Effects of Bracing System on Multistoryed Steel Building

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Abstract: In recent years, in regions of the highly seismic prone area, steel construction has changed from moment resistant frames to concentrically braced frames. To withstand earthquake forces, bracing part of the structural pattern by providing extra stiffness plays a crucial role in structural action. Concentric bracing in building frames is one of the most common horizontal load resistance patterns. For this reason, seven distinct models were created by changing the bracing pattern in the steel frame and analyzed for wind and seismic forces. A 20-story steel frame structure is explored in this presented work. From this research, it can be inferred that the bracing factor will have a very significant impact on structural behavior under seismic loading. The most desirable bracing framework is the Backward bracing pattern. Horizontal displacement at the top floor is decreased by approximately 50 percent for Backward braced in frame structure compared to without bracing pattern.

Keywords: Wind Load, Tall Building, Bracing Pattern, Staad Pro

1. Introduction

The population is rising day by day, and the supply of land area is much lesser, so the only alternative is multi-story development. Due to earthquake and wind, a tall building is suspected of horizontal loads, and these forces cause storey drift. Various kinds of tall building structures reduce storey drift. Amol and Shelke (2016) analyzed high rise RCC twenty-story building using staad pro on different bracing patterns and concluded that chevron bracing is most effective in reducing bending moments for a wind load in columns. The bending moment can be reduced up to thirty-four percent in the elevation of the building and the plan, and it can reduce up to thirty-seven percent from without bracing pattern, and concluded that the use of a bracing pattern could effectively increase the performance of the building without adding considerable extra dead load into a structure. Sarita singla et al. (2012) examined the pattern of different shapes of building under wind loading. Saurabh and Komal (2018) analyzed the effect of seismic load on the x-type of the bracing pattern using staad pro and found that x-bracing is most efficient to resist story displacement and story drift reduction when bracing is provided on two parallel sides of the building. Mohammed and Nazrul (2013) simulated the characteristics of RCC multi-story structure on various bracing patterns and concluded that displacement of RCC structure reduces after the use of bracing pattern. Cross bracing reduces the maximum horizontal displacement of the structure. Chadhar and Sharma (2015) considered the sixteen-story building with an alternate bracing arrangement and concluded that steel bracing decreases the shear force and bending moment and concluded that the doubled angle section effectively decreases the horizontal displacement. Amol Patil et al. (2018) examined the eccentric bracing pattern effect on a tall building, and they found that diagonal braced pattern has least horizontal displacement and reduces by fifteen percent concerning without bracing pattern also concluded that v braced pattern has less base shear and reduces by eleven percent as compare to without braced structure. Mishra et al. (2014) examined the reinforced concrete construction frames using various bracing patterns for seismic forces and concluded that steel bracing is an advantage in resisting seismic forces. The bracing pattern is an efficient member to manage the story drift in structure as opposed to bare frames. Shraddha J. Patil and R.S. Talikot (2015) considered wind load on tall elevation structure was examined and concluded that column reinforcement exceeds column reinforcement due to high bending moment compared to static building scenario. The coupling moment induces wind pressure that raises the stresses in the beam. Horizontal wind forces are strong on the building's upper floor, and it generates torsion and displacement. Mayank Walia et al. (2019) considered the effect of wind analysis of composite buildings with bracing patterns and...
founded that displacement of the twelve-story irregular building having x bracing as most suited to resist horizontal displacement.

Figure 1 Concentrically Braced Frames

Figure 2 Eccentrically Braced Frames

2. Design Horizontal Forces

Unlike in the current design codes, the design horizontal force distribution in the proposed method is determined using a shear distribution factor, $\beta_i$, which is extracted from and calibrated by detailed nonlinear time-history analyses of the EBF, (figure 2). When subjected to major earthquakes, this distribution of horizontal force accounts for EBF inelastic behavior and can be expressed as (Lee et al., 2004; Chao and Goel, 2005)

$$\beta_i = \frac{V_i}{V_n} = \left(\frac{\sum w_i h_i}{w_n h_n}\right)^{0.75T(-0.2)}$$

(1)

$$F_n = V \left(\frac{w_n h_n}{\sum_{j=1}^{n} w_j h_j}\right)^{0.75T(-0.2)}$$

(2)

$$F_i = (\beta_i - \beta_{i+1})F_n$$

(3)

When $i = n$, $\beta_{n+1} = 0$

Where $\beta_i$ = shear distribution factor at the level, i

$V_i$, $V_n$ = story shear forces at level i and at the top (nth) level, respectively

$w_i$, $w_j$ = seismic weights at level i and j, respectively

$h_i$, $h_j$ = heights of levels i and j from the ground, respectively

$h_n$ = seismic weight of the structure at the top level

$h_n$ = height of roof level from the ground

$T$ = fundamental structure period obtained by code specified methods or elastic dynamic analysis

