Innovative Infrastructure Solutions (2021) 6:160
https://doi.org/10.1007/s41062-021-00548-3

TECHNICAL PAPER

Analysis of multi-story buildings with hybrid shear wall: steel bracing structural system

Shubam Sharma[1] · **Aditya Kumar Tiwary**[1]

Received: 19 December 2020 / Accepted: 22 May 2021 / Published online: 11 June 2021

Abstract

Numerous studies were contemplated on the structures with distinctive structural configuration and ample amount of work is currently being performed through the investigation of the response of individual behavior of shear walls and bracings by varying configurations and their material properties. Seismic design philosophies had mentioned firmly that a structure must accomplish Life Safety and Performance Level for both reinforced concrete and steel structures. This study is anchored on prevailing lateral load resisting system which is virtuous but not adequate to retain vigorous ground motion or acceleration. To overwhelm this problem, an attempt was made to familiarize a new lateral load resisting system formulated by the amalgamation of two different existing lateral load resisting systems, specifically shear walls and bracings. The hybrid structural system embraces two distinctive lateral load resisting techniques, shear walls, and bracings for moment-resisting frame. A numerical finite element study was carried out by the linear dynamic method on the response of structure subjected to seismic condition and an optimal configuration of the different structural patterns is assured by using numerous possible patterns of a hybrid structural system using finite element-based software. The criteria contemplated for study including time period, base shear, overturning moment, story drift ratio, and story displacement are compared with different models and the optimal structure is concluded based upon the recital. The comparative results revealed that there is a reduction noticed in the fundamental time period, and story displacement, where as there is negligible increment in base shear and overturning moment for the hybrid structural system as compared to other configurated models.

Keywords Hybrid structure · Shear wall · Steel bracings · Story drift · Story displacement · Non-linear analysis · Dynamic response · Finite element analysis

Introduction

The shear walls and bracings both are tremendous techniques that can be implemented in the building to escalate seismic enactment. The shear wall as compared to the bare frame exceedingly improves the overall performance of the structure [1], revealing that there was a progressive impact seen on the frame with the shear wall compared to the bare frame. The shear wall on the adverse side upsurges the seismic weight of the building and accordingly, the overturning moment radically increases, and base shear also shows progression as compared to the bare frame, but steel bracings do not increase the overturning moment and base shear drastically. The use of steel bracings [2] and the experimental assessment concluded that there was an intensification in both lateral strength and stiffness of the frame. The use of steel braces entails a strong connection between braces and columns to turn out to be a resilient structure. Although many comparative studies have already been accomplished among the different types of bracing system such as *X*, Diagonal, Zipper, *ZX*, *K*, Eccentric, Chevron with and without vertical links and Knee bracing system [3–7], reveals that *X*-bracings show good inelastic behavior [5], but in terms of ductility diagonal bracing system predominates. The seismic assessment [6, 8, 9] shows an upsurge in the stiffness, energy dissipation rate, and strength reduction factors. Other than distinctive bracing patterns, many studies on assessing different steel sections are also conducted [4] and a relative study on the performance of *I* (HEA and IPE) and the

✉ Shubam Sharma
shubhumsharma03@hotmail.com

Aditya Kumar Tiwary
adadtiwary15@gmail.com

[1] Department of Civil Engineering, Chandigarh University, Mohali 140413, India

tube sections were conducted, indicating that the tube section had performed better than the others [4]. It was also found that the small tube section yields high ductility than the larger section (Tube 220 to 300) [4]. Non-linear static analysis [10] outcomes resolved that there is a reduction in seismic vulnerability by the use of steel braces as a retrofitting technique. Contrasting economic factors, steel bracings yy are economical as a retrofitting method compared to other unorthodox methods like adding shear wall, providing base isolation system, and adding a concrete wall. There are sufficient provisions used as lateral load resisting system, but tolerable performance is only obtained when lateral drift is under limits as it gives severe damage to the structure. The seismic study embraces various parameters (story drift, story displacement, overturning moment, and time period of the building) that should be based and checked upon different codes before verifying a structure is safe. Every single aspect has a different consequence and upon all of these storeys, drift is highly critical [11], and IS 1893:2016 [12] defined limits for it. The use of a bracing system results in a considerable amount of increase in the axial forces in the column [5]. Contrasting time period of the building [13–15] revealed that the height of the building was contributing more than other parameters. Past works also concluded that [16–20] the extreme amount of peak ground acceleration not necessarily to result in the maximum value of roof acceleration, displacement, and base shear. There are numerous distinctive configurations, by which steel bracings are added [4, 8, 9, 14, 15, 21–23] and similarly distinctive patterns of shear walls, primarily L, coupled and rectangular. Provoked from the literature, as a new lateral load resisting system, i.e., Hybrid Structural System (HSS) is introduced to enhance seismic performance so that the demerits of shear walls are overwhelmed by steel bracings and vice versa. The hybrid structural system enhances the efficiency of the model by reducing story displacement and story drift while base shear and overturning moment show minimal increments, which is acceptable. Comparing the hybrid structural system with the shear walls, story drifts, and displacements were reduced but the base shear and overturning moment also increased in case of the shear wall which is overwhelmed by hybrid structural system. Further steel bracings are advantageous as no such drastic increment is noticed in base shear and overturning moment but their efficiency to reduce story drifts and displacements is less. Thus, hybrid structural system fulfills both the conditions, i.e., reduction of story displacement and story drift by controlling the base shear and overturning moment.

Modeling

Linear dynamic behavior [16] of a reinforced concrete frame located in Tehran, Iran is analyzed and various parameters were contemplated in this study. Fifty reinforced concrete MRFs (Moment-Resisting Frames) having a plan of 5 by 3 bays traversed by 23 m by 12 m by varying 10, 20, 30, 40, and 50 stories located at vulnerable seismic zone IV and IS 1893:2016 [12] provisions were followed for seismic classification. The loading conditions were followed as per IS 875:1975 [24] for dead load, IS 875:1987 [25] for live load, and for seismic loading conditions IS 1893:2016 [12] was followed. The structural member dimensions were assumed as per IS 13920:2016 [26] and IS 456:2000 [27]. The thickness of the shear walls was assumed as the minimum required specified as per IS 13920:2016 [26]. The grade of concrete adopted was M25 as a minimum required as per IS 13920:2016 [26]. The seismic analysis was carried out using Response Spectrum Method IS 1893:2016 [12], and the design spectrum is shown in Fig. 1 for Seismic Zone IV corresponding to 5% damping ratio and Type-2 soil having an importance factor of 1.2.

