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NONLINEAR ANALYSIS OF OPEN GROUND STORIED STRUCTURE RETROFITTED BY CROSS-STEEL BRACINGS

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Abstract

This case study focuses on mitigating the open ground storey (OGS) effect in a seven storied residential building situated in Guwahati (India) by considering cross steel bracings as a possible retrofitting scheme. Nonlinear dynamic procedure (NDP) was adopt-ed and scaled intensities of acceleration time history of a suite of six earthquakes were used. Appropriate scale factors were calculated by studying the peak ground acceleration (PGA) of these earthquakes in order to scale them as per the target response spectrum of Zone-V in accordance with IS:1893(Part-1)-2002. The effect of infill walls in the considered OGS building was studied. The response of the buildings was analyzed in terms of modal time periods, capacity spectrum, sequence of hinge formation, storey displacement, storey drift, and lateral shear. A comparative analysis was then done which revealed that the performance points for the retrofitted building are much higher. It was also observed that the retrofitted structure exhibited higher ductility displacement with least number of hinges formed in the early stages. Finally, conclusions were drawn regarding the suitability of cross steel braces as an effective retrofitting technique for the considered medium rise building.

Keywords: *Infill walls; Nonlinear dynamic procedure; Performance points; Scaling of ground motion; Soft storey.*

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1. Introduction

Earthquake reconnaissance reports of past earthquakes has shown that the presence of soft storey or open ground storey in multistorey buildings leads to complete collapse of the structure. A structure with presence of infill walls in all the floors, except ground floor, for parking or social gatherings, is termed as OGS structure.

Distribution of strength, stiffness and mass should be consistent throughout the building horizontally and vertically, as per seis-mic design philosophy. Improper orientation of wall infill, vertically and horizon-tally, in the structure will result in soft storey, weak storey, torsion, and short column effect. Presence of irregularity in structure will alter the load path that lead to severe damage during seismic events. Due to the real estate boom in metros, availability of space is difficult for parking and other facilities, and that leaves the choice of OGS construction. Thus, OGS as construction practice is difficult to eliminate from the architect's design criteria and hence it is preferable to provide special design criteria for such structural configuration.

Absence of infill walls in the ground storey will change the force transfer mechanism in the structure and OGS columns will accumulate higher stresses that lead to higher damage [1]. More amount of energy will be absorbed by soft storey members, causing larger interstorey drift leading to higher deformation in ground storey columns. Design criteria of OGS structures de-pend on relative stiffness and strength of ground floor with respect to the adjacent upper floor. International seismic codes suggest that columns and beams of the floor having soft storey are to be designed for higher moments to reduce the soft storey effect. Indian seismic code IS:1893(Part-1)-2002 recommends, beam and columns having soft storey effect require to be de-signed for 2.5 times higher design forces, to reduce soft storey effect [2]. Seismic response of OGS structures with full infill in the upper storey cannot be improved significantly even after using an amplification factor of 5 for ground storey columns [3]. Presence of openings in infill panel de-creases the stiffness and strength, thus recommended amplification factor for design of soft storey in up-per floors should depend on the opening area in the upper storey.

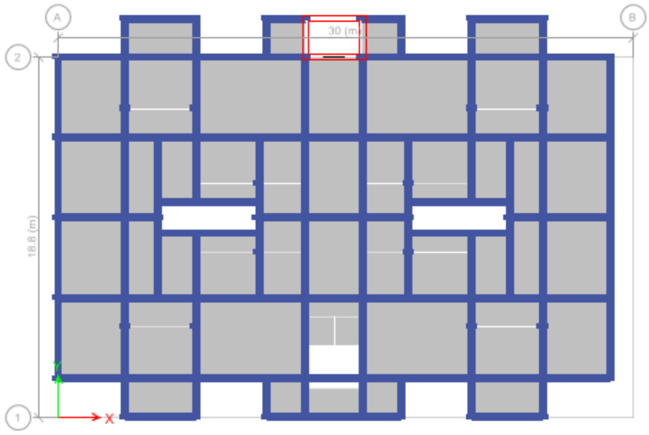


Fig. 1 - Plan of the building

In such buildings, major percentage of the base shear is required to be resisted by the beam-column joints of the ground storey. This leads to eventual collapse of the building. So it is very important to mitigate the effect of soft storey in buildings to a greater extend. In order to achieve this, various structural arrangements can be provided in the buildings [3], [6]–[13]. The most commonly adopted methods are: (i) providing infill walls, (ii) providing shear walls, (iii) providing steel bracings, (iv) providing cross steel bracings, and (v) using stiffer columns. It is very necessary to conduct an in-depth study on the nonlinear behaviour of the structure so that it gives the proper response of the structure during earthquakes [5]–[8]. In the present case study, a seven storied residential building was taken up. The buildings is situated at Guwahati, India which lies in the most seismically active zone of the country. Each floor, apart from the ground floor had four independent 3BHK flats with a box type shear wall at one end, serving the purpose of lift shaft and dog-legged stairs on the other end. The plan of the building are shown in Fig. 1 and 2. The blue lines indicate the placement of beams in the structure and the red lines indicate the positions of shear walls.

