Effect of Short Column Behavior on the Seismic Performance of a Reinforced Concrete Structure on Sloping Lot

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Abstract— **Vast devastation in the recent earthquakes have challenged the research works to focus more on the short column effect. Short column effect is one among the main reason that attracts larger earthquake forces due to the existence of short and tall columns within the same storey level. Short columns usually suffer more damage compared to the others. There are several situations that give rise to short column behaviour in a building. One among is the level difference of ground. Present study focuses on the performance of RC structure with short column effect on sloping lots. This paper involves the analysis of a five-storey Reinforced Concrete building with varying slope using SAP2000 and the performance is compared with that of a flat lot structure. Results shows that with the increase in sloping angle, the columns become more shorter, absorb large earthquake forces and get damaged prior to the other normal columns.**

Keywords— Short column effect, Short column, Reinforced concrete, Sloping lots, Level Difference

I. INTRODUCTION

The earthquake disasters are the major reasons for destruction of buildings, engineering infrastructures and social systems. According to experience from previous earthquakes, structures which are disordered show higher potential for destruction when compared with other ones. Structures disorders mainly because of architectural and aesthetic considerations and technical necessities. When general slope is into account, some of these consideration may lead to the disorder in building height, which give rise to the destructive phenomenon of short column at the lowest floor.

The Reinforced Concrete columns, are mostly subjected to primary stresses which are caused by axial force, flexure and shear. Secondary stresses are associated with deformations and are mainly very small in most columns which are used in practice. These type of columns are referred to as short columns. The capacity of a short column and the capacity of its section under primary stresses are the same, irrespective of its length. In previous earthquakes, Reinforced Concrete (RC) building frames which were having columns with different height either in horizontal or vertical are found to suffer damage more in shorter columns than normal or taller columns. The buildings with short columns are found to fail due to large compressive stresses more than limit state.

II. CASE STUDY DETAILS

To evaluate the performance of an RC building with short column effect on sloping lots, a 5 storey RC structure is considered. It is consisting of four bays in both the directions. The spacing along X and Y directions is 4m and the story height is taken as 3m. The chosen zone of frame corresponds to seismic zone IV.

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

a) No: of Bays along X axis : 4
b) No: of bays along Y axis : 4
c) Spacing along X axis : 4m
d) Spacing along Y axis : 4m
e) Height of storey : 3m
f) No. Of floors : G + 4
g) Size of column : 500mm x 500mm
h) Size of beam : 400mm x 230mm
i) Slab :125mm thick

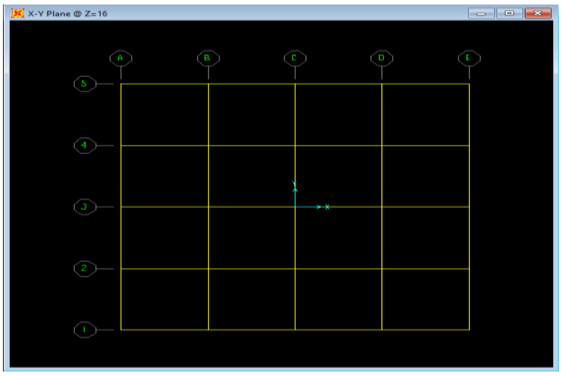

Fig. 1. Plan of building frame

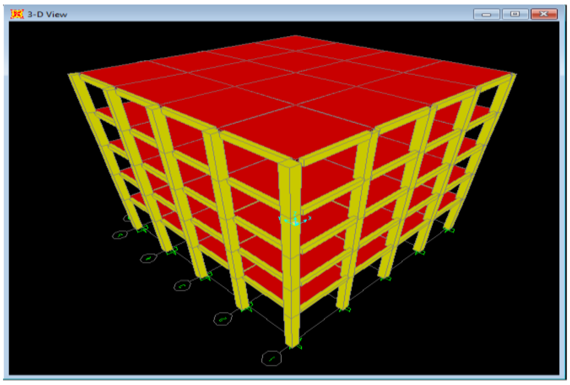

Fig. 2. 3D model of the building frame

TABLE I. Details of models with different percentage of slope percentage of slope

Si No.	Model	Percentage of slope
1	M1	0%
2	M2	5%
3	M3	10%
4	M4	15%
5	M5	20%

III. RESULTS OBTAINED

C. 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 II

TABLE II. Time period and mode shapes obtained from modal analysis for various models