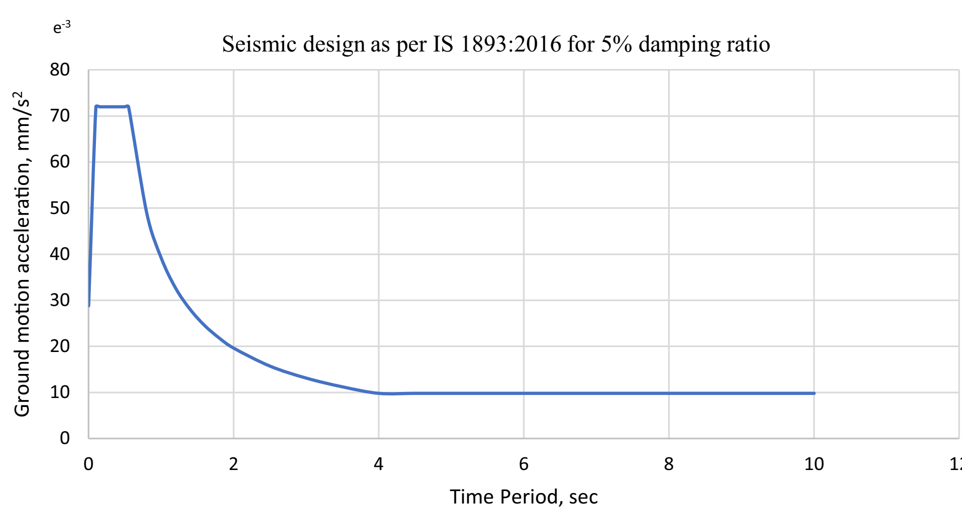


Fig. 1 Seismic design considered for study

Table 1 Material and mechanical properties

S. no	Property	Value
I	Density of concrete	25 kN/m^3
II	Modulus of elasticity of concrete	25,000 MPa
III	Poisson ratio of concrete	0.2
IV	Coefficient of thermal expansion of concrete	0.0000055
V	Shear modulus of concrete	10,416.67 MPa
VI	Directional symmetry type of concrete and steel	Isotropic
VII	Modulus of elasticity of rebar	200,000 MPa
VIII	Coefficient of thermal expansion of rebar and steel	0.0000117
IX	Minimum yield strength of rebar	415 MPa
X	Minimum tensile strength of rebar	485 MPa
XI	Expected yield strength of rebar	456.5 MPa
XII	Expected tensile strength of rebar	533.5 MPa
XIII	Modulus of elasticity of steel	210,000 MPa
XIV	Poisson ratio of steel	0.3
XV	Shear modulus of steel	80,769.23 MPa
XVI	Minimum yield strength of steel	250 MPa
XVII	Minimum tensile strength of steel	410 MPa
XVIII	Expected yield strength of steel	275 MPa
XIX	Expected tensile strength of steel	451 MPa

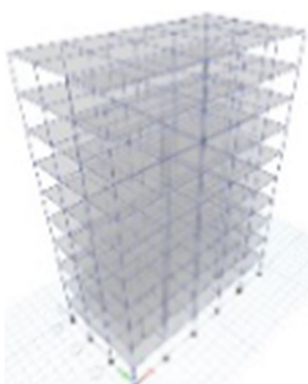


Fig. 2 Bare frame (BF)

Five groups viz. G1, G2, G3, G4, and G5 were prepared for analysis and each group contains 10 models with different possible patterns. Group G1 indicates the 10-story models, G2 represents the 20-story models and correspondingly G3, G4, and G5 represent the models of 30, 40, and 50 stories concerning viable configurations. Table 1 represents the material and mechanical properties of concrete, rebars, and steel considered for modeling and analysis.

Figures 2, 3, 4, 5, 6, 7, 8, 9, 10 and 11 illustrate the models of 10-story buildings, Bare Frame (BF), Shear Wall (SW), Steel Bracings (SB), Shear Walls with Bracings (SWBR) or Hybrid Type-1, and rest 6 models (SW + SB)

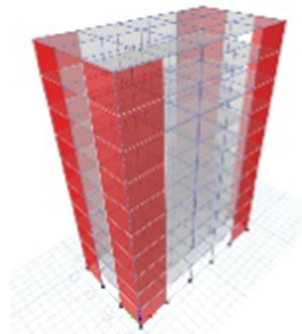


Fig. 3 Shear wall (SW)

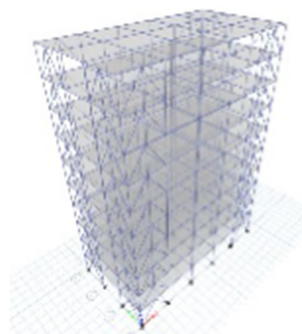


Fig. 4 Steel bracings (SB)

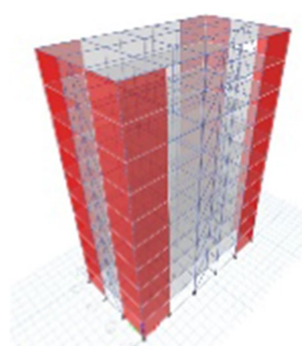


Fig. 5 Shear wall with steel bracings (Hybrid Type-1)

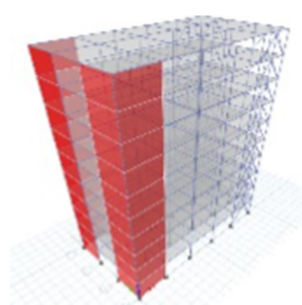


Fig. 6 Shear wall replacing bracing pattern 1 (Hybrid Type 2-1)

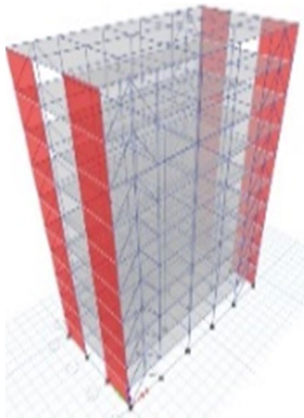


Fig. 7 Shear wall replacing bracing pattern 2 (Hybrid Type 2-2)

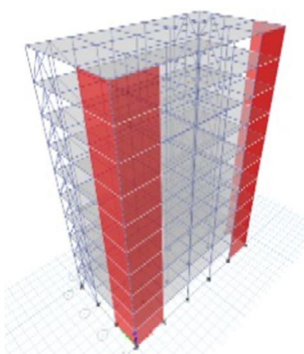


Fig. 8 Shear wall replacing bracing pattern 3 (Hybrid Type 2-3)

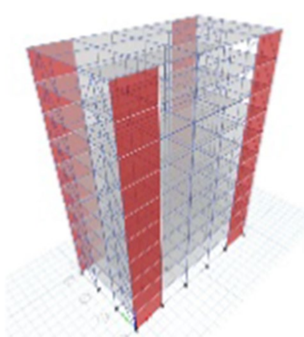


Fig. 9 Shear wall replacing bracing pattern 4 (Hybrid Type 2-4)

or Hybrid Type 2 are the possible patterns with the location of shear wall spared with bracings, respectively. The base dimension and member sizes are analogous in all the models. The bracings used were Zipper, and the tube section is preferred as it is highly ductile [4]. The plan is similar to all the models represented in Fig. 12. Similarly, the groups G2, G3, G4, and G5 are represented in Figs. 13, 14, 15 and 16,

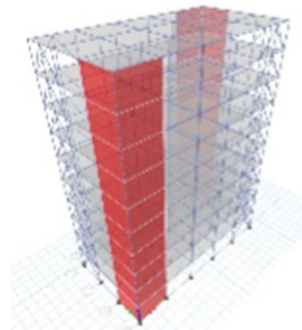


Fig. 10 Shear wall replacing bracing pattern 5 (Hybrid Type 2-5)

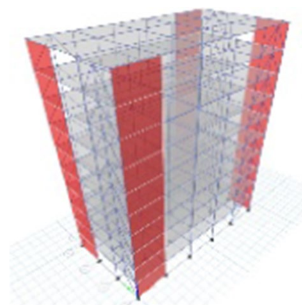


Fig. 11 Shear wall replacing bracing pattern 6 (Hybrid Type 2-6)

respectively. The diaphragm is such that it possesses actual in-plane possessions and thus reflects deformation and the forces associated with it. The joint behavior between the steel braces and the concrete members is rigid. As depicted in Fig. 12, the mesh size was adopted as such it is uniform all over the assigned members to obtain enhanced FEM results. The size of the mesh was auto-detected by the software for uniform division of members. The mesh size was assigned as 0.92 m and 1 m in X- and Y-direction, respectively, by using ETABS inbuilt mesh tool.

