Hydraulic and Civil Engineering Technology VIII
M. Yang et al. (Eds.)

doi:10.3233/ATDE230712

Analyzing the Effectiveness of Bracing Patterns in High-Rise Building

Prateek ROSHAN [b], Rahul Kumar MEENA [a,b] and Indrajeet SINGH [b,1]
[a] *Punjab Engineering College, Civil Engineering Department, Chandigarh, 160012, India*
[b] *Delhi Technological University, Civil Engineering Department, Delhi, 110042, India*

Abstract. The design of a multi-storied steel building requires a lateral load resisting system in addition to the gravity load system, as these are the governing factors in the design and affect its service-life performance. This study aims to demonstrate the impact of several bracing systems in multi-storied steel buildings. Since most multistorey structures comprise reinforced concrete (RC) frame construction, ensuring the design is safe against lateral loads is essential. Steel bracing is mainly used to resist these lateral loads in designing a tall building. Due to its high rigidity, strength, and lateral load-resisting capacity, steel bracing is an excellent alternative for providing lateral support in a high-rise building. The bracing element in a structural design offers additional rigidity, which helps the structure resist earthquake forces. Because of its ease of manufacture and low cost, concentric bracing is one of the most used lateral load-resisting measures in building frames. This study presents the analysis results of various types of bracing (X-bracing, V-bracing, K-bracing and Diagonal bracing) in a structural system using STAAD Pro software and a comparison is presented in terms of maximum lateral displacement, shear forces and bending moments observed due to the application of lateral loads. Tall buildings having 34 storeys with different bracing patterns were analyzed. This study concludes that using bracing units in a structural design significantly alters and improves the structural response of a high-rise building under seismic and wind loads.

Keywords. Wind load, tall building, bracing pattern, lateral displacement, bracings, storey displacement

1. Introduction

Land is limited in the cities, and the population is migrating to the cities; hence, it becomes essential to study the effect of lateral load in different bracing patterns used in the tall building system. Tall buildings are susceptible to lateral loads from earthquakes and wind, which cause storey drift. A steel frame can be strengthened in various ways to resist lateral stresses. Girder-to-column connections with moment resistance, brace brackets with moment bearing connections, brace frames with hinge pin connections, and brace frames with pin connections and moment load connections are all examples of such systems. Bracing is the most common method for designing load-bearing systems inside steel buildings to resist lateral forces while offering several advantages. It also reduces the deflection of columns and beams while increasing the system

[1] Indrajeet SINGH, Corresponding author, Delhi Technological University, Civil Engineering Department, Delhi, 110042, India; E-mail: indracivil1191@gmail.com

rigidity. Therefore, the most crucial consideration is selecting the appropriate bracing pattern and type of connection.

2. Literature Review

Story drift occurs due to lateral forces acting on the structure, which increase as the height rises. In the design of tall structural systems, lateral stiffness is a critical factor in meeting the strength and serviceability limits of the high-rise structure [1,2]. A fundamental concept used to determine the lateral stiffness of a building is the "drift index". The drift index is a simple estimation of the lateral stiffness of the structure and is used almost exclusively to limit damage to non-structural components. Inter-story drift ratio (IDR) is the relative translational displacement between two consecutive floors divided by the story height.

$$Drift\ Index = \frac{displacement}{height} \quad (1)$$

$$Total\ drift\ Index = \frac{Total\ drift}{Building\ height} \quad (2)$$

The drift index is defined as the ratio of the highest deformations at the building to the highest point in the entire height of the building. Many structural designs for tall structures can be used to improve lateral stiffness and reduce the drift index. A steel-braced frame is a framework used in multi-story constructions to reduce the lateral load [3,4].

Steel bracing increases the structure's rigidity and stability, which makes it more resistant to horizontal forces [5]. Bracings stabilize the structural system by transmitting the horizontal loads to the ground; hence, the lateral load effect is reduced in such type of structure using the bracing pattern. In RC multi-storied structures [6]; [3,4,6] steel bracing members are less expensive, easier to use, take up less space and provide the necessary quality and stiffness to the high-rise structure. Bracing techniques include [3,7] X-bracing, K-bracing, V-bracing, and diagonal bracing. Concentric and eccentric bracing systems are the two major types of bracing systems. Primarily, bracing is used in the structure with more dimensions in vertical height compared to the horizontal dimension. Steel bracing is frequently used [1,8] to resist more lateral load. This technique can significantly increase stiffness while only slight weight is added to the tall building.