Si 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

D. Pushover analysis

The performance of the building frame is investigated in terms of performance point base shear and displacement through nonlinear static pushover analysis on the above building frames. For pushover analysis, various pushover load cases are considered such as gravity, push X, push Y. The various load combinations are also used for this purpose. After the pushover analysis capacity curves and demand curves are obtained in order to get the performance point of the corresponding structures. The performance point is of model is obtained according to ATC 40 capacity spectrum method. The base shear and displacement at performance point for various configuration of slope angle are listed in table III below:

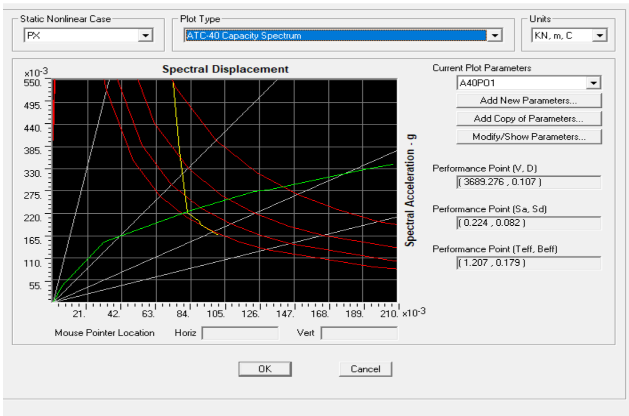

Fig. 3. Pushover curve for the model with 0% slope

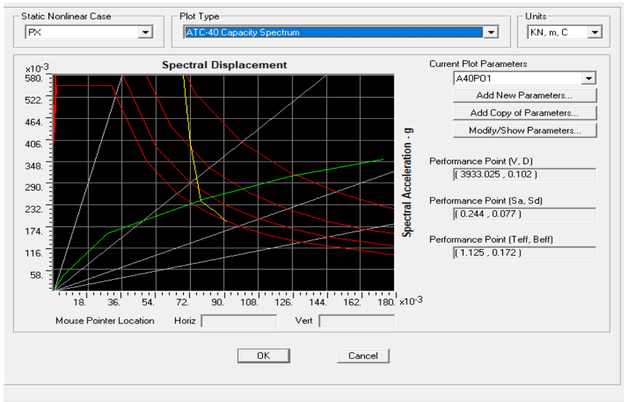

Fig. 4. Pushover curve for the model with 5% slope

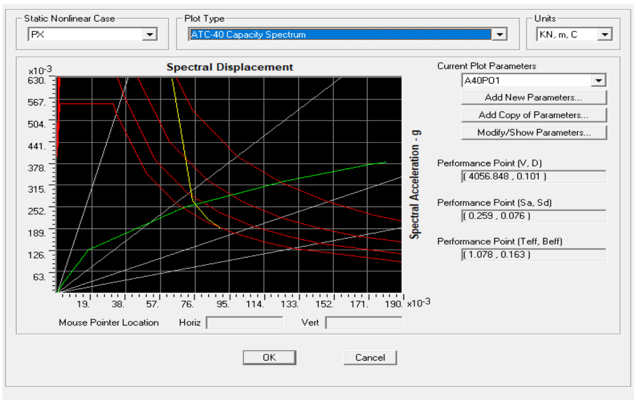

Fig. 5. Pushover curve for the model with 10% slope

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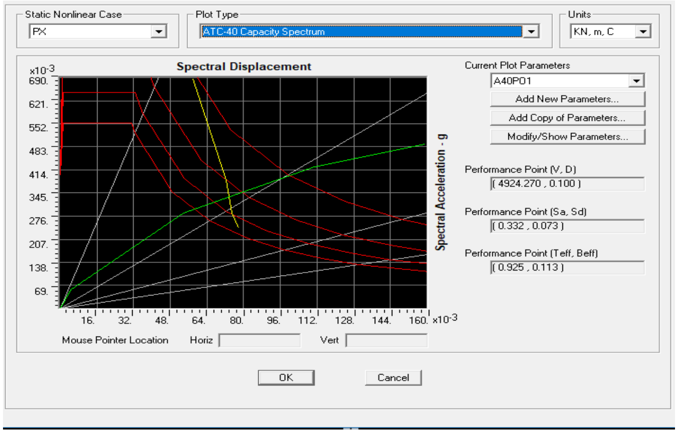

