SKIT Research Journal Vol 15; ISSUE 1:2025 ISSN: 2278-2508(P) 2454-9673(O)

Short Column Effect

Sunita Tolani, Pooja Gupta, Amit Kumar, Anurag Meena, Arpit Meena
Department of Civil Engineering, Swami Keshvanand Institute of Technology, Management & Gramothan, Jaipur, 302017 (India)
Email: **sunitatolani1@gmail.com, pooja.gupta@skit.ac.in, btech19eskce013@skit.ac.in, btech19eskce019@skit.ac.in, btech19eskce020@skit.ac.in**
Received 23.09.2024 **received in revised form** 15.12.2024, **accepted** 10.01.2025
DOI: 10.47904/IJSKIT.15.1.2025.25-28

Abstract- Reinforced concrete (RC) buildings resting on sloping ground are more vulnerable to damage under seismic excitation than buildings on flat ground due to the presence of short columns. Due to high stiffness, short columns attract more earthquake force than the long columns, resulting in more damage. The present study aims to review recommendations mentioned in the available literature to minimize the short column effect on RC buildings, investigate the performance of a building resting the sloping ground, and study the impact of spacing of column lateral ties in minimizing damage of short columns. For this purpose, a three-storey RC building is modeled considering flat ground and sloping ground using ETABS software. The behavior of both the models under seismic excitation is studied using nonlinear time history analysis. Acceleration time history of past earthquakes El Centro (1940) is applied to the RC frame and the response of both the structures are compared. The structural response under seismic loading is investigated in terms of number of plastic hinges formed, top-storey displacement, and inter-storey drift.

Keywords– nonlinear time history analysis, structural response, RC building, ETABS

1. INTRODUCTION

When a building is situated on sloping ground, during an earthquake, all columns at a given floor level move horizontally by equal amounts along with the floor slab. If there are both short and tall columns on the same floor level, the shorter columns experience significantly higher earthquake forces and consequently incur more damage compared to the taller columns [1]. Under seismic excitations, these short columns exhibit very low ductility, and the behavior is governed by shear [2], [3].

1.1 Lateral Reinforcement in columns

The Indian Standard IS:13920-2016 [4] mandates that columns susceptible to the short column effect in RC structures must have continuous special confining reinforcement extending the entire height as per ductile detailing requirements. By experimental investigations, Jin et al., 2017 [5] demonstrated that under axial loading conditions, the increase in stirrup yield strength and stirrup ratio improves the strength and ductility of the columns. Cagatay et al., 2010 [6] studied the effect of placing infill walls surrounding the short columns of single and multistorey buildings, concluding that it reduces the shear force carried by the short column, thereby improving its performance under lateral loading.

1.2 Composite Sections

The experimental and finite element analyses conducted by Chaitanya et al., 2018 [7] have shown that by replacing the rounded bar of an RC column with mild steel angle sections, crushing failure of short columns can be reduced, as it improves the strength of the column significantly. According to Moretti and Tassios, 2007 [8], longitudinal reinforcement can be partially substituted by bi-diagonal reinforcement to enhance the ductility of short columns subjected to cyclic loading. Zhang et al., 2019 [9] concluded that the reinforced engineered cementitious composite (RECC) short columns and H-steel reinforced engineered cementitious composite (SRECC) short columns have high shear strength, crack control capacity, and ductility. Also, SRECC columns have higher ductility than RECC columns. Shahrour and Allouzi, 2020 [10] suggested that the shear capacity of columns can be increased by replacing limestone aggregates with basalt aggregates.

1.3 Retrofitting

Many investigations have examined the use of Fiber Reinforced Polymer (FRP) and Carbon fiber reinforced polymer (CFRP) in retrofitting existing structures to reduce the short column effect [11]–[15]. Colomb et al., 2008 [12] noted a significant alteration in the failure mode of columns due to FRP reinforcement. In the case of fully wrapped columns, the transition from brittle shear failure to ductile bending failure was observed, whereas strip-reinforced columns exhibited shear-bending failure. It was found that strip reinforcement offers a more favorable dissipative behavior compared to fully wrapped columns. Guo et al., 2022 [13] investigated the effect of retrofitting with TR-FRC, a textile-reinforced mortar system made of CFRP grid-reinforced short-fiber-reinforced concrete. It was observed that the retrofitted column has high ductility, energy dissipation capacity, and shear capacity. Dirikgil and Atas [16] noted that CFRP wrapping and the provision of diagonal reinforcement can significantly improve the lateral load behavior of columns.