Seismic evaluation

The models were subjected to linear dynamic analysis using Response Spectrum method and the analysis was carried out as per provisions of IS 1893:2016 [12] using finite element method based software CSI-ETABS [23].

Various critical parameters investigated were time period, story drift, story displacement, base shear, and overturning moments and an ideal structure was recommended. The fundamental time period of the building as mentioned in Fig. 17 clearly indicates that Hybrid structure type-1 is performing better than others, and the performance of Hybrid Type-2–4 lies between buildings with shear walls and steel bracings. Aiming at the base shear as in Fig. 18 for different

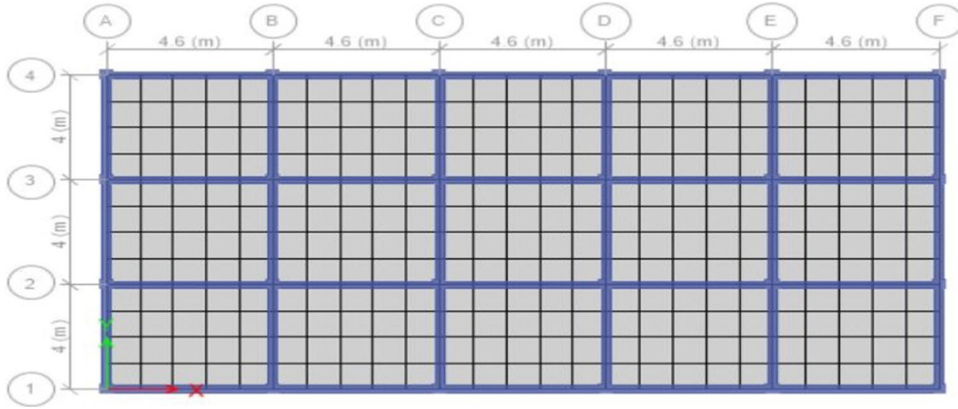


Fig. 12 Plan view

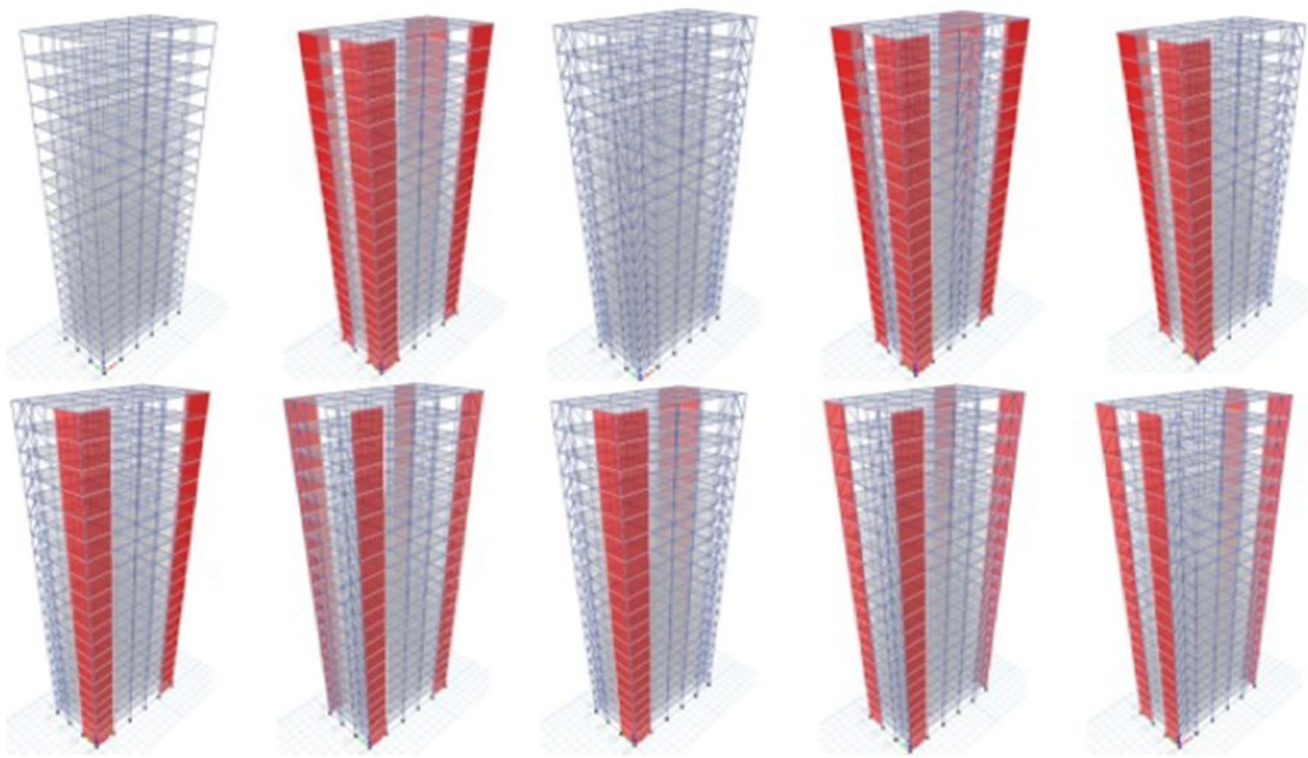


Fig. 13 Models grouped as G2

configurations, there is a clear indication of the least increments of base shear seen in the buildings with steel bracings as 0.95%, 0.66%, 0.83%, 1.79%, and 1.05% for groups G1 to G5, respectively. After that hybrid structural type-2 with variations of 11.09% to 12.04% for G1, 10.19% to 11.52% for G2, 10.19% to 11.75% for G3, 11.46% to 12.92% for G4, and 10.42 to 11.9% for G5 is noticed. The shear wall structures and Hybrid structure type-1 show maximum increment rates of 21.55%, 20.92%, 21.34%, 22.58%, and 16.42% for the shear wall structures from G1 to G5, and the rates of increment for hybrid structure type 1 are 21.87%, 21.58%, 21.70%, 23.70%, and 22.84% for G1 to G5, respectively. Table 2 represents the variation of dynamic results of base shear between manual calculations and software results and are under the maximum permissible limit.

