (Teff, Beff): ( 1.079 , 0.163 )

Fig. 5. Pushover curve for the model with 10% slop

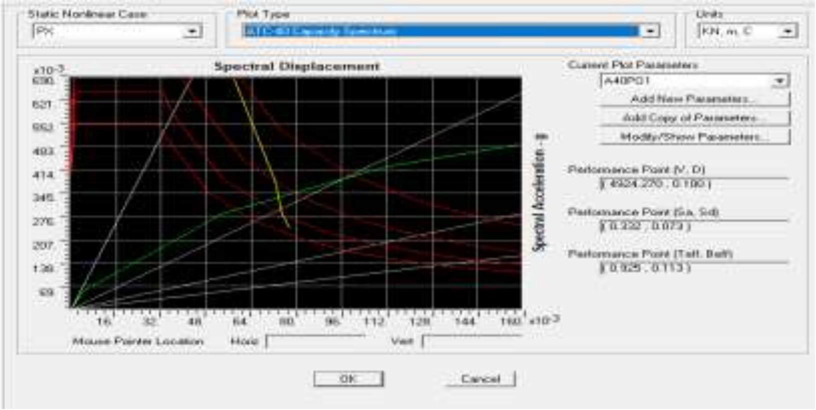
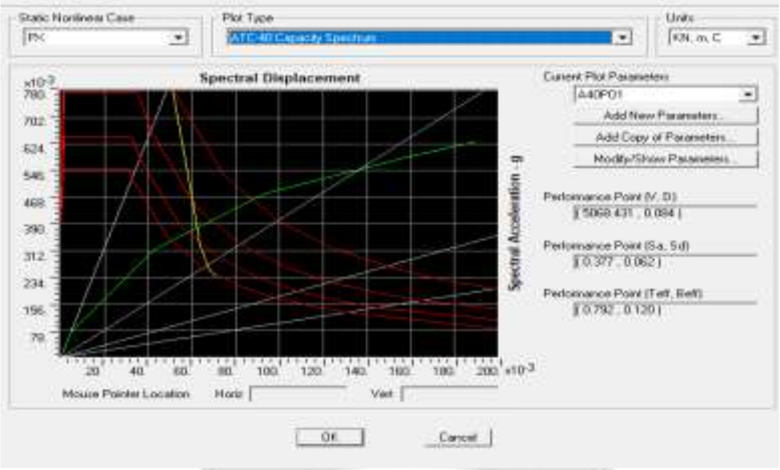

Static Nonlinear Case: PX
Plot Type: ATC-40 Capacity Spectrum
Units: KN, m, C
Current Plot Parameters: A40PO1
Performance Point (V, D): ( 4924.270 , 0.100 )
Performance Point (Sa, Sd): ( 0.232 , 0.073 )
Performance Point (Teff, Beff): ( 0.925 , 0.113 )

Fig. 6. Pushover curve for the model with 15% slope



Static Nonlinear Case: PX

Plot Type: ATC-40 Capacity Spectrum

Units: KN, m, C

Current Plot Parameters: A40PO1

Performance Point (V, D): ( 5068.431 , 0.084 )

Performance Point (Sa, Sd): ( 0.377 , 0.062 )

Performance Point (Teff, Beff): ( 0.792 , 0.120 )

Fig. 7. Pushover curve for the model with 20% slope

| Sr. No | Percentage of slope | Base shear (kN) | Displacement (m) |
|---|---|---|---|
| 1 | 0 | 3689.28 | 0.107 |
| 2 | 5 | 3933.02 | 0.102 |
| 3 | 10 | 4056.85 | 0.101 |
| 4 | 15 | 4924.27 | 0.100 |
| 5 | 20 | 5068.43 | 0.084 |

Table 3: Variation of Performance Point Base Shear and Displacement for various percentage of slope

