



Study on Alleviation of Seismic hazard in Irregular Building Located on Plain and Sloping Ground

Dr. K.B. Parikh¹, Jayant Shaligram²

Associate Professor and Head¹, PG student²

^{1,2} Applied Mechanics Department, Government Engineering College-Dahod,
Jhalod Road, Dahod, Gujarat, INDIA

Abstract: It is impossible to avoid irregularities in building when better aesthetics and functional aspects are predominant. Building becomes extremely irregular if it possesses irregularity in vertical and horizontal direction with stiffness irregularity. In this paper, plan irregular open ground storey setback buildings resting on plain and 45 degree sloping ground have been analyzed using nonlinear time history analysis with and without replacing open ground storey columns by reinforced concrete filled steel tube columns. Mainly two models are considered resting on plain as well as on sloping ground i.e. RCCOL model and RCFSTC model. Performance of both the models has been evaluated in terms of storey displacement, storey drift, base shear and torsional response. It is observed that storey displacement, storey drift and torsional response are decreased by greater extent. Thus, RCFST columns provided in open ground storey alleviate the devastating effects due to presence of irregularities in the building during strong earthquake ground motion.

Keywords: Setback building, Open ground storey, Nonlinear time history analysis, Irregularities, RCFST column, ETABSv17

I. Introduction

Construction of irregular buildings are common due to land unavailability, functional as well as architectural aspects. Mahmoud et al. (2017) analyzed 12 storey Reinforced concrete moment resisting frame with and without fully infill walls as well as frame building with open soft storey at different levels in ETABS. It is noted that existence of a soft storey at a specified level highly magnifies storey drift at that level[1]. Choudhury and Kaushik (2018) assessed the seismic vulnerability of low to medium-rise masonry infill RC frames with different infill configurations. Nonlinear static pushover analysis was carried out in SAP2000 software for performance assessment of three types of building models such as bare frame, OGS and Fully infill model. It was observed that opening in masonry infills do not influence on lateral load behaviour of OGS frames and Seismic fragility of OGS frames found higher than the fully infilled and bare frames because OGS columns have lack adequate ductility, stiffness, and strength required to resist high storey shear[2]. Halkude et al. (2013) analyzed two different types of building frames which are common in hilly region namely step back and set back with step back using Response spectrum analysis. It was concluded that step back frames shows higher base shear, top storey displacement, time period and torsional response compared to Setback and Step back frame. As Hill slope increases top storey displacement and time period decreases[3]. Prakashvel et al. (2012) carried out experiment on RC frame building with open ground storey using Shake table test. The test was conducted for earthquake time history compatible to Response spectrum given in IS1893 taking Zone V and Soft soil. Shake table test results shows that strain values are higher in open ground storey columns and predominant hinges are formed in the same. Stiffness ratio after testing was reduced by 31.68% leading to exaggeration of soft storey effect[4]. Nagarjuna and Patil (2015) analyzed G+10 storey building resting on slope with varying angle from 10 to 40 degree having two different type of structural configuration namely step back and setback with step back building for earthquake loading as per linear static method and response spectrum method of IS 1893(Part-1). It was concluded that setback step back building configuration with shear wall placed at corners is suitable for the construction of building on sloping ground[5]. Mevawala and Desai (2016) analysed the G+5 and G+10 building resting on varying degree of slope using nonlinear time history analysis in SAP2000 software. It was observed that Bending moment and displacement increases as slope and height of the building increases[6]. Khan and Rawat (2016) studied the RC framed building with eccentric bracing at soft storey level and masonry infill at other upper storeys. The seismic performance of eccentric bracings for a G+6 building located in Indian seismic zone – V as per IS 1893-2002 were investigated using nonlinear static pushover analysis. The results of pushover analysis shows that buildings with eccentric bracings have lower drift demand and probability of collapse[7]. Ghosh and Debbarma (2017) studied on G+4