Contrasting top story displacements shown in Figs. 19 and 20, there was a drastic reduction seen in Hybrid structure type-1 with a reduction of 90% in *Y*-direction in 50-story building structures compared to the bare frame.

Contrasting on the overturning moment from Fig. 21, it is cleared from the results that the *X*-direction steel bracings perform better than other structural systems as 10, 20, and 50 story buildings show reductions of 1%, 23% and 50% as compared to the bare frame. The 30 and 40 story frame

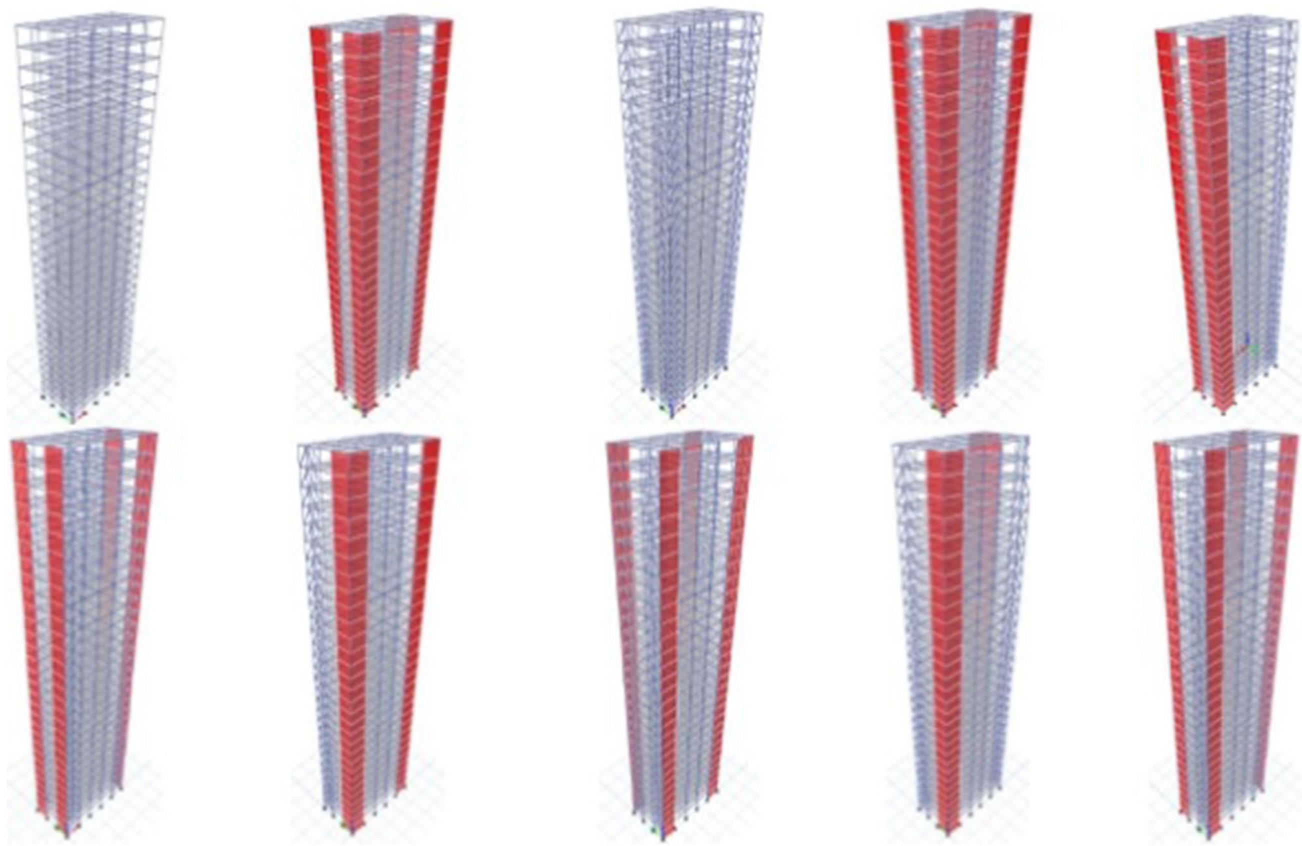


Fig. 14 Models grouped as G3

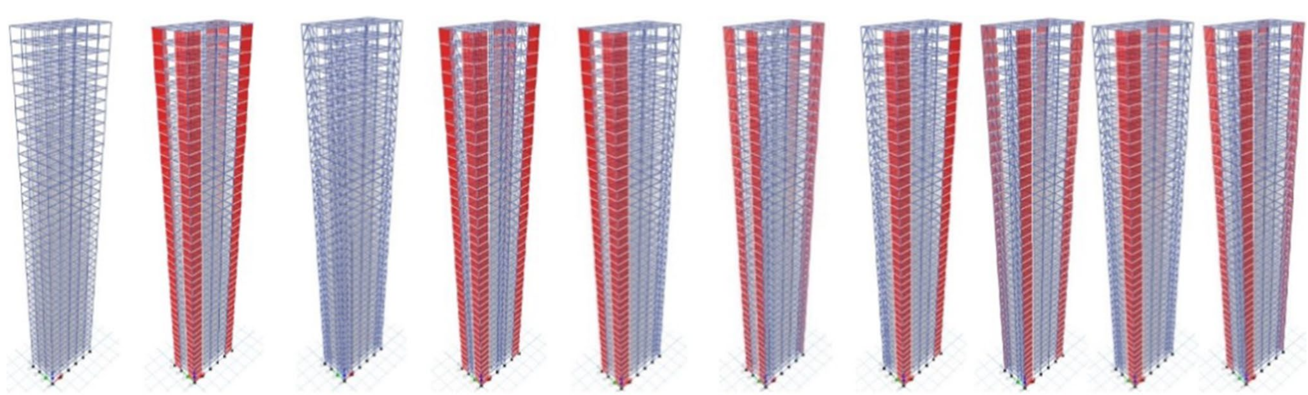


Fig. 15 Models grouped as G4

buildings with shear walls and Hybrid type-1 predominate with a reduction of 29.1% and 35.26%, respectively. Similarly, for *Y*-direction Fig. 22 shows that the overturning moment is reduced in the case of steel bracings for 20 and 50 story building by 21.32% and 45%, and the hybrid type-1 reduces the overturning moment for 30 and 40 story buildings by 34%, and 31%, respectively. Contrasting story drift,which is the most important parameter causing structural damage during the seismic condition, Fig. 23 clearly shows that hybrid structure type 1 predominates in all the cases for G1 to G5 and reduces the drift ratios by 85.8%, 87.4%, 86.4%, 83%, and 80.8% in *X*-direction, respectively. Similarly, for *Y*-direction in Fig. 24, the drift ratios is reduced by 91.47%, 92.13%, 90.73%, 91.25%, and 89.75%, respectively, which are the peak reductions noticed.