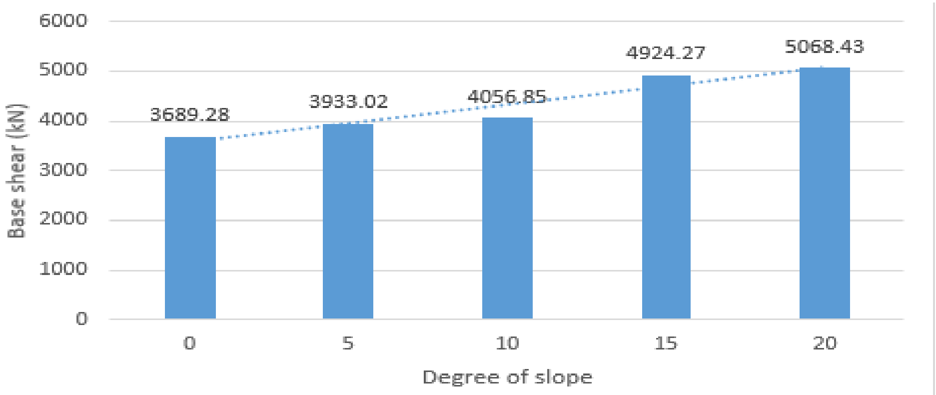


Fig. 8. Performance point base shear variation for different percentage of slope

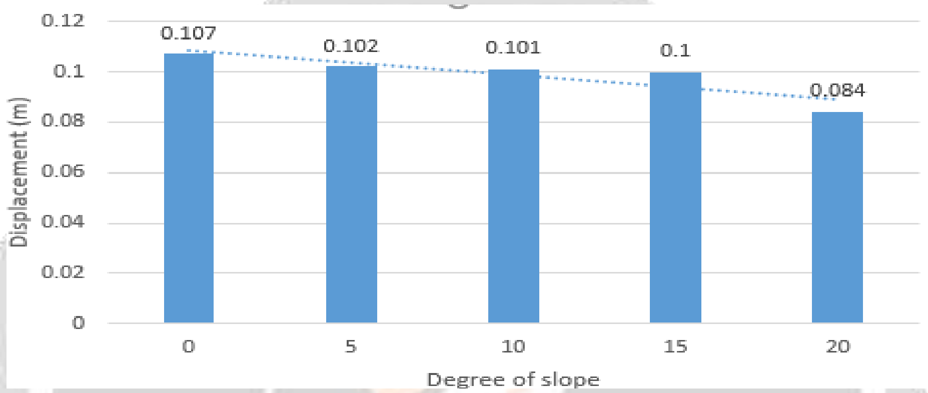


Fig. 9. Performance point displacement variation for different degree of slope

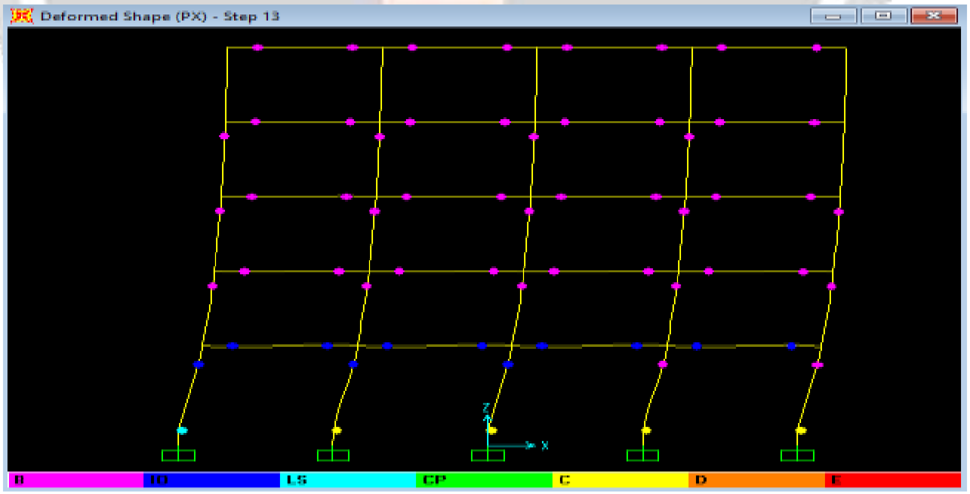


Fig. 10. Hinge pattern in for the model with 0% slope