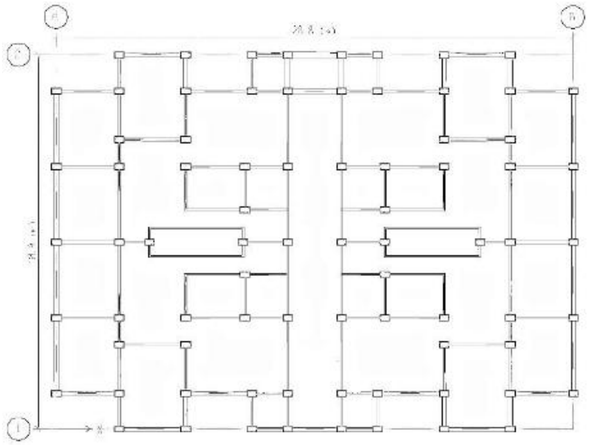


Fig. 2 - Wall placement in the structure

2. MODELING & ANALYSIS

For modelling the structure, line elements are used for beams and columns and concrete elements were used for slabs. All the degree of freedom is restrained by making the base of the structure rigid. The buildings are located in seismic zone V according to IS:1893-2002 (Part-1) and is founded on soil type II (medium soil). The details of the structural and non-structural members used in modelling are given in Table 1.
felling is given in Table 1.

Table 1: Building Description

S.No.	Description	Specifications
1.	Building Frame System	OMRF
2.	Ground Storey height	3.5m
3.	Typical Storey height	3.0m
4.	Type of soil	Medium (II)
5.	Support Condition	Fixed
6.	Grade of concrete	M30
7.	Grade of steel	Fe 415
8.	Live Load	3.5 kN/m^2
9.	Floor Finish	1 kN/m^2
10.	Infill Panel	Brick Masonry
11.	Importance factor	1
12.	Response Reduction Factor	3
13.	Column Size	600mm x 300mm
14.	Beam size	500mm x 350mm
15.	Slab Thickness	120mm
16.	Stair Slab Thickness	100mm
17.	Thickness of brick wall	230mm

The nonlinear hinge properties are assigned in the ETABS model. Moment hinges (M3) are assigned to the both ends of the beams, Shear hinges (V2) are assigned at mid length of the beams, axial force and biaxial moment hinges (P-M-M) are assigned to both ends of the columns, axial hinges (P) are assigned to the steel bracings. Geometric nonlinearity (P-delta) and large displacement is considered.

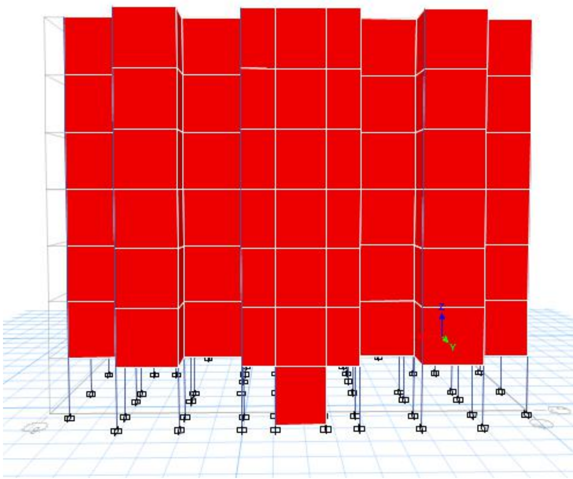


Fig. 3 - Basic elevation of the structure

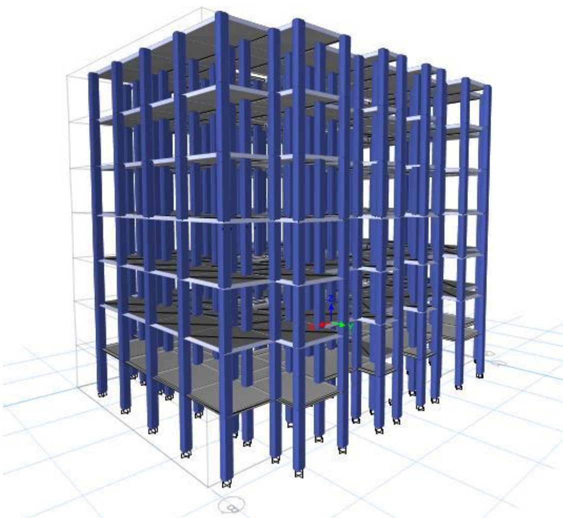


Fig. 4 - Parametric view of the Generated model (without infills)