Story drift ratio is the most critical parameter which solely responsible for the collapse of the structure. Thus, focusing on the story drift ratio, Fig. 25 represents the

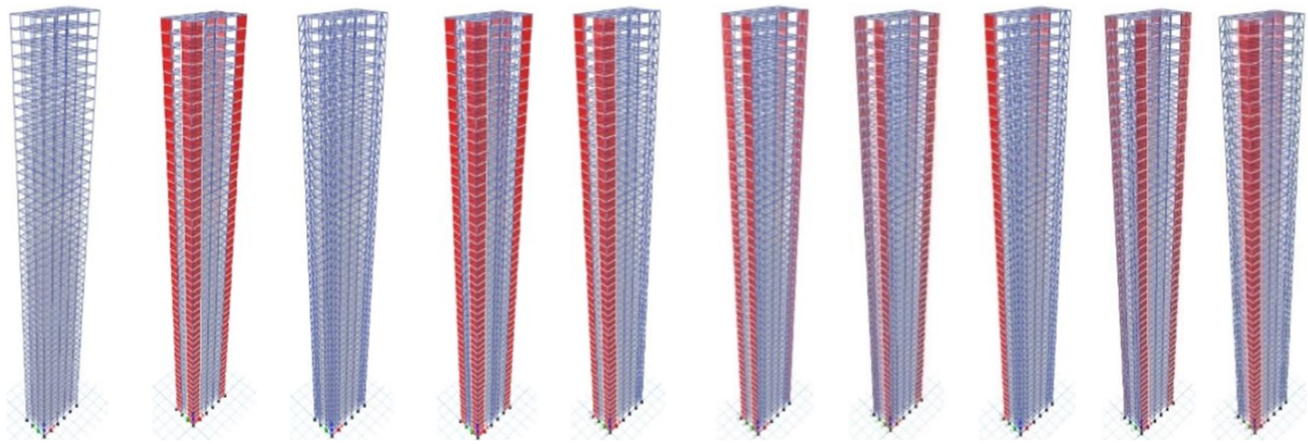


Fig. 16 Models grouped as G5

Fig. 17 Time periods of the studied buildings

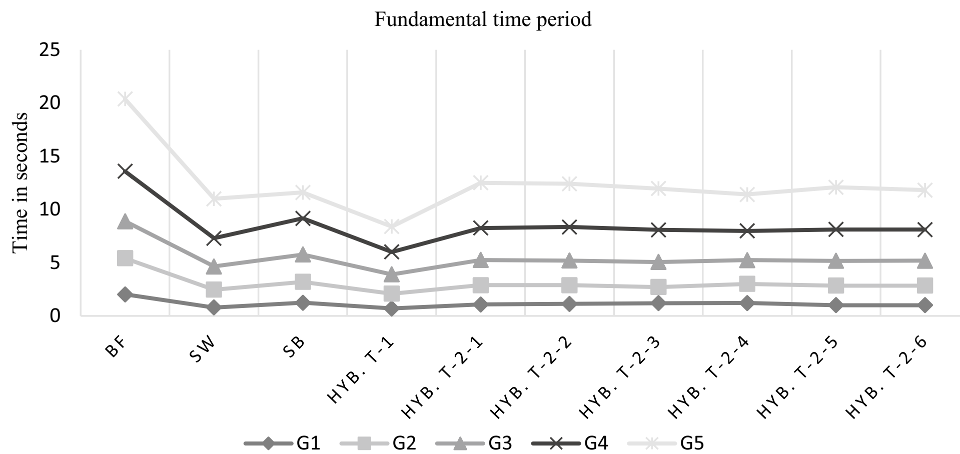
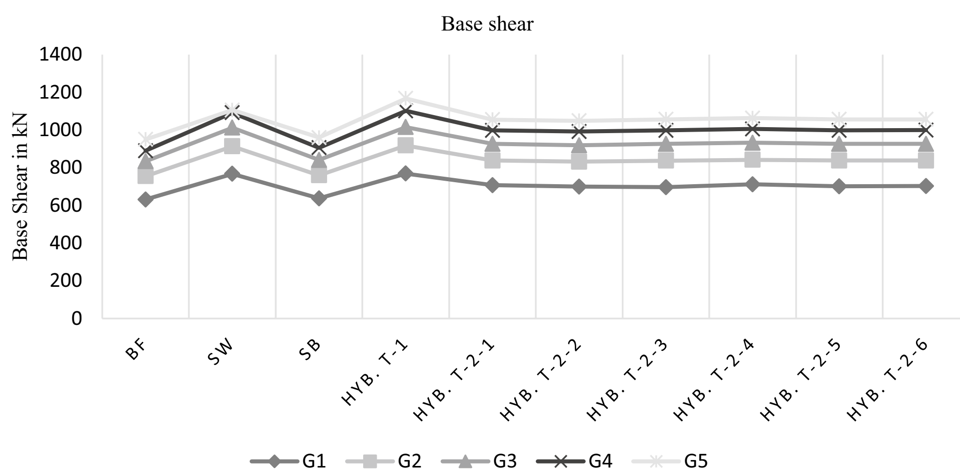


Fig. 18 Base shears of the studied buildings



inter-story drift distribution ratio for the best structure from each group. The 10 story building represents the inter-story drift distribution of building with shear wall, similarly 20, 30, 40, and 50 story building reveals inter-story drift distribution for buildings with hybrid structure type-1, respectively. It was cleared from the graph that there was no such unevenness noticed in drift distribution of the optimal structure and the response was

Table 2 Variation of base shear between manual and software results

S. no	Story height (m)	Manual results (kN)	Software results (kN)	Percentage error	Remarks
I	32	732	742	1.34 < 5	Acceptable
II	64	896	887	1.07 < 5	Acceptable
III	96	995	981	1.40 < 5	Acceptable
IV	128	1071	1057	1.32 < 5	Acceptable
V	160	1132	1118	1.23 < 5	Acceptable

under control for all the storeys. Figure 25 clearly revealed that peak reduction in inter-story drift ratio was 82.90% of 10 story building with shear wall, and similarly for 20, 30, 40, and 50 story building with hybrid structure type-1, reduction noticed was 92.13%, 90.73%, 91.25%, and 89.75%, respectively.

Results

The comprehensive analysis results from groups G1 to G5 give positive outcomes for the hybrid structure systems and all the necessary seismic parameters can be controlled using this new technique. From the analysis results:

- Elaborating it for 10 story buildings, on relating the enactments of the bare frame with the shear wall, hybrid structure type 1, and steel bracings, There are diminutions of 78.1%, 83.2%, and 59% in the story displacement discerned for the shear wall, Hybrid type-1, and steel bracings. The corresponding relative displacement also demonstrates advantageous reductions by a least of 81.3%, 85.8%, and 65.1%, respectively, also hybrid structure type-1 reveals the peak reduction by 91.47%. The other critical parameters like base shear show augmentations in the buildings with shear wall and hybrid type-1 by 21.5% and 21.8% and negligible for steel brac-