2. NUMERICAL INVESTIGATION: SHORT COLUMN EFFECT IN RC BUILDING

2.1 Description of building model

To study the short column effect on RC building and the effect of lateral reinforcement in reducing this effect, a three-storey RC building is modeled using ETABS software considering two ground profile conditions: flat base and sloping base. The plan dimensions of the building are 16m x 12m with grid size 4m x 4m. Each storey height is 3m. Figure 1 shows a three-dimensional view of the building frame. The grade of concrete and steel reinforcement is M30 and Fe500 respectively. The building frame is designed for the gravity loads and earthquake load (for seismic zone V) as per the Indian standards [17]–[20]. Member dimensions and reinforcement percentages are as follows:

Column size: 450mm x 450mm; column reinforcement: 1.8%; ties: 10mm @ 150 mm c/c; beam size: 300mm x 450mm; beam reinforcement: 1.2% at the top face, 0.6% at the bottom face; slab thickness: 150mm. Beams are assigned with moment hinges at the ends, whereas for columns both moment and shear hinges are used to investigate the short column effect in columns. Nonlinear time history analysis is performed to investigate the performance of the structure. El Centro N-S (1940) acceleration time history is used for the analysis as it is the most well-documented earthquake ground motion. Its key characteristics are as follows: peak ground acceleration of 0.348g (N-S component); vertical component of 0.21g; and strong motion duration:30seconds.

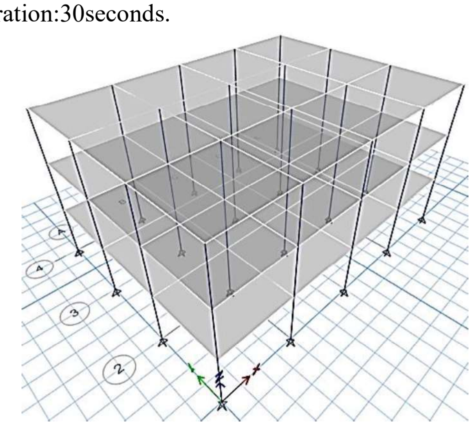

Figure 1: 3-dimensional view of the building frame

3. RESULTS AND DISCUSSIONS

3.1 Comparison of structural performance on flat ground and sloping ground

To compare the responses of the building under the two base conditions, four response parameters are considered: fundamental period, top storey displacement, inter-storey drift, and hinges formed in the structure. Figures 2 (a) and (b) show hinges formed in the structure after conducting a nonlinear time history analysis. It can be observed that when the building resting on the flat ground develops hinges at the ends of the beams the collapse state is not attained (no red hinges). Whereas, in the case of the structure resting on sloping ground, the bottom storey column at grid B failed due to shear, as the hinges have reached the collapse state.