2.1. Records for Time History

In the present study, the nonlinear dynamic analysis was adopt-ed. The generated models were subjected to a suite of six earthquakes whose intensities were scaled as per the target spec-trum of Zone-V as per IS:1893(Part-1)-2002. In this method, the response of a structure during an actual earthquake is obtained directly in terms of performance levels. This procedure of non-linear time history analysis (NTHA) is quite accurate for struc-tural design applications in which it gives an approximate peak response.

Table 2: Considered earthquakes for NTHA

SN	Earthquake	Country	Date	Station	Hypocentral Distance
1.	Chi Chi	Taiwan	25 Sept, 1999	TCU080	10.2 km
2.	El Centro	USA	19 May, 1940	USGS Stn. 0117	12.2 km
3.	Kobe	Japan	16 Jan, 1995	KJMA	1.0 km
4.	Landers	USA	28 June, 1992	CSMIP Stn. 22170	10.0 km
5.	Loma Prieta	USA	18 Oct, 1989	CSMIP Stn. 1667	65.2 km
6.	Northridge	USA	17 Jan, 1994	CSMIP Stn. 24514	9.9 km

Table 3: Scaling of Ground Motions (Target PGA of Zone V = 0.36 g)

SN	Earthquake	PGA (cm/s^2)	Target PGA (cm/s^2)	Scale factor
1.	Chi Chi	527.23	353.16	0.669
2.	El Centro	341.61	353.16	1.033
3.	Kobe	805.45	353.16	0.438
4.	Landers	268.31	353.16	1.316
5.	Loma Prieta	281.40	353.16	1.255
6.	Northridge	826.80	353.16	0.427

Table 4: Spectral Matching Details as per 'Seism Match 2016'

SN	Earthquake	Average Misfit	Maximum Misfit	Maximum Acceleration
1.	Chi Chi	5.1 %	23.9 %	0.973 g
2.	El Centro	4.3 %	29.2 %	1.128 g
3.	Kobe	4.4 %	28.1 %	0.963 g
4.	Landers	5.4 %	57.7 %	1.332 g
5.	Loma Prieta	6.5 %	21.0 %	1.084 g
6.	Northridge	3.0 %	22.8 %	1.110 g