2.1. Concentric Bracings

The lateral stiffness of the steel frame is increased by concentric bracing, raising the resonant period and, in most circumstances, reducing lateral storey drift [7,9]. The bracings also minimise bending stresses and shear forces in the column while simultaneously increasing the axial forces in the column to which they are connected.

2.2. Eccentric Bracings

The lateral rigidity could be decreased in the high-rise structure, and bracing may enhance the dissipation of energy up to some extent. Steel is more ductile, which offers considerable warning before its failure. All of these qualities of steel are essential in earthquake design [10-13]. In this study, various bracing systems are investigated for use in tall buildings to provide lateral stiffness and analysis results were narrowed down to suggest the suitability of the best option.

2.3. Seismic Force Resisting Systems

The main aim of every structure system employed in constructing structures is to effectively transfer gravitational loads (dead, live, and snow loads) effectively. Buildings are also exposed to external loads due to wind, blasting, or earthquakes, apart from the vertical loads. The structure should be strong enough to withstand gravity loadings and resist lateral loads [14]. The response of every structure is different in the event of an earthquake. As a result, designers must design structural systems that meet the structural requirements and can withstand site-specific hazards like seismic and wind loads [15].

3. Methodology

In this study, analysis was done to determine the structural behaviour of a steel structure with various bracing systems under the action of seismic and wind loadings.

3.1. Dead and Live Loads

Dead and live loads were taken as per the provisions of Indian Standards (IS) Code. The unit weight of concrete (for floors) is taken as 25 kN/m^3 and unit weight of steel is taken as 78.5 kg/m^3. The thickness of the slab is considered as 150 mm and live load of 4 kN/m^2 is considered.

3.2. Seismic Load

For seismic analysis, the values adopted [16] are, seismic zone IV (Zone factor, Z is 0.24), soil type- medium, importance factor, I - 1.0, response reduction for a steel frame with concentric bracing, R - 4.5 and damping ratio - 0.02.

3.3. Wind Load

Wind load is a significant factor in tall building design, and as height rises, so does the effect of the wind; thus, the wind load needs special attention. Following Indian standards for wind loads [17], the values taken up are, namely, basic wind speed as 47.00 m/s, the terrain category considered as 2, the class of the structure is taken as B type, probability factor k_1 is taken equal to 1.07, the values of k_2, k_3 and k_4 were suitably adopted.

3.4. Load Combinations

The load combinations considered for the structural models in the present study are, 1.5 (D.L.+L.L.), 1.2 (D.L.+L.L.+E.L.), 1.2 (D.L.+L.L.+W.L.), 0.9 D.L. + 1.5E.L., 0.9 D.L. + 1.5W.L. (D.L. is dead load, L.L. is live load, E.L. is earthquake load and W.L. is wind load).

4. Analysis of Models

Analysis is performed using Staad Pro and the provisions for the design loads and load combination of the latest Indian Standards are adopted. The plan area of the building is 900 m^2 and having 6 bays along the plan cross-sectional area. The different bracing patterns adopted in the present study is depicted in figure 2.

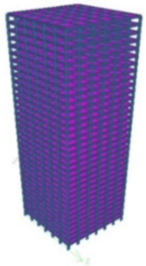

Figure 1. 3-D view of building without bracing

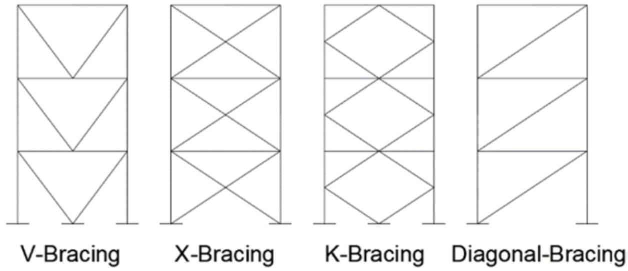

Figure 2. Different bracing patterns considered in the present study

4.1. Model-1: Steel Frame without Bracing

The 3D view of the building model without any bracing is shown in figure 1. Steel sections 180016A40012 and 180016A50016 were assigned for the column and beam members, respectively. Figure 3 shows that the displacement increases along with an increase in height. The 34-storey has a maximum storey displacement of 54.79 mm, whereas the first storey of the building model without any bracing reported a minimum storey displacement of 1.475 mm.