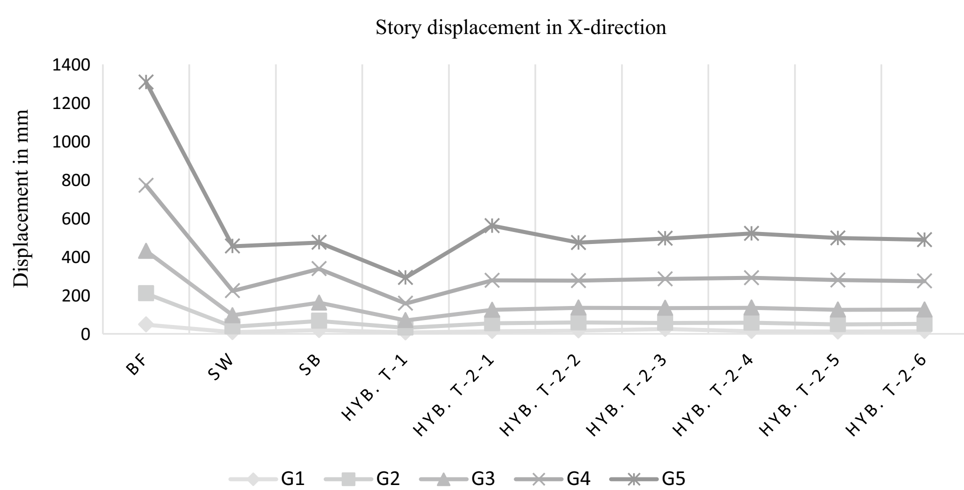


Fig. 19 Top story displacements of the studied buildings in *X*-direction

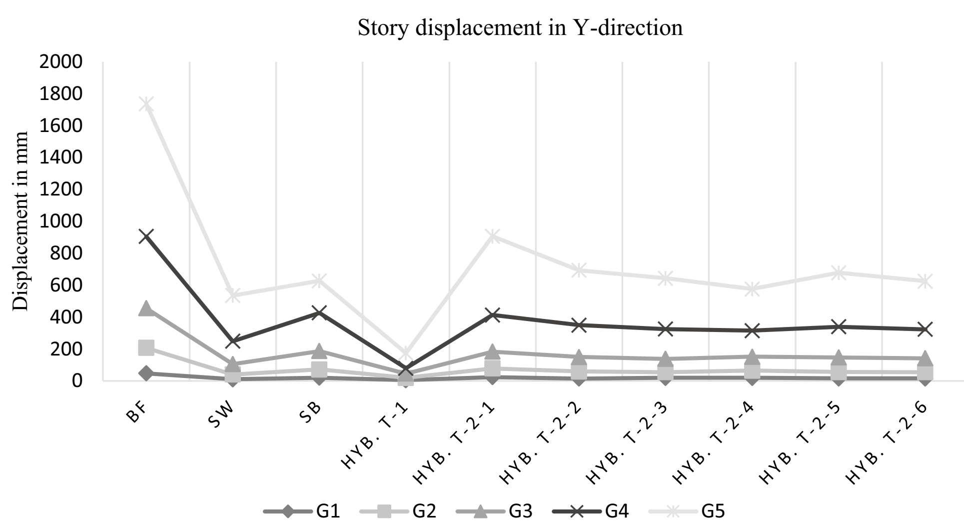


Fig. 20 Top story displacements of the studied buildings in *Y*-direction

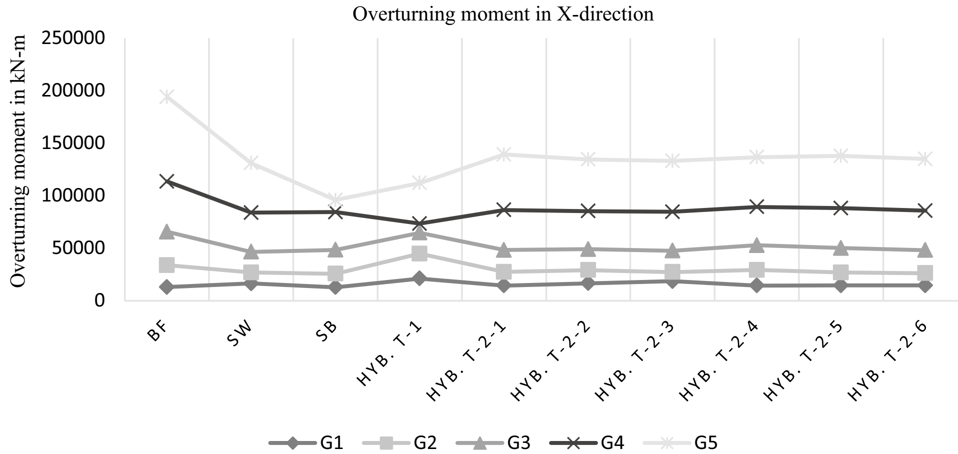


Fig. 21 Overturning moments of the studied buildings at the base in *X*-direction

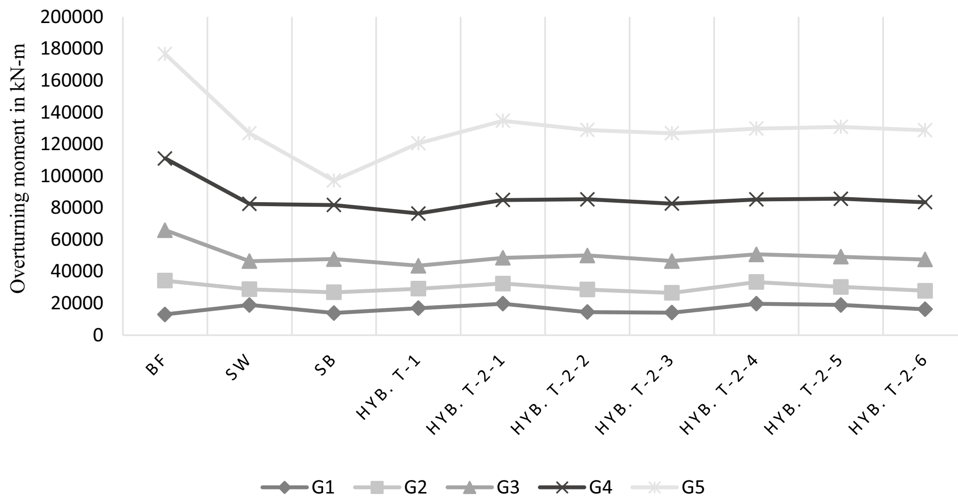


Fig. 22 Overturning moments of the studied buildings at the base in *Y*-direction

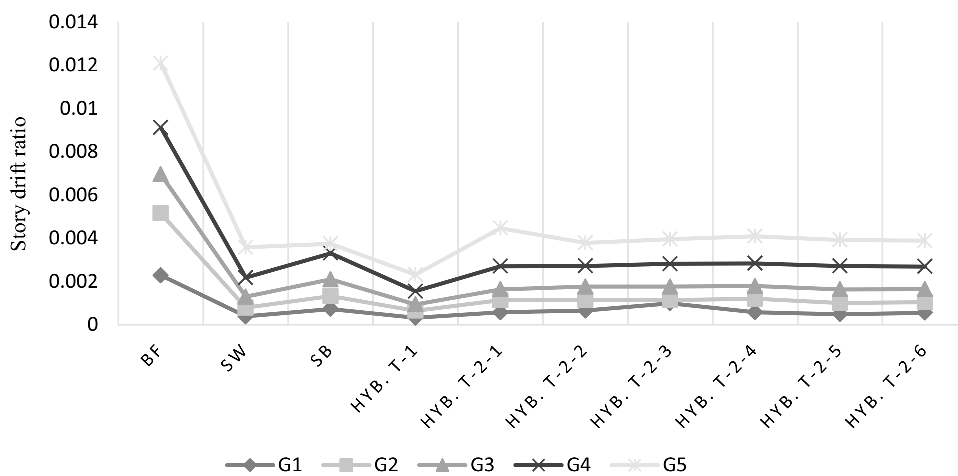


Fig. 23 Relative displacements of the studied buildings in *X*-direction

ings. Overall, there was a negligible base shear increment between building with shear walls and hybrid structure type-1, so steel bracings can be used effectively. When hybrid structure type-1 is contrasted over overturning moments, it stakes the base moment by a peak value of 62.1%,which is below par when compared to buildings with shear walls as 47.3%. Steel bracings show a maximum increment of 7.9% to base moments.