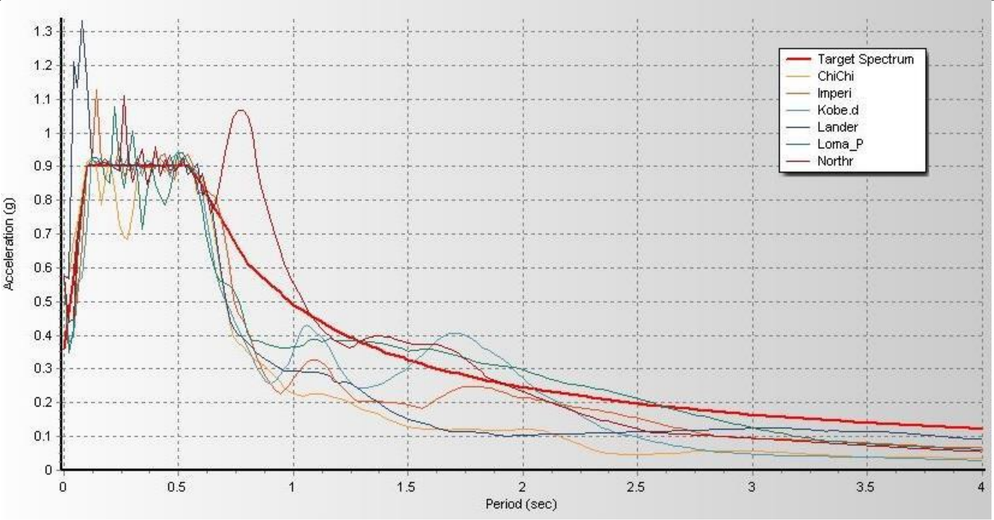


Fig. 5 - Scaled acceleration time histories of considered earthquakes

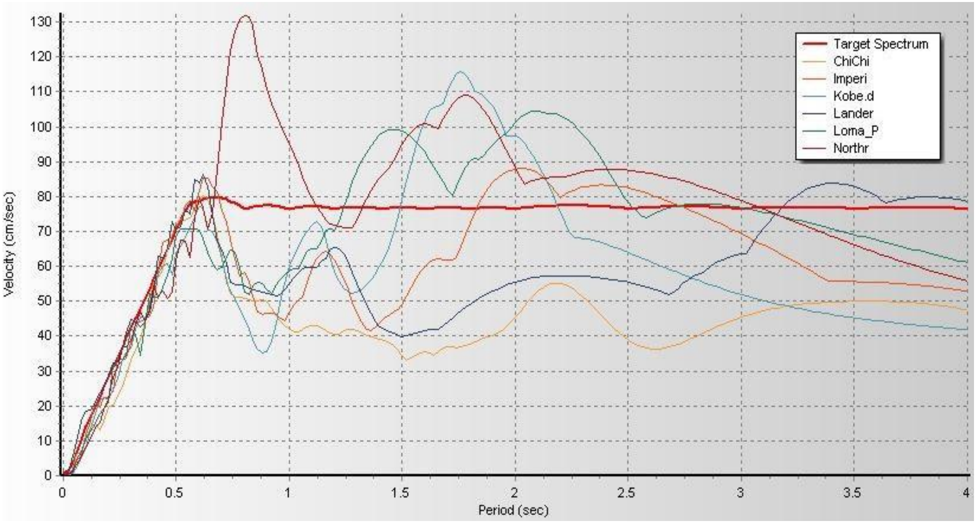


Fig. 6 - Scaled velocity time histories of considered earthquakes

2.2 Nonlinear Analysis

The structural performance level of the building can be classified into (i) Operational Level (OP) (ii) Immediate Occupancy (IO) (iii) Life Safety (LS) (iv) Collapse Prevention (CP). This definition of the performance level is provided by the FEMA 356 guidelines [10].

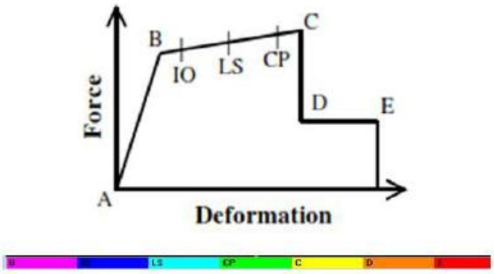


Fig. 7 - Force-Deformation for pushover analysis (Kiran et al, 2017)

A, B, C, D and E are the five points which are used to define the force-deflection behaviour of the hinges. In this, the region A-B represents the elastic state, B-IO represents the immediate occupancy state, IO-LS represents between immediate occupan-cy and life safety state, LS-CP represents between life safety and collapse point, CP-C represents between collapse point and ultimate capacity, C-D represents between collapse point and residual strength, D-E represents residual strength and collapse and >E shows collapse [18]–[20]. In ETABS, these states can be identified by color bands which shows the plastic hinge for-mation in each stage.

In the performance-based design approach, the inelastic seismic demands are based on the inelastic seismic ca-pacity of the structure. In the Capacity Spectrum Method, it gives the perfor-mance point at which the building shows the maximum perfor-mance due to seismic conditions and the design of the building is based on the dis-placement obtained from that performance point [8]–[12].

2.3. Retrofitting Using Cross Steel Bracings

The original OGS structure was retrofitted using cross steel brac-ings. These braces were added to the ground floor at pre-determined locations as shown below in Fig. 10, with the red lines showing the position of braces in the plan. Among the many possible alternatives, the most feasible section was found using the 'Auto Select' feature of ETABS and finally ISHB 150 was used for the braces, which were pinned to the existing beam column joints.

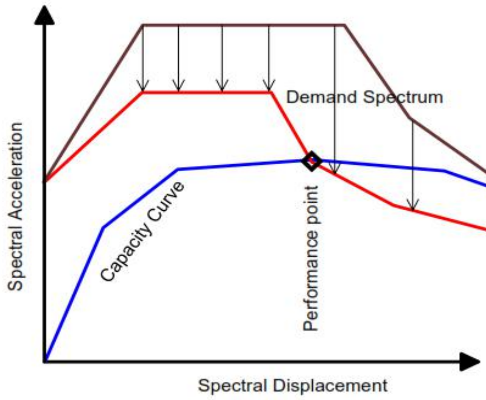


Fig. 8 - Performance based design approach (Kiran et al, 2017)