setback building resting on plain and sloping ground in which he compared three different mitigation measures such as provision of shear wall in OGS, designing the ground storey columns by 2.5 times moment and shear forces as per code and replacing ground storey columns by RCFSTC. RCFSTC found advantageous for setback building with OGS because RCFSTC do not block any access in OGS moreover stiffness is uniformly distributed over the whole base of the structure and RC column section is also not changing at the junction.[8] Structural irregularities are undesirable due seismic vulnerability. Urge of extracting natural beauty of the mountains and valleys, setback buildings become popular. But this kind of building hold various irregularity and if they rest on sloping ground, it becomes more severe condition during earthquake. Due to these undesirable factors present in the building, it is very important to investigate the response of such irregular building take suitable mitigation measures to save the life and property of inhabitants. In this study, plan irregular setback building is analysed with and without provision of reinforced concrete filled steel tube columns as a preventive measure and investigated the performance of the building using nonlinear dynamic analysis.

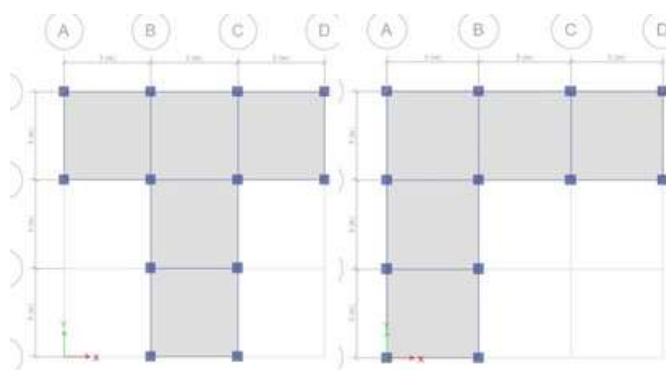
II. Research Methodology

The prime objective of study to evaluate the performance of the plan irregular setback building with and without replacing OGS columns by RCFST columns. To investigate the suitability of RCFST columns as a mitigation measure for plan irregular building resting on plain and sloping ground. Parameters under study are Storey Displacement, Base shear, Storey Drift and Torsional Response etc.

A. Details of Building model

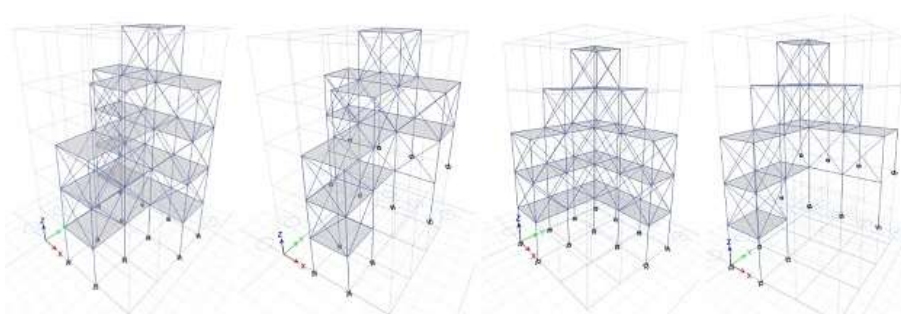
In this paper, Plan irregular T and L shaped G+4 Setback building with open ground storey located on plain and sloping ground is analysed in ETABS v17. Slope angle is kept as 45 degree with horizontal. Setback is provided on fourth and fifth storey. Infill walls are provided in the building in all the storeys except ground storey. Infill walls are modelled as equivalent diagonal strut using macro modelling approach. Equivalent strut length is same as diagonal length of wall. Width of strut is kept as one fourth of the diagonal length and thickness of strut is taken same as the thickness of wall Ghosh and Debbarma (2017). Diagonal Struts are modelled as two noded pinned line element. Columns are modelled as two noded vertical line elements and beam is modelled as horizontal line elements. Square shaped columns are used to avoid the effects of orientation of columns in this study. Slabs are modelled as four noded rectangular shell elements. Size of beams and columns are kept such that strong column-weak beam theory is justified. Base of each column is restrained all degrees of freedom, i.e. fixed support condition. Rigid diaphragm is applied to make all the structural elements act as a single unit. In this study, plan irregular T and L shaped G+4 setback building with plan dimension 9m × 9m building is taken resting on plain and sloping ground. Plan & 3D views of T and L shaped building are shown in Fig. 1 and in Fig. 2.