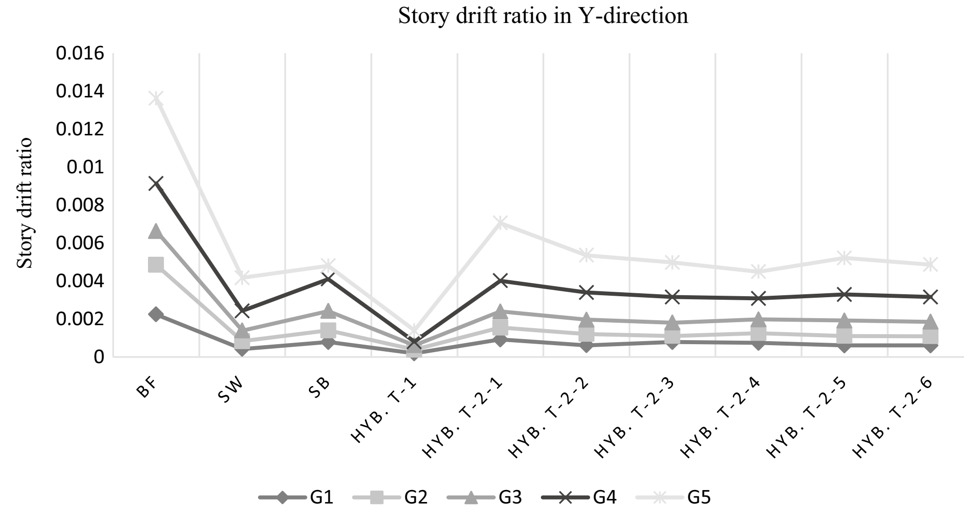


Fig. 24 Relative displacements of the studied buildings in *Y*-direction

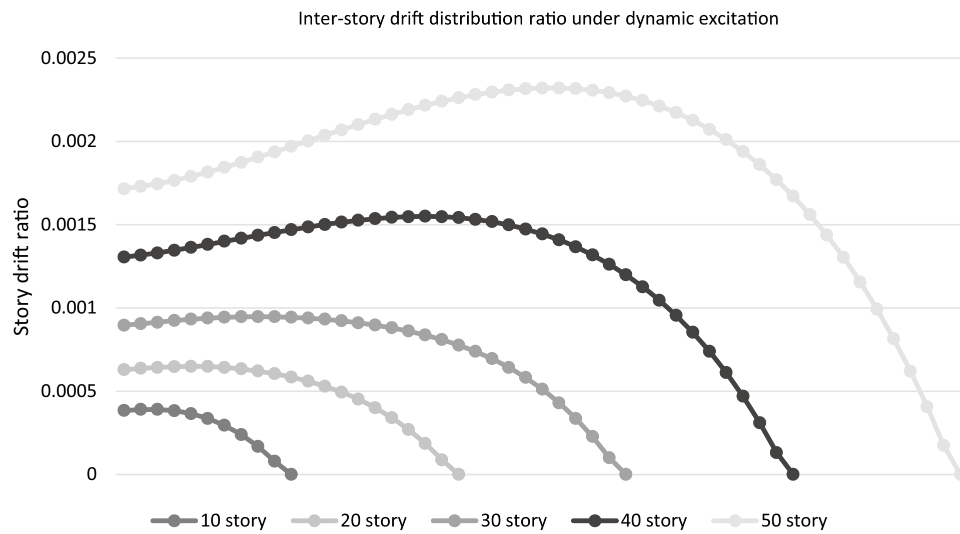


Fig. 25 Inter-story drift distribution ratio of best structure from each group

- Comparing 20 story frame models, minimum diminutions of story displacement by 80.5%, 84.8%, and 65.3% for the buildings with shear wall, hybrid type-1 and steel bracings were observed. Relative story displacement with reductions of 82.8%, 87.4%, and 71.11% was observed. There were increments of base shear in all three models, but for steel bracings it was negligible and for shear walls the base shear was raised by a maximum of 21.1% and hybrid type-1 raised by 21.8%. There was no such significant difference in base shear noticed between the buildings with shear walls and hybrid structure type-1. As the story height rises, the overturning moments tend to decrease utmost by 24.1% and a merest by 19.7% by the buildings with shear walls, which in steel bracings as 28.0% and 25.5%, respectively. The hybrid structure type-1 shows a 31.1% escalation in *X*-direction and a diminution of 32% in *Y*-direction.
- Contrasting on the 30-story frame, the efficiency of hybrid type-1 upsurges as compared to both structures with shear walls and with only bracings. The peak displacement reductions for hybrid type-1 is 89.8% associating it for the shear walls it was only 79.6%, and 62.4% for steel bracings. The peak story drift ratio reduction for hybrid type-1 was detected as 90.7%, 81.3% for the shear wall, and 69.8% for steel bracings. The relative base shear increments for the shear wall and hybrid structures were negligible with the maximum values of 21.4% and 21.9%, respectively. For the overturning moment, the performance of hybrid type-1 shattered the performance of shear walls and bracings. The shear wall reduces base moment by 32.3% and 32.8% in X and Y direction, respectively, whereas hybrid structure type-1 reduces to 28.1% and 51.7% as compared to steel bracing which is 27.6% and 28.9% in X and Y direction, respectively.

Concisely, hybrid structural system type-1 is better in all aspects.