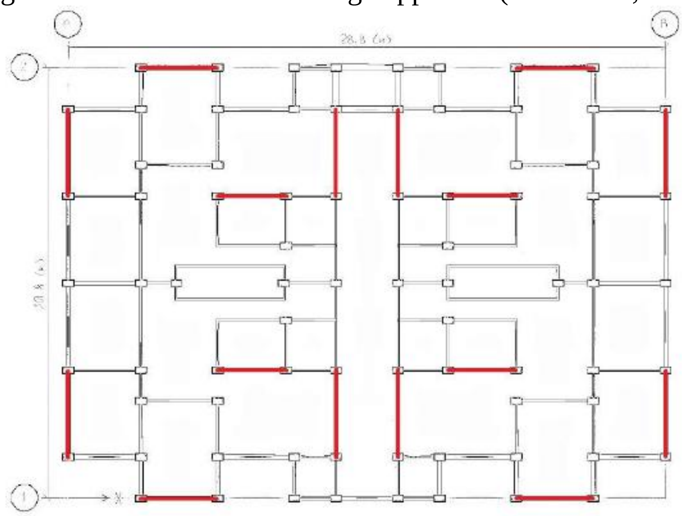


Fig. 8 - Performance based design approach (Kiran et al, 2017)

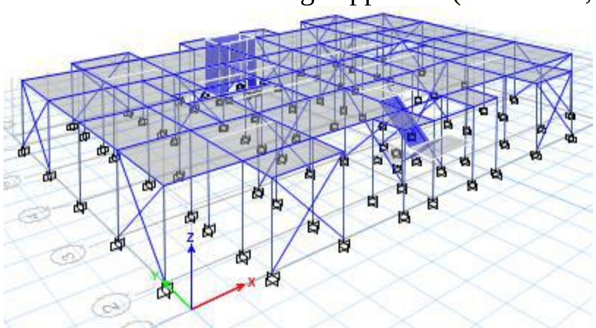


Fig. 9 - Mean Matched Spectrum

3. Results & Discussions

The structure models have been analyzed and the following result has been obtained. From Fig. 12, it can be seen that there is large displacement occurring at the bottom storey of the building which may be attributed to the absence of infills in the ground floor. But by the provision of cross steel bracings, the overall displacement of the building can be reduced to much extent.