Fig. 6. Pushover curve for the model with 15% slope

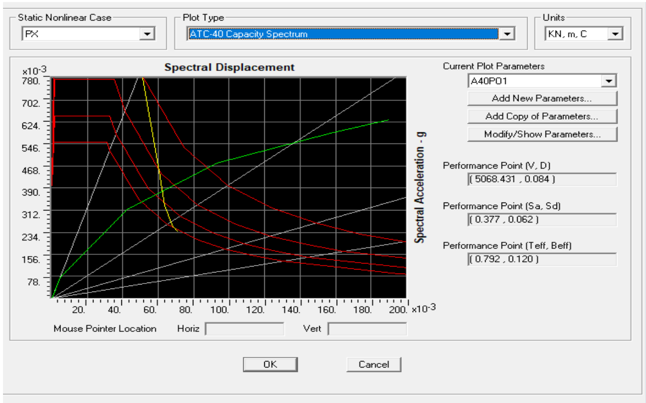

Fig. 7. Pushover curve for the model with 20% slope

TABLE III: Variation of Performance Point Base Shear and Displacement for various percentage of slope

Si 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

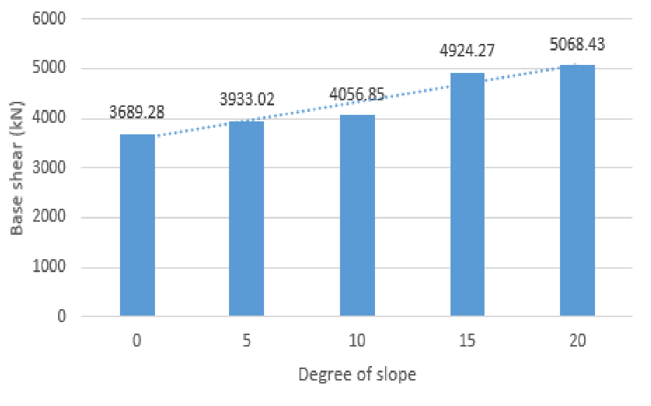

Fig. 8. Performance point base shear variation for different percentage of slope

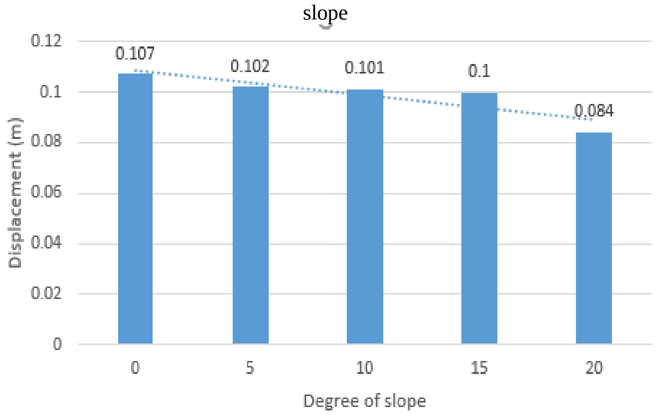

Fig. 9. Performance point displacement variation for different degree of slope

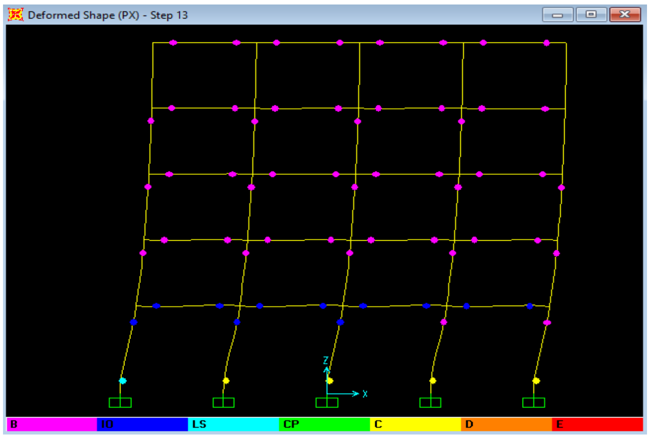

Fig. 10. Hinge pattern in for the model with 0% slope

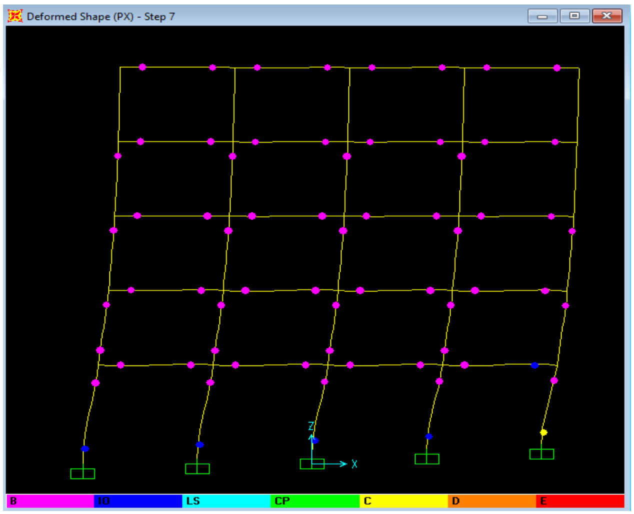

Fig. 11. Hinge pattern in for the model with 5% slope

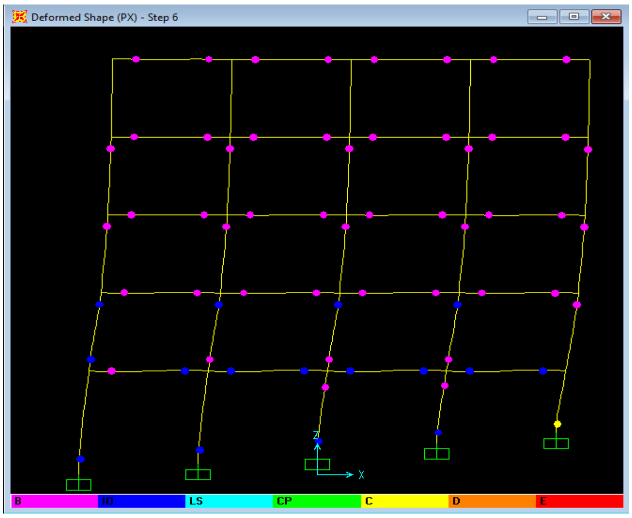