4.2. Model -2: Steel Frame with Diagonal Bracing

Columns, beams, and braces are made of steel sections 180016A40012, 180016A50016, and ISA 200X200X20, respectively. Figure 3 shows the maximum storey displacement at the top floor, 49.37mm, and the lowest at the first level, 0.891mm. The storey displacement results indicate that as the height of the tall building model increases, the top floor displacement increases relative to the base.

4.3. Model-3: Steel Frame with X-bracing

From figure 3, the top floor of the building with X-bracing has a storey displacement of 35.82 mm at its highest and 0.78 mm at its lowest. It is also evident from figure 3 that the storey displacement at the top is smaller when the diagonal bracing is used, and the storey drifts at the first floor are less when the diagonal bracing is used. However, a considerable increment is shown on the first floor when the bracing system is not used.

4.4. Model-4: Steel Frame with K- Bracing

From figure 3 it may be deduced that the top floor of the building with K-bracing has maximum storey displacement of 55.34 mm, while the first floor has minimum storey displacement of 1.84 mm. The storey displacement is more noticeable with a K-bracing has a maximum storey displacement of 55.34 mm, while the first floor has a minimum storey displacement of 1.84 mm. The storey displacement is more noticeable with a K-bracing system compared to the diagonal than the building without bracing systems. The first-floor level displacement is less different when comparing K-bracing and the absence of bracing. However, adequate reductions in storey displacement in diagonal and X-bracing systems were observed compared to building models with K-bracing and without bracing systems.

4.5. Model-5: Steel Frame with V- Bracing

Values of storey drift from figure 3 imply that the top floor has 52.74mm maximum storey displacement and the first floor has 1.12mm minimum storey displacement. The relationship between displacement and story on the graph is comparable, and the maximum and minimum displacement are almost identical to the diagonal bracing system employed in analysing various bracing systems with equal plan area.

5. Results and Discussion

5.1. Displacements

The maximum storey displacement is demonstrated at the top level in the case of X-bracing, which is 0.543mm greater than the case without bracing, as seen in figure 3. While initially, a decrease is observed in the V-bracing system, the maximum displacement at the top level is approximately the same for K-bracing and without bracing. However, using K-bracing will significantly increase the high-rise structure's overall stiffness. The observed displacement pattern versus storey number is nearly identical for buildings with K-bracing systems and without bracing. However, if a comparison is made, it can be determined that the X-bracing system is more effective at reducing lateral loads in the design of multistorey steel buildings.

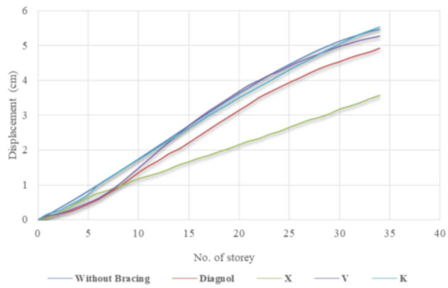

Figure 3. Displacements values obtained for building models

5.2. Shear Force

Table 1 shows that the highest shear force, of 107137.82 kN, is found in the X-bracing, while the minimum shear force, or 54458.397 kN, is found in the K-bracing. Table 1 shows that the shear force variation is almost the same for the V-and diagonal bracing systems used in the study of the tall building design and is practically similar when bracing systems are absent and when K-bracings are adopted.

Table 1. Recorded values of shear force and bending moments for different bracing systems.

Models	Shear Force (kN)	Bending Moment (kN-m)
W/O Bracing	56753.352	11187.69
Diagonal Bracing	68796.49	14322.414
X-Bracing	107137.82	15368.229
K-Bracing	54458.397	8676.736
V-Bracing	63294.723	10529.637

5.3. Bending Moments

Table 1 shows the values of bending moment observed for building models with various bracing systems. The minimum bending moment is observed for K-bracing, i.e., 8676.736 kN-m, while the maximum bending moment is observed for the X-bracing system i.e., 15368.229 kN-m, which is almost slightly more than the diagonal-bracing system. The bending moment is highest for the building model having X-bracing because it resists more lateral load than the other bracings used in this analysis.