Figure 1 Plan of T and L shaped setback building



Each bay length is taken 3m and Slope angle is taken 45° with horizontal. Equivalent diagonal struts are designed as compression members. Here, tension limit, 0kN is assigned to struts. In this analysis takeda hysteresis model is employed. This model is considered as one of the best models that follow hysteresis rules for describing the nonlinear relation between the applied force and the corresponding deformation of the structural members Mahmoud *et al.* (2017). Two different models are used in analysis namely Open ground storey model and model with RCFSTC (Reinforced concrete filled steel tube column in ground storey for each shape of building on plain & sloping ground. Total 8 number of models are prepared. Notations of all these models are described in the Table 1.

Figure 2 3D view of building models in ETABS v17



B. Analysis methods

In this paper, all eight models have been analysed using nonlinear dynamic analysis method i.e. nonlinear time history analysis. Nonlinear time history analysis has been performed by employing Takeda hysteretic model. This model is considered as one of the best hysteretic models which follows hysteresis rules for describing the nonlinear relation between the applied force and the corresponding deformation of the structural elements. It is widely used by many researchers for nonlinear time history analysis and CSI also recommended to use it for reinforced concrete members. Nonlinear hinges such as Fibre P-M2-M3 hinges were assigned in RCFST columns and Defaults hinges M3 and P-M2-M3 were assigned to beams and columns respectively. As per ASCE 7 (2010), Minimum three earthquake ground motion data are required. In this study, Northridge (1994), Imperial Valley (1979) and San Fernando (1971) earthquake ground motions data have been used in time history analysis and scaling has been done by matching it with IS response spectrum using time domain approach of spectral matching in ETABS v17. Unscaled ground motion data is available at PEER ground motion database <https://ngawest2.berkeley.edu/>.

Table I Notations of 8 different set back building models

Models on Plain ground			Models on Sloping ground		
L Shape	OGS	LP1	L Shape	OGS	LS1
L Shape	RCFSTC	LP2	L Shape	RCFSTC	LS2
T Shape	OGS	TP1	T Shape	OGS	TS1
T Shape	RCFSTC	TP2	T Shape	RCFSTC	TS2

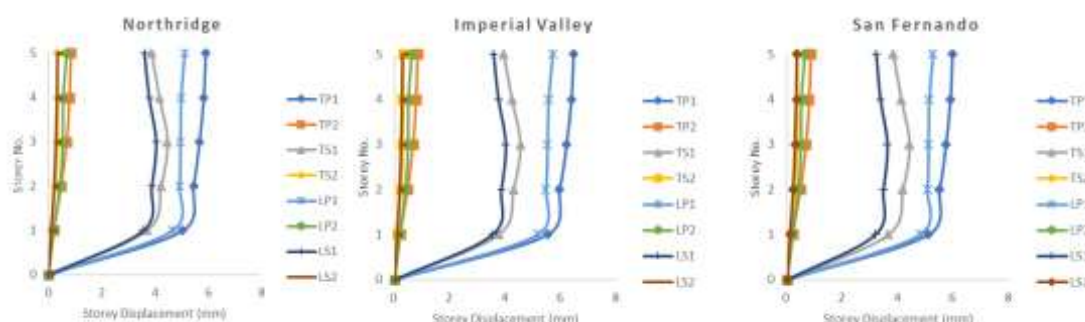
III. Results and Discussion

After analysing eight different models such as T & L shaped setback building resting on plain and sloping ground with various configuration two namely open ground storey (OGS) model and OGS model with RCFSTC at OGS. Both components of ground motion acceleration time history were applied in both orthogonal directions. Maximum response of the all building models in terms of various seismic parameters were recorded for each earthquake.