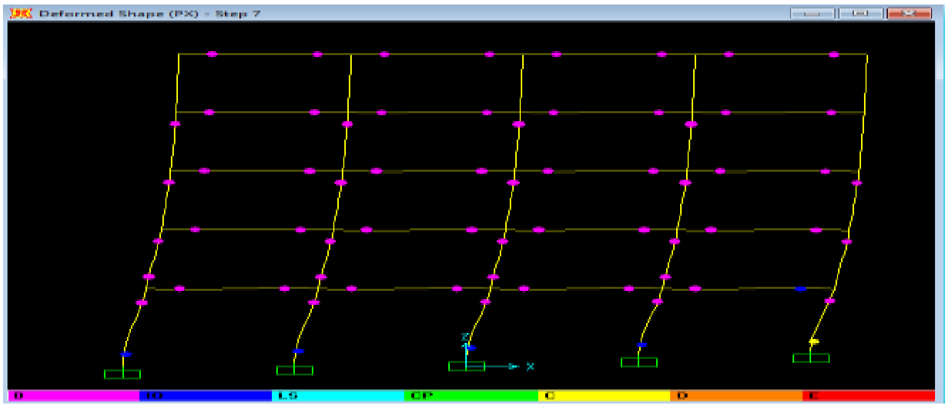


Fig. 11. Hinge pattern in for the model with 5% slope

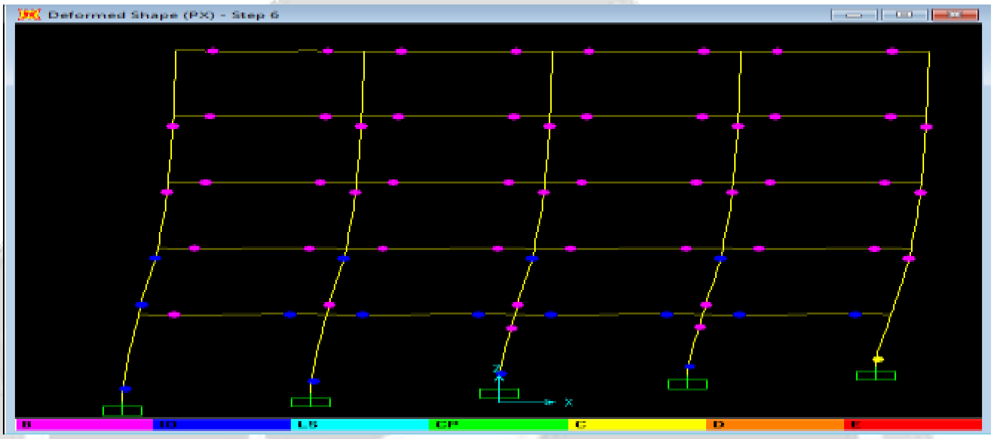


Fig. 12. Hinge pattern in for the model with 10% slope

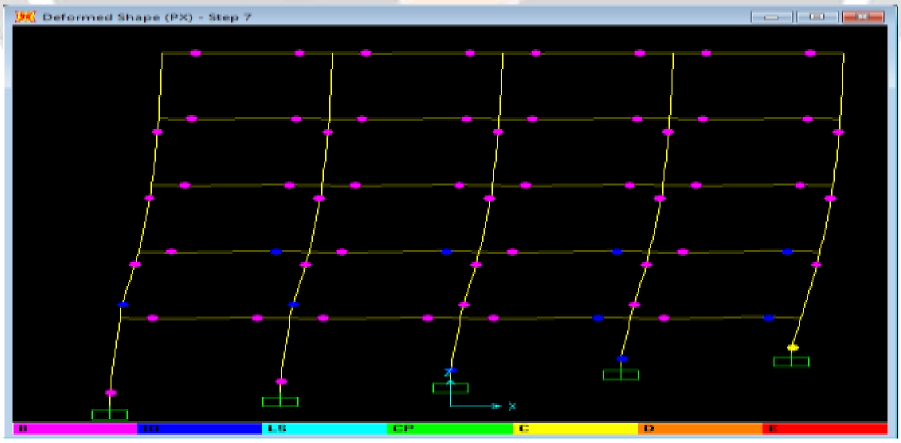


Fig. 13. Hinge pattern in for the model with 15% slope

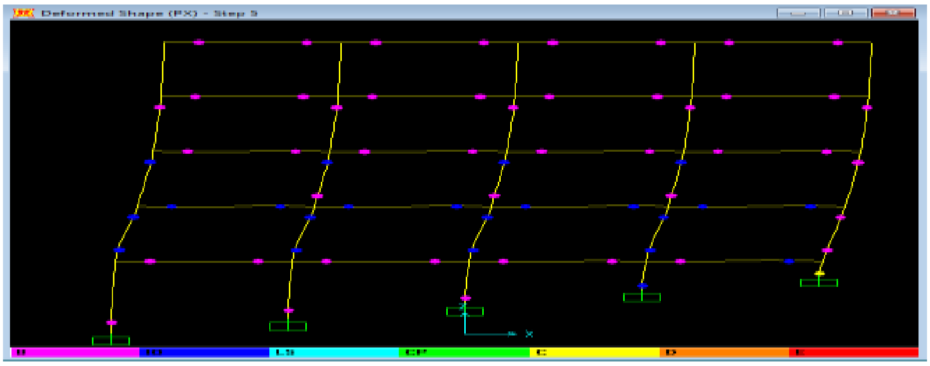


Fig. 14. Hinge pattern in for the model with 20% slope

| Model | C1 (kNm) | C2 (kNm) | C3 (kNm) | C4 (kNm) | C5 (kNm) |
|---|---|---|---|---|---|
| M1 | 101.93 | 103.84 | 103.9 | 103.84 | 101.93 |
| M2 | 124.8 | 127.28 | 127.41 | 127.28 | 124.8 |
| M3 | 149.4 | 152.27 | 152.66 | 152.27 | 149.4 |
| M4 | 171.17 | 185.77 | 185.95 | 185.77 | 171.17 |
| M5 | 179.9 | 196.8 | 197.08 | 196.8 | 179.9 |