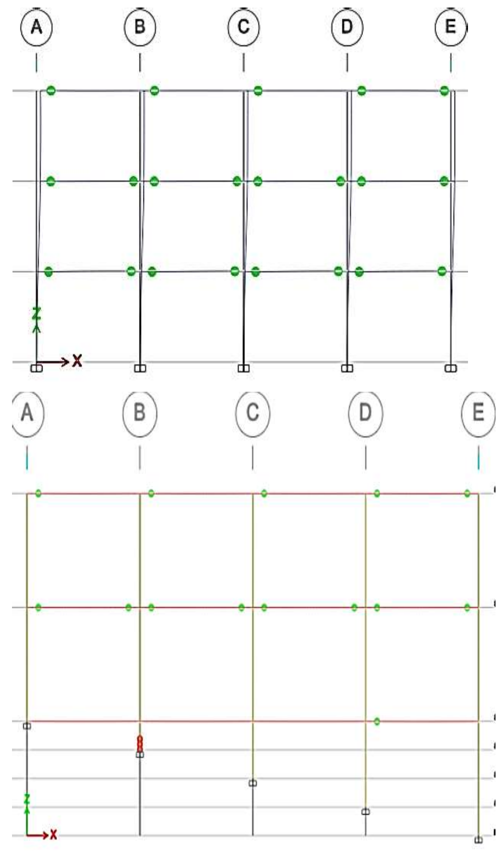

Figure 2: Hinges formed in building (a) on flat ground, (b) on sloping ground

Table 1 shows the comparison of the responses for the two cases mentioned above. The fundamental period of the building on sloping ground is less because the structure is stiff at the base. This increased stiffness also reduces the top storey displacement and inter-storey drift of the building.

Table 1. Fundamental period of structure (sec.)

Response quantity	Building on flat ground	Building on sloping ground
Fundamental period (sec.)	0.37	0.25
Top storey displacement (mm)	5.98	3.3
Inter-storey drift (%)	0.082	0.058

3.2 Effect of the ties spacing on the performance of structure on sloping ground

Figure 3 shows hinges formed in the building when tie spacing is reduced to 100mm c/c. When the results are compared with Figure 2(b), it can be observed that the column at grid B which was damaged in the previous case, is safe against shear when the tie spacing is reduced. As per IS 456: 2000 [17], the spacing of the ties shall not exceed the least of: (i) lateral size of the column; (ii) 16 d (d is the diameter of the longitudinal bar); and (iii) 300 mm. Also, ductile detailing code IS 13920:2016 [4] recommends that tie spacing should not exceed half of the lateral column size. The proposed spacing (100 mm) is within the permissible limit.

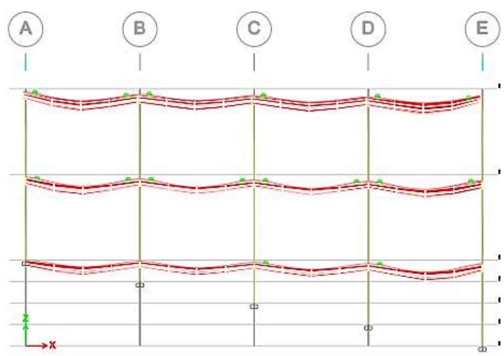

Figure 3: Hinges formed in the building for ties spacing 10mm @100mm c/c

4. CONCLUSIONS

Buildings resting on the sloping ground are highly susceptible to damage due to the short column effect. In the present study, various methods mentioned in the available literature for strengthening short columns are summarized. The effect of tie spacing on the performance of short columns under seismic excitation is also investigated with the help of numerical simulation using ETABS 20 software. The study draws the following conclusions:

1. The Fundamental period of structure is less in the case of building on sloping ground than on flat ground. Thus the building becomes stiffer when resting on sloping ground.
2. Inter-storey drift and top-storey displacement of buildings under earthquake excitation are less for buildings on sloping ground.
3. Reduction in stirrups spacing in bottom storey columns of building resting on sloping ground makes a significant effect on the performance of short columns. For this particular case of 3 storey building, when Elcentro (1940) time history is applied on both structures with 150mm spacing of column stirrups, the structure on flat ground is safe but the structure on sloping ground failed at the short column. When the spacing of stirrups is reduced to 100mm for building on sloping ground, the structure becomes safe.
4. The available literature suggests that by (i) increasing the yield strength of tie reinforcement and reinforcement ratio; (ii) providing composite sections; and (iii) retrofitting columns with FRP and CFRP, the performance of short columns under both gravity and seismic loading conditions can be improved

4. REFERENCES

[1] Murty, C. V. R., Earthquake Tip 22 - Why Are Short Columns More Damaged During Earthquakes?, Learning Earthquake Design and Construction, IITK-BMTPC, (2004).

[2] Li, Y. A., Huang, Y. T., and Hwang, S. J., Seismic Response of Reinforced Concrete Short Columns Failed in Shear, ACI Structural Journal, (2014), 111(4), pp. 945–954.

