Influence of diagonal braces in RCC multi-storied frames under wind loads: A case study

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ABSTRACT

Structures are classified as rigid and flexible. Tall structures are more flexible and susceptible to vibrations by wind induced forces. In the analysis and design of high-rise structures estimation of wind loads and the inter storey drifts are the two main criteria to be positively ascertained for the safe and comfortable living of the inhabitants. Estimation of wind loads is more precise with gust factor method. Inter storey drift can be controlled through suitable structural system. The present investigation deals with the calculation of wind loads using static and gust factor method for a sixteen storey high rise building and results are compared with respect to drift. Structure is analyzed in STAAD Pro, with wind loads calculated by gust factor method as per IS 875-Part III with and without X- bracings at all the four corners from bottom to top.

Keywords: Wind analysis, gust factor, inter-storey drift, drift.

1. Introduction

In the case of static structures the flow interacts only with the external shape of the structure. When the structure is very stiff deflections under the wind loads will not be significant, and the structure is said to be “Static”. The only design loading parameter of importance is the maximum load likely to be experienced in its lifetime. The parameters most relevant to the assessment of design loading are Influence functions, size parameters of the structure, load duration and assessment of load for design. In the case of dynamic structures, there is an additional interaction with the motion of the structure. When the structure is sufficiently flexible, the response to wind loads is significant to the design of the structure. The conventional approach to the analysis of dynamic response of lightly damped structures is by resolving the response into the natural modes of vibration, characterizing each normal mode as a set of model parameters: 1) Model shape, 2) Model mass, 3) Model stiffness and 4) Model damping. Using these parameters a frequency response function can be defined that describes the dynamic characteristics of the structures. Gust Effectiveness Factor method is a more realistic and rational approach to deal with wind loads on tall building towers. Various studies have also been made regarding the provision of steel braces and infill walls. (T. El-Amoury et.al, 2005) developed two rehabilitation techniques were proposed to improve the dynamic response of framed structures. Fiber reinforced polymer (FRP) jackets were used as a local rehabilitation technique to enhance the joint shear strength and ductility. As another
option, X-steel braces were installed in the middle bay of the frame along its height as an alternate lateral load resisting system. For each frame, failure sequence and inter storey drift were examined. It was found that FRP wrapping eliminated the brittle failure modes without significant change in the structural response. However, steel bracing significantly contributed to the structural stiffness and reduced the maximum inter storey drift of the frames. (Mahmoud R. Maheri, 2005) adopted various local and global retrofitting techniques of RC frames and used various external and internal steel bracing systems in a structure. (Mahtab et.al, 2008) made an economical comparison for steel plate shear wall and cross bracing system for a ten storey bending frame using push over analysis as per FEMA 356 and it was observed that using steel plate shear walls, the consumed steel volume is 30% lower than that of bracings. (Pravin B. Waghmare, 2011) compared the retrofitting of RC building using steel bracing and infill walls. Of both the methods use of structural wall in the ground storey panel gave the maximum strength and ductility. (Cengizhan Durucan et.al, 2010) focused on a proposed seismic retrofitting system (PRS) configured to upgrade the performance of seismically vulnerable reinforced concrete (RC) buildings. The PRS is composed of a rectangular steel housing frame with chevron braces and a yielding shear link connected between the braces and the frame. The retrofitting system is installed within the bays of an RC building frame to enhance the stiffness, strength and ductility of the structure.

The objective of this paper is to study the response of sixteen storied building with and without the provision of corner bracings. Variations of Axial loads, moments, total drift and inter-storey drift at different heights are presented and discussed.

2. Problem modeling

The sixteen storied building is modeled using STAAD Pro software. The structure consists of 2 bays along Z-direction and 8 bays along X-direction with a total height of 45 m.

![Figure 1: Plan (Top view Size of the beams - 230 X 300; Size of the Columns - 600 X 600)](image)

2.1 Loading Conditions

Dead Load: Self weight + floor load 4KN/m² + UDL of 12 KN/m for fifteen floors + UDL of 6 KN/ m on the roof. Live Load: Floor load 2 KN/m². Wind pressures on the structure are calculated manually using static and gust factor method.
3. Calculation of wind load

Wind load is calculated based on two different methods a) Static method and b) Gust factor method.

3.1 Static method

The basic wind speed $V_b$ of a region correspond to certain reference conditions as highlighted in the earlier section, and shall be modified to include the effects of risk level, terrain
roughness, height, structure size and local topography to obtain design wind speed, $V_z$ in m/s at height $z$ for the chosen structure as given below

$$V_z = V_b k_1 k_2 k_3; \text{ Where } V_z = \text{Design wind speed (in m/s) at height } z$$

$$P_z = 0.6V_z^2$$

$V_b$ = Basic wind speed for the site (50 m/s)

$k_1$ = Probability factor or risk coefficient with return periods

$k_2$ = Factor for the combined effects of terrain (ground roughness) height and size of the component on structure. Table-2, Terrain category3, Class B- from IS 875 Part III- 1987

$k_3$ = Factor for local topography (hills, valleys, cliffs, etc.)