A. Storey displacement

Storey displacement is recorded for all the setback building models and results are shown in Fig.3

Figure 3 Maximum storey displacement (mm)

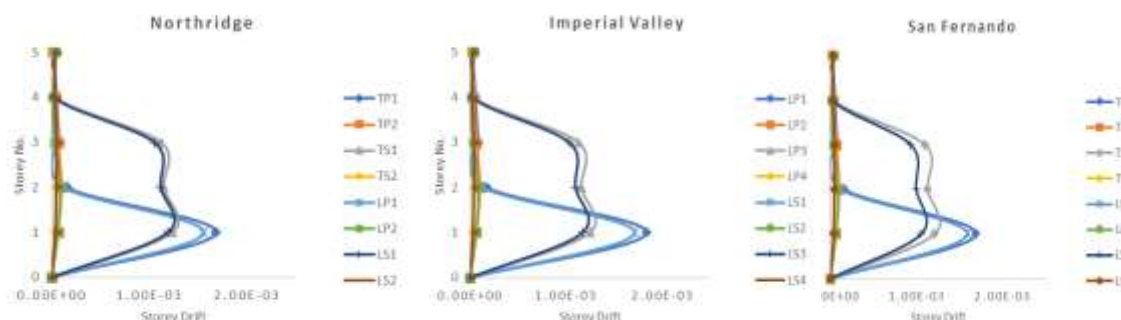


It has been found that provision of RCFST column enhances the performance by minimizing storey displacement by 85% to 88% in T & L shape setback building model on plain ground. For models on slope, storey displacement has been decreased by 88% to 92% after replacing OGS columns by reinforced concrete filled steel tube columns.

B. Storey drift

Storey drift is the relative displacement of two adjacent floors per unit storey height. Results of storey drift are shown in Fig.4 for all three earthquakes.

Figure 4 Maximum storey drift



It has been observed from the results of all three earthquakes that storey drift has been decreased by 96% in T & L shape setback building model located on plain ground. Whereas models on sloping shows decrease in storey drift by 97% with provision of RCFST columns in place of normal RC columns in open ground storey.

C. Base shear

Base shear depends upon mass and stiffness of the structure. Base shear of T & L shaped setback building models resting on plain and sloping ground is shown in Fig.5.

Figure 5 Base shear (kN)

From graphs of all three earthquakes, it can be observed that variation of base shear in different earthquake has found different after replacing open ground storey columns by reinforced concrete filled steel tube columns. The percentage variation of base shear has been described in Table 2.



Table IIIPercentage variation in base shear for different earthquakes

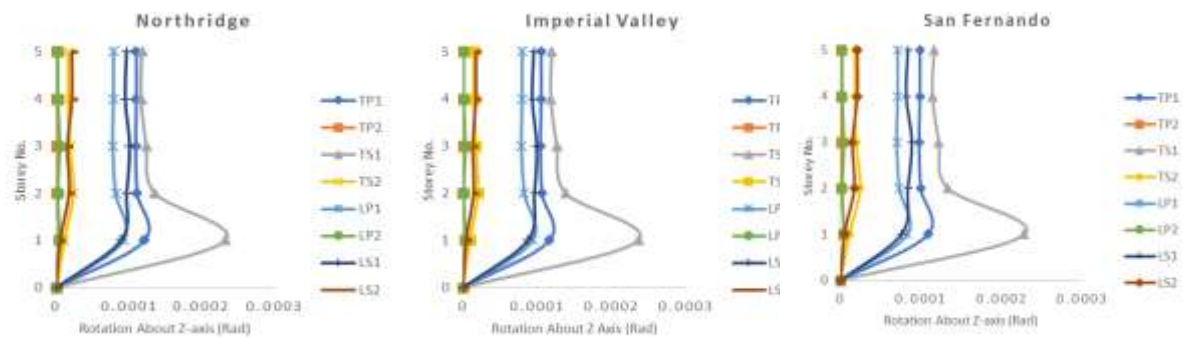
Northridge	-12.4	6.2	-12.1	13.8
Imperial valley	-8.6	12.4	-13.8	7.6
San Fernando	13.7	28.0	19.4	23.2

D. Torsional response

Plan irregular setback building models resting on plain and sloping ground possess irregularity in vertical as well as horizontal direction in terms of mass, stiffness and geometry. Due to this irregularities center of mass does not coincide with center of rigidity. Due to eccentricity, torsion arises. The building will rotate about its vertical axis. In this study, results are recorded in terms of rotation about vertical Z-axis in radian unit as shown in Fig.6.