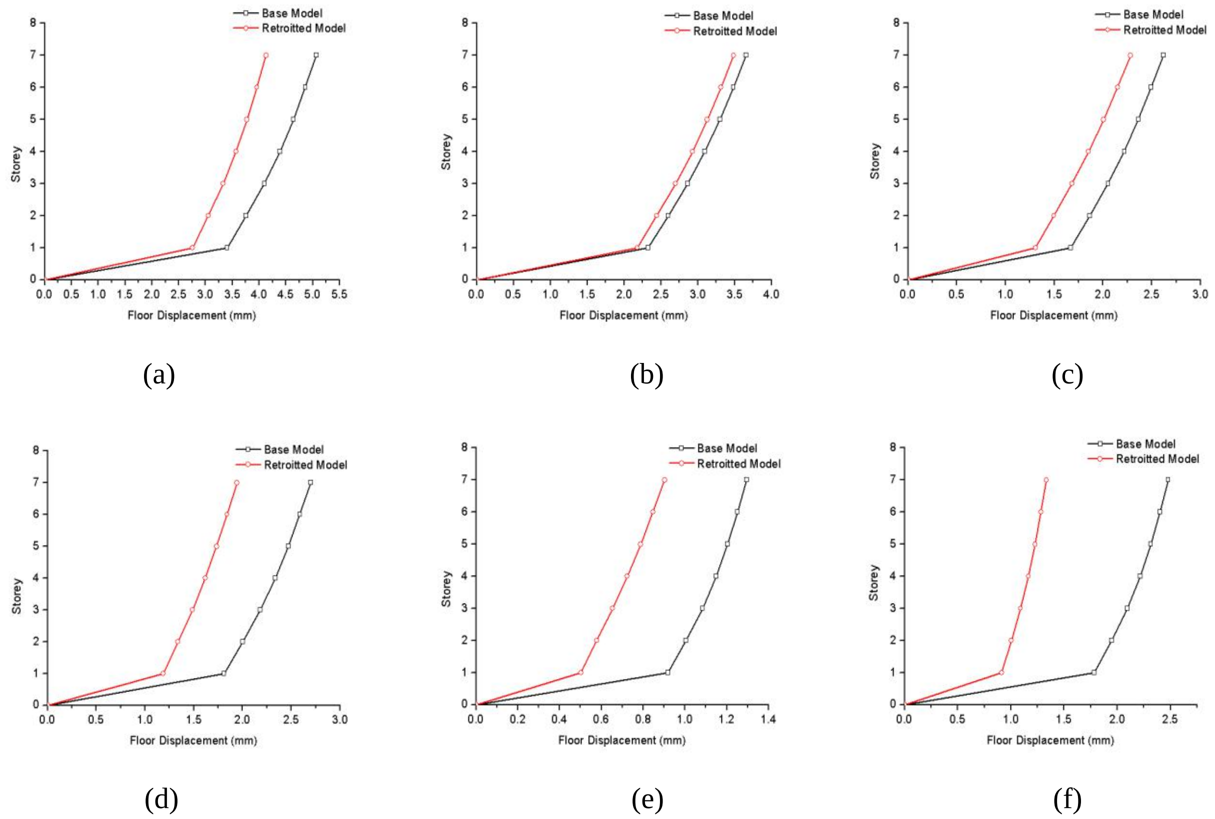
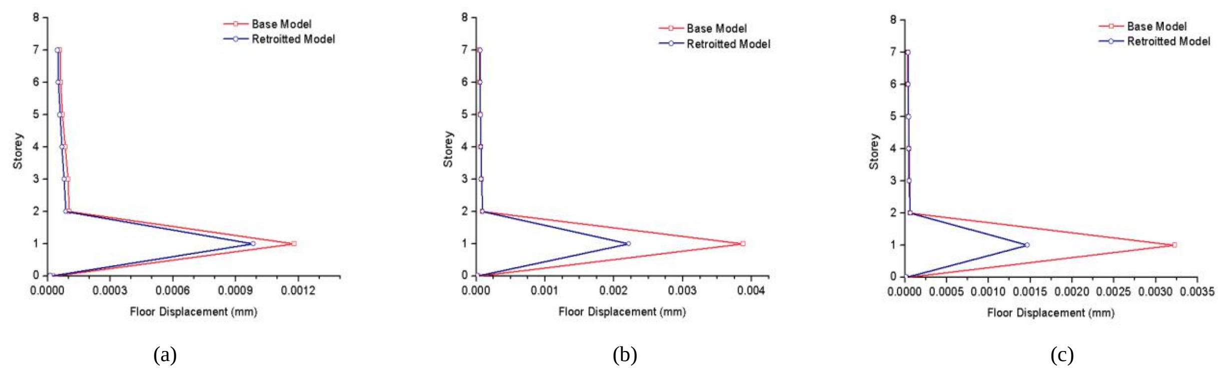
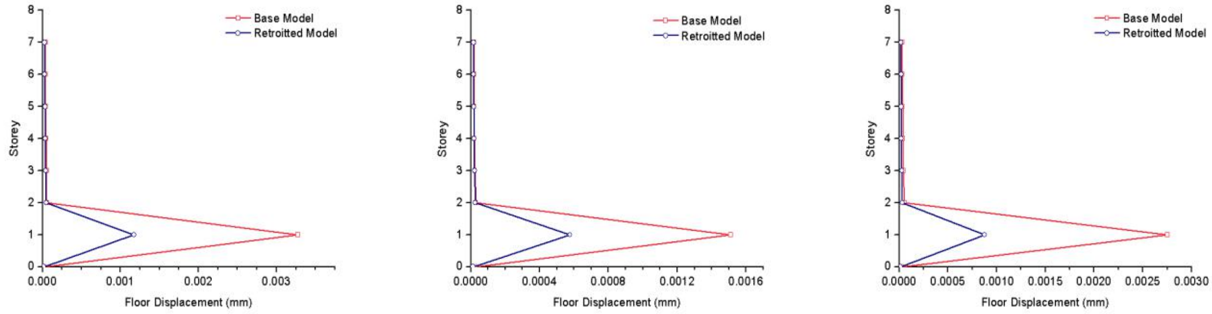


Fig. 12 - Observed values of Storey Displacement for: (a) Chi-Chi, (b) El-Centro, (c) Kobe, (d) Landers, (e) Loma Prieta, and (f) Northridge





(d) (e) (f)

Fig. 13 - Observed values of Storey Drift for: (a) Chi-Chi, (b) El-Centro, (c) Kobe, (d) Landers, (e) Loma Prieta, and (f) Northridge

From Fig. 13, it can be pointed out that as the height of the building increases, the storey drift is consider-ably reducing, i.e., there is a larger drift at the first storey level as compared to oth-er storey of the open ground storey building. It can be seen that the addition of bracings greatly reduces the ground storey drift, making the retrofitted model more earthquake resistant in com-parison to the base model.