The following table shows Static pressures calculated using IS: 875 (Part III)

### Table 1: Wind Pressure at different elevations using static method

<table>
<thead>
<tr>
<th>Level</th>
<th>Elevation (m)</th>
<th>$K_z$</th>
<th>$V_z$ (m/s)</th>
<th>$P_z^1$ (KN/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>48</td>
<td>1.084</td>
<td>54.20</td>
<td>1.762</td>
</tr>
<tr>
<td>2</td>
<td>45</td>
<td>1.075</td>
<td>53.75</td>
<td>1.733</td>
</tr>
<tr>
<td>3</td>
<td>42</td>
<td>1.066</td>
<td>53.30</td>
<td>1.704</td>
</tr>
<tr>
<td>4</td>
<td>39</td>
<td>1.057</td>
<td>52.85</td>
<td>1.675</td>
</tr>
<tr>
<td>5</td>
<td>36</td>
<td>1.048</td>
<td>52.40</td>
<td>1.647</td>
</tr>
<tr>
<td>6</td>
<td>33</td>
<td>1.039</td>
<td>51.95</td>
<td>1.619</td>
</tr>
<tr>
<td>7</td>
<td>30</td>
<td>1.030</td>
<td>51.50</td>
<td>1.591</td>
</tr>
<tr>
<td>8</td>
<td>27</td>
<td>1.015</td>
<td>50.75</td>
<td>1.545</td>
</tr>
<tr>
<td>9</td>
<td>24</td>
<td>1.000</td>
<td>50.00</td>
<td>1.50</td>
</tr>
<tr>
<td>10</td>
<td>21</td>
<td>0.985</td>
<td>49.25</td>
<td>1.455</td>
</tr>
<tr>
<td>11</td>
<td>18</td>
<td>0.964</td>
<td>48.20</td>
<td>1.394</td>
</tr>
<tr>
<td>12</td>
<td>15</td>
<td>0.940</td>
<td>47.00</td>
<td>1.325</td>
</tr>
<tr>
<td>13</td>
<td>12</td>
<td>0.904</td>
<td>45.20</td>
<td>1.225</td>
</tr>
<tr>
<td>14</td>
<td>9</td>
<td>0.904</td>
<td>45.20</td>
<td>1.225</td>
</tr>
<tr>
<td>15</td>
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<td>16</td>
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</tr>
<tr>
<td>17</td>
<td>0</td>
<td>0.904</td>
<td>45.20</td>
<td>1.225</td>
</tr>
</tbody>
</table>

### 3.2 Gust Factor method

According to IS: 875 (Part III) the following table is calculated using different relations.
Table 2: Wind Pressure at different elevations using gust factor method

<table>
<thead>
<tr>
<th>Level</th>
<th>Elevation (m)</th>
<th>$K^1$</th>
<th>$V_{z}^1$ (m/s)</th>
<th>$P_{z}^1(KN/m^2)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>48</td>
<td>0.694</td>
<td>37.70</td>
<td>2.348</td>
</tr>
<tr>
<td>2</td>
<td>45</td>
<td>0.685</td>
<td>34.25</td>
<td>2.287</td>
</tr>
<tr>
<td>3</td>
<td>42</td>
<td>0.676</td>
<td>33.80</td>
<td>2.227</td>
</tr>
<tr>
<td>4</td>
<td>39</td>
<td>0.667</td>
<td>33.35</td>
<td>2.168</td>
</tr>
<tr>
<td>5</td>
<td>36</td>
<td>0.658</td>
<td>32.90</td>
<td>2.110</td>
</tr>
<tr>
<td>6</td>
<td>33</td>
<td>0.649</td>
<td>32.45</td>
<td>2.053</td>
</tr>
<tr>
<td>5</td>
<td>30</td>
<td>0.640</td>
<td>32.00</td>
<td>1.996</td>
</tr>
<tr>
<td>6</td>
<td>27</td>
<td>0.625</td>
<td>31.25</td>
<td>1.904</td>
</tr>
<tr>
<td>7</td>
<td>24</td>
<td>0.610</td>
<td>30.50</td>
<td>1.814</td>
</tr>
<tr>
<td>8</td>
<td>21</td>
<td>0.595</td>
<td>29.75</td>
<td>1.725</td>
</tr>
<tr>
<td>9</td>
<td>18</td>
<td>0.574</td>
<td>28.70</td>
<td>1.606</td>
</tr>
<tr>
<td>10</td>
<td>15</td>
<td>0.550</td>
<td>27.50</td>
<td>1.474</td>
</tr>
<tr>
<td>11</td>
<td>12</td>
<td>0.520</td>
<td>26.00</td>
<td>1.318</td>
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<tr>
<td>12</td>
<td>9</td>
<td>0.500</td>
<td>25.00</td>
<td>1.219</td>
</tr>
<tr>
<td>13</td>
<td>6</td>
<td>0.500</td>
<td>25.00</td>
<td>1.219</td>
</tr>
<tr>
<td>14</td>
<td>3</td>
<td>0.500</td>
<td>25.00</td>
<td>1.219</td>
</tr>
<tr>
<td>15</td>
<td>0</td>
<td>0.000</td>
<td>0.00</td>
<td>0.00</td>
</tr>
</tbody>
</table>

4. Results and discussion

A sixteen storied structure is modeled and analyzed for wind pressures using STAAD PRO with and without braces. The following inferences have been made.