[3] Li, Y. A., Weng, P. W., and Hwang, S. J., Seismic Performance of Reinforced Concrete Intermediate Short Columns Failed in Shear, ACI Structural Journal, (2019), 116(3), pp. 195–206.

[4] Bureau of Indian Standards, IS 13920:2016 Ductile Design and Detailing of Reinforced Concrete Structures Subjected to Seismic Forces, BIS, (2016).

[5] Jin, L., Du, M., Li, D., Du, X., and Xu, H., Effects of Cross Section Size and Transverse Rebar on the Behavior of Short Squared RC Columns Under Axial Compression, Engineering Structures, (2017), 142, pp. 223–239.

[6] Cagatay, I. H., Beklen, C., and Mosalam, K. M., Investigation of Short Column Effect of RC Buildings: Failure and Prevention, Computers and Concrete, (2010), 7(6), pp. 523–532.

[7] Chaitanya, N., Ranga Rao, V., and Achyutha Kumar Reddy, M., Performance of Composite Reinforced Short Column Under Axial Loading, International Journal of Engineering and Technology (UAE), (2018), 7(3), pp. 1376–1380.

[8] Moretti, M., and Tassios, T. P., Behaviour of Short Columns Subjected to Cyclic Shear Displacements: Experimental Results, Engineering Structures, (2007), 29(8), pp. 2018–2029.

[9] Zhang, Y., Deng, M., and Dong, Z., Seismic Response and Shear Mechanism of Engineered Cementitious Composite (ECC) Short Columns, Engineering Structures, (2019), 192(May), pp. 296–304.

[10] Shahrour, N., and Allouzi, R., Shear Behavior of Captive- and Short- Column Effects Using Different Basalt Aggregate Contents, Journal of Building Engineering, (2020), 32(March), p. 101508.

[11] Haji, M., Naderpour, H., and Kheyroddin, A., Experimental Study on Influence of Proposed FRP-Strengthening Techniques on RC Circular Short Columns Considering

Different Types of Damage Index, Composite Structures, (2019), 209, pp. 112–128.

[12] Colomb, F., Tobbi, H., Ferrier, E., and Hamelin, P., Seismic Retrofit of Reinforced Concrete Short Columns by CFRP Materials, Composite Structures, (2008), 82(4), pp. 475–487.

[13] Guo, L., Deng, M., Li, R., Li, T., and Dong, Z., Shear Strengthening of RC Short Columns with CFRP Grid-Reinforced FRC Matrix: Cyclic Loading Tests, Journal of Building Engineering, (2022), 47(October 2021), p. 103915.

[14] Galal, M. A., Bandyopadhyay, M., and Banik, A. K., Dual Effect of Axial Tension Force Developed in Catenary Action During Progressive Collapse of 3D Composite Semi-Rigid Jointed Frames, Structures, (2019), 19(February), pp. 507–519.

[15] ElMandooh Galal, K., and Ghobarah, A., Flexural and Shear Hysteretic Behaviour of Reinforced Concrete Columns with Variable Axial Load, Engineering Structures, (2003), 25(11), pp. 1353–1367.

[16] Dirikgil, T., and Atas, O., Experimental Investigation of the Performance of Diagonal Reinforcement and CFRP Strengthened RC Short Columns, Composite Structures, (2019), 223(April), p. 110984.

[17] Bureau of Indian Standards, IS 456:2000 - Code of Practice for Plain and Reinforced Concrete, BIS, (2000), pp. 1–114.

[18] Bureau of Indian Standards, IS 875 (Part 1):1987 - Design Loads (Other Than Earthquake) for Buildings and Structures – Dead Loads, BIS, (1987).

[19] Bureau of Indian Standards, IS 875 (Part 2):1987 - Design Loads (Other Than Earthquake) for Buildings and Structures – Imposed Loads, BIS, (1987).

[20] Bureau of Indian Standards, IS 1893 (Part 1):2016 - Criteria for Earthquake Resistant Design of Structures, BIS, (2016).