$F_i$, $F_n$ = horizontal forces applied at level i and top-level n, respectively

$V$ = Design shear force

3. Methodology

This paper analysis carried to find the displacement response of space steel frame under seismic and wind loadings in different bracing patterns. Also, determine the horizontal drift at each floor level for Concentric Braced Frames (CBFs) for fully restrained column base. Loading consideration is as per the Indian Standard codes.
Dead load is determined by using considered components and their weight density. assumed live load as 4.0 kN/m². Wind load calculated as per IS 875 part 3 (2015),

\[ P_z = 0.6(V_z^2) \]  
\[ V_z = V_b \times K_1K_2 \times K_3 \times K_4 \]  

Where \( P_z \) is wind pressure design in N/m² at height, \( z \) and \( V_z \) is wind velocity design in m/s at height \( z \), and \( V_z \) determined by simple wind velocity accounting \( V_b \) probability factor(\( k_1 \)), terrain height and structure factor(\( k_2 \)), topography factor(\( k_3 \)) and Importance factor for the cyclonic region (\( k_4 \)). The seismic load is measured using a static method equivalent to:

Base shear:

\[ V_b = (A_h \times W) \]  

Where, \( A_h \) = design horizontal seismic coefficient for a structure, \( W \) = seismic weight of the building

\[ A_h = \left( \frac{2IS_d}{2Rg} \right) \]  

\( Z \), in Table 2 of IS 1893:2016, is the zone factor (part 1). I is the important factor and R is the reduction factor of response; \( Sa/g \) is the average acceleration coefficient of response for rock and soil sites as defined in IS 1893:2016 (part 1). The values for the 5 percent damping of the structure are given. According to this equation, base shear distribution along the height is carried out

\[ Q_i = V_b \times \frac{W_ih_i^2}{\sum_{j=1}^{n} W_jh_j} \]  

Where,

\( Q_i \) = Design horizontal force at floor i, \( W_i \) = Seismic weight of floor at i, \( h_i \) = Height of floor measured from the base, and \( n \) = Number of the story in the building at which the masses are located.

Load taken into consideration are Seismic Loading, Zone factor – 0.24, Soil type – 2 (medium Soil), Importance Factor – 1.50, Response reduction – 4.00, Foundation Depth – 3.00 meter And Damping Ratio - 0.02

For Wind loading Basic Wind speed – 47.00 m/s, Terrain category – 2, Class – B, Probability Factor ‘\( k_1 \)’ = 1.07.

Load load is 3.88 Kn/m² Live load is 4.0 Kn/m².

Load Combinations

1) 1.5 (DL+ IL)
2) 1.2 (DL+ IL + EL)
3) 0.9 DL+ 1.5 EL
4) 1.2 (DL+ IL + WL)
5) 0.9 (DL+ 1.5 WL)

4. Analysis of Models

The building used for this study was designed to the standards presented in the IS 800: 2007 and is 1893 (part 1): 2016 In STAAD Pro, a multi-story steel building is analyzed. The building's design depends on the least specifications, as mentioned in the Indian Standard Codes.
4.1 Steel Frames

The frame used for this study is a 20 (G+19) story, steel braced structures. The typical floor height is 3 m with a total of 60 m of the building. In the plan, the sides span 20 meters by 20 meters divided into 5-meter square bays as represented in figure 6.

Below mentioned models are considered for the analysis:

1. Steel frame without bracing
2. Steel frame with backward bracing
3. Steel Frame with forward bracing
4. Steel frame with X- bracing
5. Steel frame with inverted V- bracing
6. Steel frame with K- bracing
7. Steel frame with V- bracing

Model 1:- Steel frame without bracing
The steel section chosen for the column is ISMC 400 and for beam ISMB 600. The elevation view of the concentric frame is represented in figure 4. The elevation view in 3D is represented in figure 5 and the storey displacement in x and z direction for without bracing is represented in figure 6.
Figure 4 Elevation of the Steel frame without bracing

Figure 5 3D view of steel building without bracing
**Figure 6** Storey displacement in X & Z - direction without bracing

**Model 2: - Steel frame with backward bracing**  
All supports are fixed and the steel section used for beams is ISMB 600 and columns are ISMC 400 and for the bracing pattern it is ISA 200×200×12. The elevation view of the frame with backward bracing is represented in figure 7. The storey displacement in x and z direction for backward bracing is represented in figure 8.

**Figure 7** Elevation of Backward Bracing
Figure 8 Storey displacement in X & Z-direction Backward Bracing

**Model:** 3 Steel Frame with forward bracing
All supports are fixed and the steel section used for beams is ISMB 600 and columns are ISMC 400 and for the bracing pattern it is ISA 200×200×12. The elevation view of the frame with forward bracing is represented in figure 9. the storey displacement in x and z direction for forward bracing is represented in figure 10.