1. Figure 5 shows the values of wind pressures computed by static method and code based gust factor method, it can be seen that there is marginal difference between the two methods up to three floors from the ground level, but from the fourth floor the gust pressures are more than static pressures.

2. Figure’s 6 and 7 shows the variation of inter-storey drift with respect to the height of the structure considered in X and Z directions. Fig. 6 shows that the inter-storey drifts in the X- direction is controlled well due to corner bracing, but has no influence of braces on the top floors. In the unbraced structure, inter-storey drift is much less than that of braced structure in the top floors. The reason behind this is, while performing serviceability check for total drift corner bracings will have much influence on the structure. Figure.7 clearly implies that with the provision of corner bracings in Z-direction the inter-storey drift gradually decreases compared to that in X-direction.

3. Figures. 8 and 9 shows the variation of total drift with respect to the height of the structure in X and Z directions. Figure.8 shows that total drift in X-direction is controlled with the provision of braces due to corner bracing and high stiffness values. Whereas in Z- direction Figure.9 the total drift is fairly high because of insufficient stiffness in the X-direction although corner bracings are provided.
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Figure 5: Variation of Static and Gust pressure with height

Figure 6: Interstorey drift in X-direction

Figure 7: Interstorey drift in Z-direction

Figure 8: Total drift in X-direction

Figure 9: Total drift in Z-direction
For the structure analyzed, three frames i.e. Frame-1(figures 10 to 17), Frame-3(figures 18 to 25), and Frame-5(figures 26 to 33) from Figure 3 were considered parallel to the X-Z plane and checked for the variation of axial loads and column moments in X and Z directions with respect to the height of the structure and following inferences were made.

Frame-1

**Figure 10 and 11:** Variation of axial loads and height for internal and external columns in X-direction

**Figure 12 and 13:** Variation of axial loads and height for internal and external columns in Z-direction
Figure 14 and 15: Variation of moments and height for internal and external columns in X-direction

Figure 16 and 17: Variation of moments and height for internal and external columns in Z-direction

Frame 3

Figure 18 and 19: Variation of axial loads and height for internal and external columns in X-direction
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Figure 20 and 21: Variation of axial loads and height for internal and external columns in Z-direction

Figure 22 and 23: Variation of moments and height for internal and external columns in X-direction

Figure 24 and 25: Variation of moments and height for internal and external columns in Z-direction
Frame 5

Figure 26 and 27: Variation of axial loads and height for internal and external columns in X-direction

Figure 28 and 29: Variation of axial loads and height for internal and external columns in Z-direction

Figure 30 and 31: Variation of moments and height for internal and external columns in X-direction
Figure 32 and 33: Variation of moments and height for internal and external columns in Z-direction

4. Conclusions

The following conclusions may be drawn based on the analysis carried out

1) Frame 1

   a) Figures 10 to 13 shows that axial loads in the external frame exterior columns in braced structure are high when compared with unbraced structure, reduced gradually and at top floor both are almost same. No significant variation is found in the external frame interior column.

   b) Figures 14 to 17 show that Column moments in the braced structure in the external frame exterior columns are very high upto 13m and reduced drastically upto roof when compared with unbraced structure. In the internal column, moments are high in the upper floor in the braced structure when compared with unbraced structure.

2) Frame 3

   a) Figures 18 to 21 show that axial loads are almost same in both braced and unbraced structures.

   b) Figures 22 to 25 show that moments in X-direction have reduced significantly in the braced structure compared to the unbraced structure. In Z-direction moments are high in the lower floors and then reduced when compared to unbraced structure. Member forces were controlled in the interior frame columns in braced structure and reduced drastically when compared with unbraced structure right from bottom to top.

3) Frame 5

   a) Figures 26 to 29 show that axial loads are almost same in both braced and unbraced structures.
b) Figures 30 to 33 show that column moments in X-direction are almost zero in both braced and unbraced structures. In Z-direction column moments have reduced significantly in braced structure compared to that of unbraced structure.

4) In high rise buildings the stability can be achieved by suitably adding the dimensions of the corner columns with corner diagonal X-bracings. Provision of X- bracings reduces the amount of drift and bending moments in the structure.

5) Provision of corner bracings can also be used as a retrofitting technique to strengthen the existing structure as X- bracings will act more like shear walls.

5. References


20. IS 875: Part III – Code of Practice for design loads (other than earthquake) for buildings and structures.