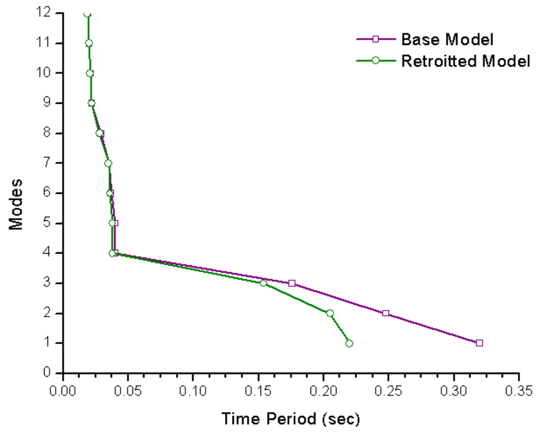


Fig. 14 - Modal Time Periods

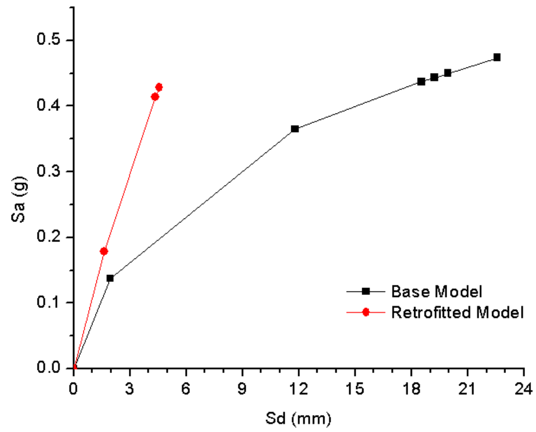


Fig. 15 - Capacity Spectrum

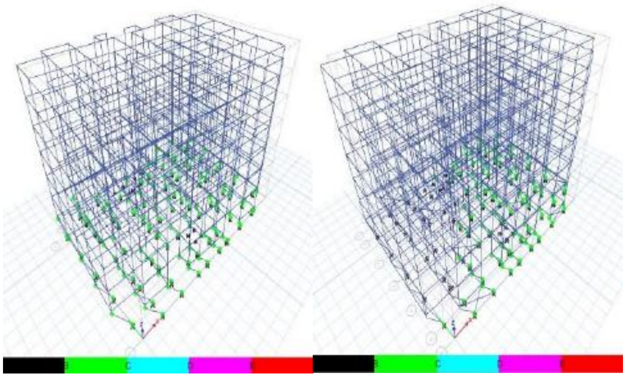
The modal time period of the retrofitted model, however, was found to be reduced in the case of first three dom-inant modes as indicated in Fig. 14, indicating that the structure was subject-ed to short period shaking. It is also evident from Fig. 15 that the retrofitted model will have a higher performance level owing to the lower spectral displacement. This performance level can be found by overlap-ping the capacity spectrum with the Sa vs. Sd curve of target spectrum where Sa stands for spectral acceleration and Sd stands for spectral displacement.

The ability of a structure to undergo inelastic deformation be-yond the initial yield deformation is termed as ductility dis-placement. The ductility displacement demand a given earth-quake load is obtained from the pushover curve. The more the ductility displacement the more ductile is the structure. It can be clear-ly seen that the retrofitted building has greater ductility displacement.

The plastic hinges may be applied to the beams, columns and bracings to study the nonlinear behaviour as they show the structural conditions at different stages. Hinges will attain a collapsible condition after passing through some intermediate stages i.e., immediate occupancy (IO) and life safety (LS) levels.

Table 5. Comparison of hinge formation in different configurations

Model	A-B	B-C	IO-LS	LS-CP	CP-C	C-D	D-E	>E	**Total**
Base Model	2529	145	53	10	15	0	0	0	2674
Retrofitted Model	2577	97	6	1	20	0	0	0	2674



(a) (b)

Fig. 16 - Hinge failure pattern for: (a) Base Model (b) Retrofitted Model

The formation of maximum number of hinges in the early stage is not good for the structure as it signifies the early reaching of collapse of the structure. From Table 5, it is clear that the number of hinge formation in retrofitted building is less compared to the base model, thereby making it safer.