It has been observed from the torsional response results of all three ground motions that torsional response has been decreased by 97% to 99% in models on plain ground and 75% to 87% in models on sloping ground after replacing open ground storey columns by RCFST columns.

Figure 6 Torsional response (rad)



IV. Conclusion

In this paper, attempt has made to alleviate seismic hazard in extremely irregular building by replacing open ground storey columns with reinforced concrete filled steel tube columns. From the results discussed, following conclusions can be drawn.

- The provision of reinforced concrete filled steel tube column in open ground storey decreases the storey displacements by 85% to 90%. Moreover, storey drift is decreased by around 97%.
- Torsion generated due to irregularities can be effectively minimized by around 98% if building rests on plain ground. It is reduced by 75% in plan irregular setback building resting on slope.
- Base shear decreases for building on plain ground and increases for building on sloping ground. Effects of various irregularities in the building during earthquake cause great damage to the building and for some strong ground motion it may also lead to collapse.
- It is concluded that RCFST columns provided in open ground storey enhance the performance of the plan irregular setback building and minimize the seismic hazard.

V. References

- [1] S. Mahmoud, M. Genidy, and H. Tahoan, "Time-History Analysis of Reinforced Concrete Frame Buildings with Soft Storeys," *Arab. J. Sci. Eng.*, vol. 42, no. 3, pp. 1201–1217, 2017.
- [2] T. Choudhury and H. B. Kaushik, "Seismic fragility of open ground storey RC frames with wall openings for vulnerability assessment," *Eng. Struct.*, vol. 155, no. August 2017, pp. 345–357, 2018.
- [3] S. A. Halkude, M. G. Kalyanshetti, and V. D. Ingle, "Seismic Analysis of Buildings Resting on Sloping Ground with Varying Number of Bays and Hill Slopes," vol. 2, no. 12, pp. 3632–3640, 2013.
- [4] J. Prakashvel, C. Umarani, K. Muthumani, and N. Gopalakrishnan, "Earthquake Response of Reinforced Concrete Frame with Open Ground Storey," vol. 2, no. 4, pp. 91–101, 2012.
- [5] Nagarjuna and Patil S, "Lateral Stability of Multistorey Building on Sloping," *Int. Res. J. Eng. Technol.*, pp. 1662–1669, 2015.
- [6] N. B. Mevawala and A. K. Desai, "Seismic Non-Linear Time History Analysis of Building Resting On Sloping Ground with Special Study on Nepal Earthquake," vol. 13, no. 3, pp. 60–66, 2016.
- [7] D. Khan and A. Rawat, "Nonlinear Seismic Analysis of Masonry Infill RC Buildings with Eccentric Bracings at Soft Storey Level," *Procedia Eng.*, vol. 161, pp. 9–17, 2016.
- [8] R. Ghosh and R. Debbarma, "Performance evaluation of setback buildings with open ground storey on plain and sloping ground under earthquake loadings and mitigation of failure," *Int. J. Adv. Struct. Eng.*, vol. 9, no. 2, pp. 97–110, 2017.
- [9] IS 1893:2016 (Part-1), "Criteria for Earthquake Resistant Design of Structures, Bureau of Indian standards, New Delhi, India.
- [10] IS 456:2000, "Criteria for Earthquake Resistant Design of Structures, Bureau of Indian standards, New Delhi, India.

VI. Acknowledgments

I would like to express my deep gratitude to Government Engineering College, Dahod, Government of Gujarat for enthusiastic encouragement and giving opportunity to carry out this research work.