Fig. 12. Hinge pattern in for the model with 10% slope

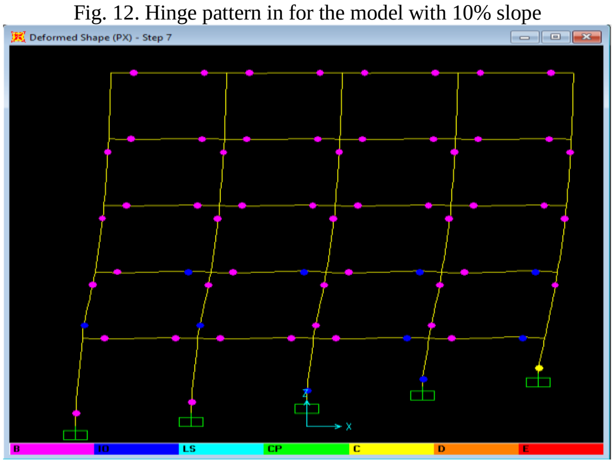

Fig. 13. Hinge pattern in for the model with 15% slope

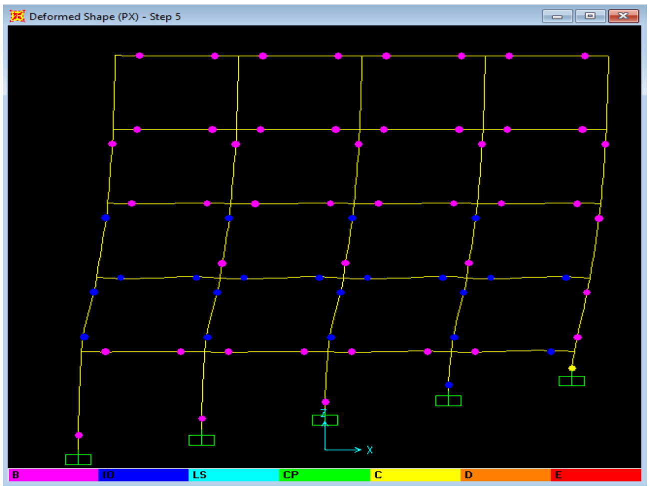

Fig. 14. Hinge pattern in for the model with 20% slope

E. Short column results (Response Spectrum Analysis)

To investigate the short column behavior of the building frame in terms of bending moment and shear force, linear – dynamic response spectrum analysis is performed on the above building frames. For response spectrum analysis, Importance factor 1, seismic zone factor 0.36 and soil type II is taken. The various load combinations are also used for this purpose. The bending moment, shear force and displacement for various configuration of slope angle are listed in table below:

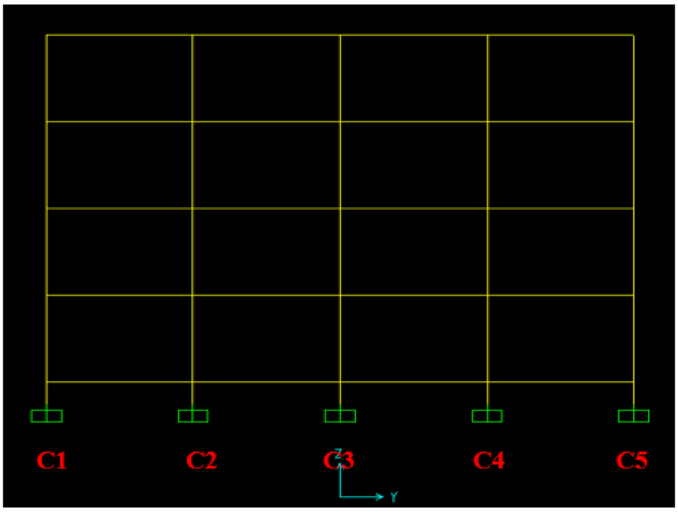

Fig. 15. Short columns chosen

TABLE IV: Variation of Bending Moment for various percentage of 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

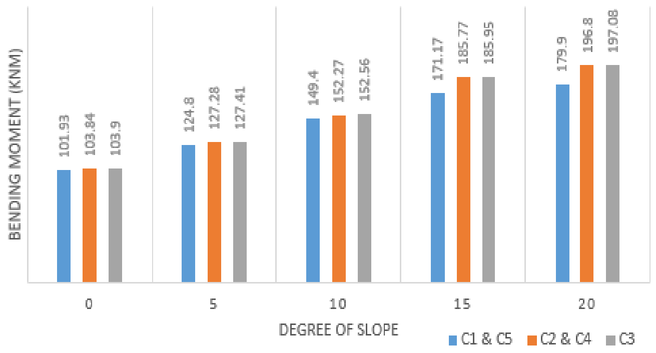

Fig. 16. Bending moment variation for various percentage of slope

TABLE V: Shear Force 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

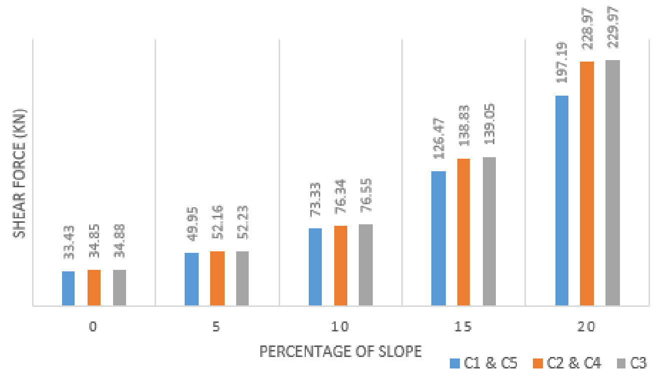

Fig. 17. Shear force variation for various percentage of slope

TABLE VI.: Variation of Displacement of of short columns for various percentage of slope

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

IV. CONCLUSIONS

1. RC buildings with short columns are found to damage severely in earthquake due to the accumulation of large stresses in short stiff columns.
2. Due to increase in stiffness of the structure the time period decreases with increase in degree of slope.
3. In flat lot structures the mode shape is translation and it changes to torsion for sloping lots. Torsional effect increases as degree of slope increases.
4. With the increase in slope the performance point base shear value increases.
5. With the increase in slope the performance point displacement decreases.
6. Bending moment and shear force of short columns increases with increase in slope.
7. With an increase of 20% slope the BM of short columns rises upto 90%.
8. With the increase of 20% slope the SF value increase 5.6 times the SF value that of flat lot structure.
9. Displacement of columns at ground level decreases as the columns become shorter and the displacement is 9 times greater for flat lot structure than for the structure on sloping lot (20% sloping).
10. In the case of flat lot structures collapse hinges are formed at lower storey columns while in sloping lot structures collapse hinges are concentrated at short columns leading to its failure through short column effect
11. In general, it is concluded that with the increase in sloping angle, the columns become more shorter and absorb large earthquake forces, resulting in their damage prior to other normal columns.

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