6. Conclusions

The present study summarises the analysis results of the effects of different bracing systems used in tall buildings. When bracings are supported by a structure, bracings either concentric or eccentric, increases its resistance to lateral deflection and is especially helpful in earthquake-prone locations. Some significant outcomes from the present studies are as follows:

- Based on the present analysis, it can be stated that an appropriate bracing system is necessary for high-rise steel structures and it considerably improves the structure's lateral stability.
- The different type of bracing system has a significant role in controlling story displacement, as it can be seen from the results that the maximum story displacement in the case of K-bracing is 54.5% more than the one with the X-bracing system.
- The story displacement is observed least in the case of X-bracing, 35.82 mm, while the maximum is observed in the case of a K-braced building, 55.34 mm.
- The X-type bracing system is the most appropriate bracing system to resist horizontal forces for tall buildings.

Acknowledgements

The authors would like to thank Delhi Technological University, Delhi, for providing the resources.

Declaration of interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

[1] Meena RK, Awadhiya GP, Paswan AP and Jayant HK. Effects of bracing system on multistoryed steel building. IOP Conf. Ser. Mater. Sci. Eng. 2021; 1128(1): 012017.
[2] Gaur H and Goliya RK. Mitigating shear lag in tall buildings. Int. J. Adv. Struct. Eng. 2015; 7(3): 269–279.
[3] Maheri MR and Rahimi A. The side-effects of retrofitting rc frames with steel x-braces. 8th Int. Conf. Seismol. Earthq. Eng. Tehran, Iran, Nov 2019: 5–6, 2019.
[4] Tanskanen P. The evolutionary structural optimization method: Theoretical aspects. Comput. Methods Appl. Mech. Eng. 2002; 191(47–48): 5485–5498.
[5] Pandey S, Roshan P and Ram S. Fuzzy-AHP Based design and performance indexing model for tall buildings. Sustain. Cities Resilience, Lect. Notes Civ. Eng. 2022; 183: 359–383.
[6] Taranath BS. Reinforced Concrete Design of Tall Buildings. 2010.
[7] Siddiqi Z, Hameed and Akmal U. Comparison of different bracing systems for tall buildings. Pak. J. Eng. Appl. Sci. 2014; 14: 17–26, 2014.
[8] Kutuk MA and Gov I. Optimum bracing design under wind load by using topology optimization. Wind Struct. An Int. J. 2014; 18(5): 497–510.
[9] Ebadi P and Sabouri-Ghomi S. Conceptual study of X-braced frames with different steel grades using cyclic half-scale tests. J. Earthq. Eng. Eng. Vib. 2012; 11(3): 313–329.
[10] Salmasi AC and Sheidaii MR. Assessment of eccentrically braced frames strength against progressive collapse. Int. J. Steel Struct. 2017; 17(2): 543–551.
[11] Seker O. Seismic response of dual concentrically braced steel frames with various bracing configurations. J. Constr. Steel Res. 2022; 188: 107057.
[12] Amoussou CPD, Lei H, Halabi Y and Alhaddad W. Performance-based seismic design methodology for tall buildings with outrigger and ladder systems. Structures. 2021; 34: 2288–2307.
[13] Ghasemi M, Fanaie N and Khorshidi H. Seismic performance factors of a dual system with IMRF and cable-cylinder bracing. J. Build. Eng. 2021; 39(1346): 102309.
[14] Roshan P, Pal S and Kumar R. Performance assessment indexing of buildings through fuzzy ahp methodology. Lecture Notes in Civil Engineering. 2020; 58: 503–519.
[15] Roshan P, Pal S and Kumar R. Seismic damage assessment index of buildings using fuzzy-ahp approach. Int. J. Tech. Innov. Mod. Eng. Sci. (IJTIMES). 2018; 4(08): 1011–1019, 2018
[16] IS-1893-Part-1-(2016). Criteria for Earthquake resistant design of structures,Part 1:General Provisions and buildings," Bur. Indian Stand. New Delhi, vol. 1893, no. December, pp. 1–44, 2016.
[17] IS: 875 (2015). Indian Standard design loads (other than earthquake) for buildings and structures-code of practice, part 3(wind loads). 2015.