- For 40 story buildings, there was a peak diminution of story displacement of 72.4% for shear wall and 91.0% for hybrid type-1 structure, and steel bracing shows a peak reduction of 56.0%. Shear wall reduces relative displacement by 76.1% and hybrid type-1 reduces it by 91.2% comparing it with steel bracing which shows a reduction of 63.7%. Shear wall increases the base shear by 22.7% and 23.9% for hybrid type-1, and there was a negligible increment noticed in steel bracings which was 1.9%. The overturning moment in all the three cases decreased but the hybrid type-1 shows a peak reduction of 43.7%, and shear walls reduced it by 27.6%, and further 26.3% by steel bracings.
- For 50 story buildings, the peak reduction in story displacement by the shear walls is 69.8% and for hybrid structure type-1 it was 89.9% comparing it with steel bracings it was only 64.7%. Similarly, the relative displacement was condensed by the shear wall by 70.4%, and hybrid type-1 by 89.74%, comparing it with steel bracings it was only 69.0%. The base shear increases by the shear wall as compared to the bare frame by 16.4% and hybrid type-1 increases it by 22.8% and steel bracings show the negligible contribution to the increment as it is only 1%. Contrasting on the overturning moments hybrid type-1 shows a reduction of 49.5% on the other hand shear wall reduced it by 32.4% and steel bracing led to a reduction of 50.5%.
- Contrasting on the variation of fundamental time period of the building shown in Fig. 17, for group G1, G2, G3, G4, and G5, the bare frame have fundamental period of 2.0 s, 5.4 s, 8.9 s, 13.6 s, 20.4 s. The peak reduced vibration period noticed was 0.7 s, 2.1 s, 3.9 s, 6.0 s, and 8.4 s, respectively in case of hybrid structure type -1. As compared to the buildings with shear walls, the vibration period was 0.8 s, 2.5 s, 4.6 s, 7.3 s, and 11.0 s, respectively. These results directly reveals that efficiency of hybrid structure type-1 increases exponentially from medium rise to tall structures and have better performance than buildings with shear walls.

Conclusion

The objective of the study was to achieve an optimal seismic response of structure by studying critical parameters including story displacement, story drift ratio, base shear, and the overturning moment was achieved by studying 50 different building models, and it is reflected from the results that the maximum story displacement and drift ratio were minimized with negligible or minimal increment in base shear and overturning moment using the hybrid structural system as a new lateral load resisting system.

From the results, it can be seen that the hybrid structural system of type-1 is efficient from low rise to tall structures, although for 10 story buildings the overturning moments were high and other parameters including story displacement, drift ratio, time period, and base shear are under control. Correspondingly, for 20, 30, 40, and 50 story buildings the base shear and overturning moment have obtained positive outcomes and further story drift ratios and story displacements are minimized.

Thus, the hybrid structural system type-1 is recommended for medium rise to tall structures and less priority is suggested to low-rise structures because the variations in the reduction of parameters between the building with shear walls, and hybrid structural systems are very small and for tall structures they are substantial.

The significance of the new lateral load resisting system can be realized as the structure responses on comparing the distinctive configurations reveal that, it is possible to achieve a high reductions in the maximum story displacement and drift ratio by keeping negligible increment in base shear and overturning moment as the base shear difference between the structure with shear walls and the hybrid structural system is negligible.

Acknowledgements The authors are grateful to the Department of Civil Engineering at Chandigarh University for the essential support by providing the golden opportunity to conduct this vigorous topic and to recognize so many innovative things. The sole work is independent of any funding agency and no financial assistance from any person, organization, or any government or semi-government firm in this research.

Declarations

Conflict of interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

References

1. Ozkul TA, Kurtbeyoglu A, Borekci M, Zengin B, Kocak A (2019) Effect of shear wall on seismic performance of RC frame buildings. Eng Fail Anal 100:60–75. https://doi.org/10.1016/j.engfailanal.2019.02.032
2. Bush TD, Jones EA, Jirsa JO (1991) Behavior of RC frame strengthened using structural steel bracing. J Struct Eng (US) 117:1115–1126. https://doi.org/10.1061/(ASCE)0733-9445(1991)117:4(1115)
3. Maheri MR, Sahebi A (1997) Use of steel bracing in reinforced concrete frames. Eng Struct 19:1018–1024. https://doi.org/10.1016/S0141-0296(97)00041-2
4. Kadid A, Yahiaoui D (2011) Seismic assessment of braced RC frames. Procedia Eng 14:2899–2905. https://doi.org/10.1016/j.proeng.2011.07.365
5. Jain AK (1986) Seismic response of RC frames with steel braces. J Struct Eng I:2138–2148

6. Tahamouliroudsari M, Entezari A, Hadidi M (2017) Experimental assessment of retrofitted RC frames with different steel braces. Structures 11:206–217. https://doi.org/10.1016/j.istruc.2017.06.003
7. Kg V, Kb P, Desai A (2010) Seismic analysis of steel braced reinforced concrete frames. Int J Civ Struct Eng 1:114–122
8. Stewart JP, Chiou SJ, Bray JD, Somerville GRW, PG, Abrahamson NA, (2002) Ground motion evaluation procedures for performance-based design. Soil Dyn Earthq Eng 22(9–12):765–772
9. Wen Y (2001) Reliability and performance-based design. Struct Saf 23(4):407–428
10. Navya G, Agarwal P (2016) Seismic retrofitting of structures by steel bracings. Procedia Eng 144:1364–1372. https://doi.org/10.1016/j.proeng.2016.05.166
11. Jose A, Pincheira JOJ (1985) Seismic response of RC frames with steel brace. J Struct Eng (US) 111:2138–2148. https://doi.org/10.1061/(ASCE)0733-9445(1985)111:10(2138)
12. Indian standard criteria for earthquake resistant design of structures (2016) Bureau of Indian Standard (BIS) IS 1893:2016
13. Kose MM (2009) Parameters affecting the fundamental period of RC buildings with infill walls. Eng Struct 31:93–102. https://doi.org/10.1016/j.engstruct.2008.07.017
14. Izuru T (2011) Building control with passive dampers: optimal performance-based design for earthquakes. Wiley
15. Powell GH (2008) Displacement-based seismic design of structures. Earthq Spectra 24(2):555–557
16. Hosseini M, Hashemi B, Safi Z (2017) Seismic design evaluation of reinforced concrete buildings for near-source earthquakes by using nonlinear time history analyses. Procedia Eng 199:176–181. https://doi.org/10.1016/j.proeng.2017.09.225
17. Buckle IG, Mayes RL (1990) Seismic isolation: history, application, and performance—a world view. Earthq Spectra 6(2):161–201
18. Priestley M (2000) Performance based seismic design. Bull N Z Soc Earthq Eng 33(3):325–346
19. Higashino M, Okamoto S (2006) Response control and seismic isolation of buildings. Routledge
20. Taniguchi T, Der Kiureghian A, Melkumyan M (2008) Effect of tuned mass damper on displacement demand of base-isolated structures. Eng Struct 30(12):3478–3488
21. Whittaker A, Constantinou M, Tsopelas P (1998) Displacement estimates for performance- based seismic design. J Struct Eng 124(8):905–912
22. Dasgupta K, Sajith AS, Unni Kartha G**,** Joseph A, Kavitha PE, Praseeda KI (2019) Lecture notes in civil engineering. In: Proceedings of secon'19. https://doi.org/10.1007/978-3-030-26365-2_57
23. Computers and Structures, CSI-ETABS v18.0, Integrated Solutions for Buildings
24. Code of practice for design loads (other than earthquake) for buildings and structures (2002) Bureau of Indian Standard (BIS) IS 875:2002
25. Code of practice for design loads (other than earthquake) for buildings and structures (1997) Bureau of Indian Standard (BIS) IS 875:1997
26. Ductile design and detailing of reinforced concrete structures subjected to seismic forces (2016) Bureau of Indian Standard (BIS) IS 13920:2016
27. Plain and reinforced concrete- code of practice (2000) Bureau of Indian Standard (BIS) IS 456-2000