Table 4: Variation of Bending Moment for various percentage of slope

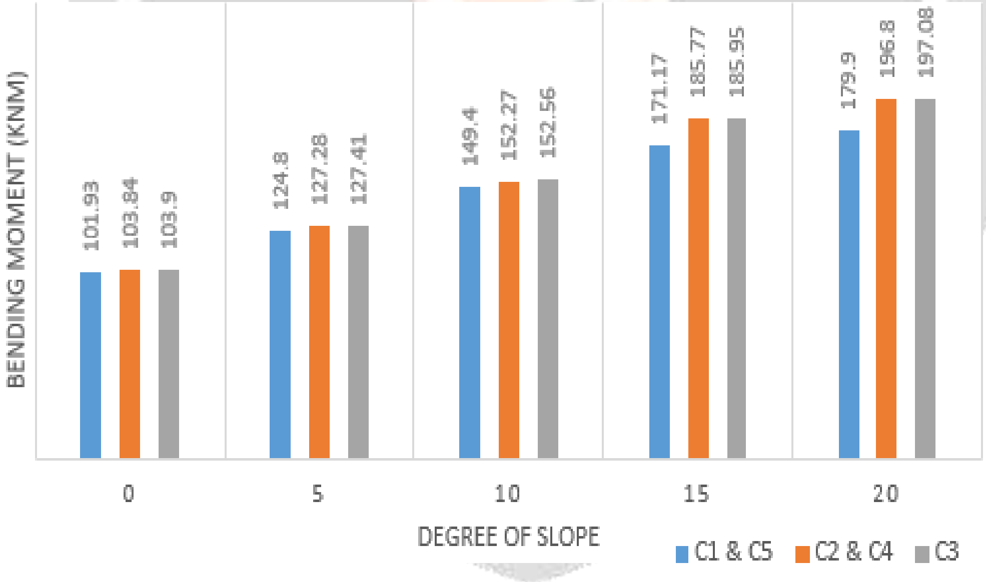


Fig. 16. Bending moment variation for various percentage of slope

| Model | C1 (kN) | C2 (kN) | C3 (kN) | C4 (kN) | C5 (kN) |
|---|---|---|---|---|---|
| M1 | 33.43 | 34.85 | 34.88 | 34.85 | 33.43 |
| M2 | 49.95 | 52.16 | 52.23 | 52.16 | 49.95 |
| M3 | 73.33 | 76.34 | 76.55 | 76.34 | 73.33 |
| M4 | 126.47 | 138.83 | 139.05 | 138.83 | 126.47 |
| M5 | 197.19 | 228.97 | 229.97 | 228.97 | 197.19 |

Table 5: Shear Force variation for various percentage of slope

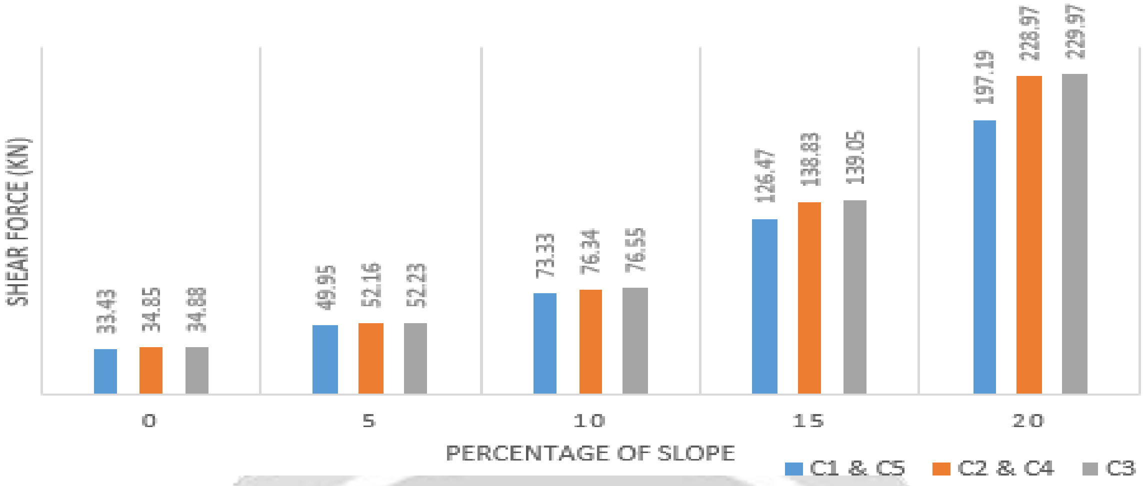


Fig. 17. Shear force variation for various percentage of slope

| Sr. No | Model | Displacement (m) |
|---|---|---|
| 1 | M1 | 0.0036 |
| 2 | M2 | 0.0029 |
| 3 | M3 | 0.0021 |
| 4 | M4 | 0.00115 |
| 5 | M5 | 0.0004 |

Table 6: Variation of Displacement of short columns for various percentage of slope

## 5. Conclusion

1. Short stiff columns in RC structures are shown to accumulate significant strains during earthquakes, which causes serious damage.

2. As the structure's stiffness increases, the time period shortens as the slope's steepness increases.

3. Translation is the predominant form in flat lot configurations; for slope lots, torsion is the predominant shape. As the slope's degree rises, the torsion impact grows.

4. The performance point base shear value rises as the slope increases.

5. The performance point displacement diminishes as the slope increases.

6. As the slope rises, short columns' bending moment and shear force rise.

7. The BM of short columns increases to 90% when the slope is increased by 20%.

8. The SF value increases by 5.6 times with a 20% slope increase compared to a flat lot construction.

9. Column displacement at ground level diminishes as the columns are shorter, and it is nine times bigger for structures on flat lots than for those on sloping (20% slope lots).

10. Collapse hinges are produced at lower storey columns in flat lot buildings, but they are concentrated at short columns in sloping lot structures, which causes them to fail due to the "short column effect."

11. In general, it has been determined that as the slope angle increases, columns become shorter and may more easily be damaged by earthquakes than regular columns.

**References**

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