4. Conclusions

The effects of OGS configuration in the considered multistoried residential building was studied. The building was situated at Guwahati, India which is the most seismically active region of India and lies in Zone-V as per IS: 1893 (Part-1)-2002. The building had the provision of parking in the ground floor be-cause of which infill walls were not added there. It was subject-ed to a suite of six different earthquakes which were scaled as per the target spectrum of Zone-V and the performance of the structure was evaluated in terms of storey drift, lateral dis-placement, capacity spectrum, modal time period and nonlinear hinge formation in the early stages. It was found that the building was still susceptible to severe damages in the ground floor owing to the soft storey arrangement. Having stated that, many possible alternatives for retrofitting were considered and finally cross steel bracings were selected. The most feasible ISHB 150 section was used and the results for retrofitted building were compared to the base model. Before mentioned discussions of nonlinear dynamic analysis all revealed cross bracing retrofitted models to exhibit enhanced performance characteristics. A financial feasibility study was also carried out, taking in to con-sideration the cost-benefit ratio, and it can be concluded that using cross steel braces is an effective technique of retrofitting the structure against lateral loadings.

References

[1] C.V.R. Murty and S.K. Jain, "Beneficial influence of masonry infill walls on seismic performance of RC frame buildings," 12th World Conf. on Earthquake Eng., 2000.

[2] Indian Standard Criteria for Earthquake Resistant Design of Structures Part I: General Provisions and Buildings, IS:1893(Part-1)-2002. New Delhi: Bureau of Indian Standards.

[3] S.S. Goud, P.K. Ramancharla, "Strengthening and repairing of 5-storey RC ductile detailed structure with open ground storey," 13th Int. Symp. New Technol. Urban Safety of Mega Cities in Asia USMCA, Yangon, 2014.

[4] A. Kaveh and P. Zakian, "Optimal seismic design of Reinforced Concrete shear wall-frame structures," KSCE J. Civ. Eng., vol. 18, no. 7, pp. 2181–2190, 2014.

[5] S. Kiran, G. D. Ramtekkar, and A. Titiksh, "Comparative study for mitigating the soft storey effect in multi storey buildings using different structural arrangements," Int. J. Civ. Eng. Technol., vol. 8, no. 3, 2017.

[6] R. S. Shekhawat, A. Sud, and P. Dhiman, "Economical Placement of Shear Walls in a Moment Resisting Frame for Earthquake Protection," Int. J. Res. Eng. Technol., vol. 3, no. 9, pp. 346–352, 2014.

[7] Y. U. Kulkarni, P. G. Chandak, M. K. Devtale, and S. S. Sayyed, "Analysis of Various Steel Bracing Systems using Steel Sections for High Rise Structures," Int. J. Eng. Technol. Manag. Appl. Sci., vol. 4, no. 6, pp. 220–227, 2016.

[8] Robin Davis, Devdas Menon and Meher Prasad, "Earthquake Resistant Design Of Open Ground Storey RC Framed Buildings", J. Struct. Eng., vol. 37, no. 2, pp. 117–124, 2010.

[9] Masanobu Shinozuka, Maria Q. Feng, Ho-Kyung Kim, and Sang-Hoon Kim, "Nonlinear Static Procedure For Fragility Curve Development", J. Eng. Mech., vol. 126, no.12, pp. 1287–1295, 2000.

[10] Bhagavathula Lohitha and S.V. Narsi Reddy, "Earthquake Resistant Design Of Low-Rise Open Ground Storey Framed Building", Int. J. Mod. Eng. Res., vol. 4, no. 6, 2014.

[11] Saurabh Singh, Saleem Akhtara and Geeta Bathama, "Evaluation of Seismic Behavior For Multistoried RC Moment Resisting Frame With Open First Storey", Int. J. Curr. Eng. Technol., vol.4, no.1, 2014.

[12] V. Govalkar, P. J. Salunke, and N. G. Gore, "Effect of Curtailment of Shear Wall in Bare Frame and Infilled Frame," Int. J. Emerg. Sci. Eng., vol. 2, no. 9, pp. 35–42, 2014.

[13] Cornell C. Allin, Fatemeh Jalayer, Ronald O. Hamburger and Douglas A Foutch, "The Probabilistic Basis For The 2000 SAC/FEMA Steel Moment Frame Guidelines", J. Struct. Eng., vol.128, no. 4, pp. 526–533, 2002.

[14] G. Bhatt, A. Titiksh, and P. Rajepandhare, "Effect of Curtailment of Shear Walls for Medium Rise Structures," in 2nd Int. Conf. Sust. Comp. Tech. Eng. Sci. Mgmt. (SCESM-2017), 27-28 January 2017, pp. 501–507.

[15] F. Hejazi, S. Jilani, J. Noorzaei, C. Y. Chieng, M. S. Jaafar, and a a A. Ali, "Effect of Soft Story on Structural Response of High Rise Buildings," IOP Conf. Ser. Mater. Sci. Eng., vol. 17, no. February, p. 12034, Feb. 2011.