Figure 9 Elevation of Forward Bracing
Figure 10 Storey displacement in X & Z-direction Forward Bracing

Model 4: Steel frame with X-bracing

All supports are fixed and the steel section used for beams is ISMB 600 and columns are ISMC 400 and for the bracing pattern it is ISA 200x200x12. Elevation view of the frame with X-bracing as represented in figure 11. The storey displacement in x and z direction for x-bracing is represented in figure 12.
Figure 12 Storey displacement in X & Z - direction with X- bracing

Model 5:- Steel frame with inverted V- bracing
All supports are fixed and the steel section used for beams is ISMB 600 and columns are ISMC 400 and for the bracing pattern it is ISA 200×200×12. Elevation view of the frame with INVERTED V-bracing as represents in figure 13. the storey displacement in x and z direction for v-bracing is represented in figure 14.

Figure 13 Elevation of the Steel frame with inverted V- bracing
Figure 14 Storey displacement in X & Z- direction with inverted V- bracing

Model 6:- Steel frame with K- bracing
All supports are fixed and the steel section used for beams is ISMB 600 and columns are ISMC 400 and for the bracing pattern it is ISA 200×200×12. Elevation view of the frame with K- bracing as represented in figure 15. the storey displacement in x and z direction for k-bracing is represented in figure 16.

K-bracing is symmetric for steel building as represented in the figure 15.
Model 7: Steel frame with V-bracing

All supports are fixed and the steel section used for beams is ISMB 600 and columns are ISMC 400 and for the bracing pattern it is ISA 200×200×12. Elevation view of the frame with V-bracing as represented in figure 17. The storey displacement in x and z direction for v-bracing is represented in figure 17.
Figure 18: Storey displacement in X & Z-direction with V-bracing.

We can also see in this case that top story displacement for inverted V-bracing is less as compared to without bracing but more as compared to X-bracing.

5. Results:

5.1 Displacements:

Figure 19: Comparison of displacements in X & Z-direction for different bracing pattern.

Figure 19 illustrates that as the number of floors increases, displacement increases without bracing and with bracing. The maximum top story displacement for without bracing is maximum that is 6.2869 cm and the least for X-bracing which is 1.2491 mm. Displacement on the first floor for without bracing is 4.802 mm and for X-bracing, it is 1.52 mm.
5.2 Storey Shear:

Figure 20 Comparison of Storey Shear for different bracing pattern

The maximum storey shear for a steel building is in v bracing and the least for inverted v bracing is shown in figure 20.

5.3 Shear Force:

Table 1 Maximum Shear Force

| Models                | Shear Force(kN) |
|-----------------------|-----------------|
| Without bracing       | 37826.570       |
| X-bracing             | 59496.387       |
| Inverted-V bracing    | 45395.121       |
| K-bracing             | 36305.188       |
| V-bracing             | 42193.262       |
| Backward Bracing      | 71376.016       |
| Forward Bracing       | 46996.742       |
The maximum shear force for a steel building without bracing and with bracing is represented in figure 21 and table 1 Maximum shear force found for backward bracing is 71376.016 kN and the least for without bracing is 37826.570 kN. For Backward-bracing, the shear force is 71376.016 kN, and the difference between without bracing and backward bracing is less.

**5.4 Bending Moments:**

| Models              | Bending moments(kN-m) |
|---------------------|-----------------------|
| Without bracing     | 7459.444              |
| X-bracing           | 8551.276              |
| Inverted-V bracing  | 6867.884              |
| K-bracing           | 5784.231              |
| V-bracing           | 7021.314              |
| Backward bracing    | 10266.527             |
| Forward bracing     | 10606.850             |
Maximum bending moment $M_y$ and $M_x$ (whichever is greater) is represented in figure 22 and table 2 for steel building without bracing and with bracing. The maximum bending moment found for Forwarding bracing is 10606.850 kN-m and least for K-bracing which is 5784.231 kN-m.

For Forwarding bracing, the maximum bending moment is 10606.850 kN-m.

### 6. Conclusion:
A general analysis of structural structures for tall buildings has been presented in this article. A pattern-based broad classification has been proposed, unlike the height-based classifications in the past. Whenever Bracings are supported with a structure even if it is concentrated or eccentric, it gives more resistance to horizontal deflection and also beneficial in areas that are vulnerable to earthquakes. The following conclusions may be drawn based on the present research:

- From all bracing patterns, the maximum shear force is provided by the inverted backward bracing pattern.
- In contrast to the other bracings, the forward bracing pattern produces maximum bending moment.
- The most appropriate bracing scheme is the method of backward bracing.
- For Backward braced in frame construction, horizontal displacement at the top floor is reduced by approximately 50 percent compared to without the bracing pattern.

Future research can be done for braces that are likely to develop substantial bending moments and shear forces in specific applications. The impact of bending moment and shear force on braced frame behaviour is unknown, and in order to simulate this, the empirical analysis may be carried out.

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