Effect of wind on tall building frames – Impact of aspect ratio

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ABSTRACT

In modern times many tall structures and high-rise towers are being built around the world. Because of its dynamic nature, wind plays an important role in the design of tall structures. Effect of wind is predominant on tall structures depending on location height of the structure. In this paper equivalent, a static method is used for the analysis of wind loads on buildings with the impact of different aspect ratios. The aspect ratio can be varied by changing the number of bays. Different aspect ratios were considered to carry out the present study and the analysis is carried out using STAAD PRO.

Keywords — Aspect ratio, Staad Pro, Tall buildings, Wind load

1. INTRODUCTION

Due to the recent advancements in the field of construction, various techniques have emerged for the construction of a structure that is often, to a degree unknown in the past, but is remarkably low in damping and light in weight. Such structures are more affected by the action of wind. It is the responsibility of the structural engineer to ensure that the structure should be safe and serviceable during its anticipated life even if it is subjected to dynamic loads. The wind forms the predominant source of all dynamic loads, in tall free-standing structures. The effect of wind causes a fluctuating force on a structure which induces large dynamic oscillations.

Structure oscillates during the vibration and inertia forces are mobilized in them. Then, these forces travel different paths through structural elements until they are transferred to the soil through the foundation. The effect of wind can be divided into two components:

(a) Along-wind Effect
(b) Across-wind Effect

- **Along-wind load**: It is caused by the drag components of the wind force.
- **Across-wind load**: It is caused by the corresponding lift component.

1.1 Objectives

The most prominent objectives of this study are:

(a) To study the various wind dynamic parameters on reinforced concrete moment resisting frames with a varying number of bays in horizontal configurations and number of stories in vertical configurations.

(b) To investigate the influence of aspect ratios along with the increasing height and increasing bays of the structure.

(c) To study the various patterns of displacement due to the effect of aspect ratio on the structure of different stories.

2. LITERATURE REVIEW

2.1 Wind Load on Tall Buildings

The action of natural wind, gusts and other aerodynamic forces will continuously affect a tall building. The force generated based on oscillatory motion and the final transfer of force through the foundation are significantly influenced by the overall geometry of the building. The structure will deflect about a mean position and will oscillate continuously. If the wind energy that is absorbed by the structure is larger than the energy dissipated by structural damping, then the amplitude of oscillation will continue to increase and will finally lead to destruction. The structure becomes aerodynamically unstable. The structural forms used these days have greater flexibility with less mass and damping than those used in olden days.

Knowledge on the maximum steady or time averaged wind loads can ascertain the overall stability of a structure. IS 875(2015) Part –III deals with wind load. The effect of wind is high in case of buildings over 10 storeys. Wind loads must be considered for the design of buildings over 10 storeys.
3. NATURE OF WIND
The wind is the movement of air from atmospheric domes of high pressure, beneath which air is sinking, to zones of low pressure, where the air is rising. It is of great complexity because of the many flow situations arising from the interaction of wind with structures. Thus, the wind speed is zero at ground level and maximum at the critical height.

4. METHODOLOGY
The present study is carried based on IS-875 Part 3(2015) which regulates thorough information on the calculation of wind load. This study includes a comparative study of the behaviour of High-Rise R.C.C. building frames considering different geometrical plan configurations based on different aspect ratios under wind forces. Following steps of methods of analysis are adopted in this study:

Step 1: Selection of different models having different building geometry and no. of bays for horizontal aspect ratio.
Step 2: Selection of basic wind speed and terrain category.
Step 3: Calculation of design wind pressure for each storey using the equivalent static method.
Step 4: Formation of a load combination.
Step 5: Modelling of building frames using STAAD Pro software.
Step 6: Analyses each model considering each load combinations.
Step 7: Comparative study of results in terms of storey displacement.

4.1. Equivalent Static Method
The basic wind speed ($V_b$) for any site shall be obtained and modified to include the following effects to get design wind speed ($V_z$) at any height ($z$), for the chosen structure:

(a) Risk level,
(b) Terrain roughness and height of the structure,
(c) Local topography,
(d) Importance factor for the cyclonic region.

4.2 Design Wind Pressure
It can be mathematically expressed as follows:

$$P_z = 0.6(V_z)^2$$

$$V_z = V_b \times K_1 \times K_2 \times K_3 \times K_4$$

Where,

$P_z$ = Design wind pressure;

$V_z$ = Design wind speed at height $z$, in m/s;

$V_b$ = Basic wind speed at height $z$;

$K_1$ = Probability factor (risk coefficient);

$K_2$ = Terrain roughness and height factor;

$K_3$ = Topography factor and

$K_4$ = Importance factor for the cyclonic region.

### Table 1: Details of design wind pressure parameters

<table>
<thead>
<tr>
<th>Design Wind Pressure Parameters</th>
<th>Location</th>
<th>Hyderabad</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basic Wind Pressure, $V_b$</td>
<td>44 m/s</td>
<td></td>
</tr>
<tr>
<td>Terrain Category</td>
<td>Category II</td>
<td></td>
</tr>
<tr>
<td>Class of Building</td>
<td>General</td>
<td></td>
</tr>
<tr>
<td>Topography</td>
<td>Plain/Flat</td>
<td></td>
</tr>
<tr>
<td>Probability Factor, $K_1$</td>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td>Topography Factor, $K_3$</td>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td>Importance Factor, $K_4$</td>
<td>1.0</td>
<td></td>
</tr>
</tbody>
</table>

4.2 Static pressure variation with height
The table indicates the values of static pressure which varies with the height of the storeys in structure:

<table>
<thead>
<tr>
<th>Table 2: Static Pressure Variation with Height</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height (m)</td>
</tr>
<tr>
<td>------------</td>
</tr>
<tr>
<td>0</td>
</tr>
<tr>
<td>3</td>
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<tr>
<td>6</td>
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<tr>
<td>9</td>
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<td>12</td>
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<td>18</td>
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<td>21</td>
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<td>24</td>
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</tbody>
</table>
5. STRUCTURAL MODELLING
5.1 Formulation of models
The length divided by the width (both in the plan) of a building is termed as its aspect ratio. The aspect ratios are formulated in terms of a number of bays - 2 bay, 4 bay and 6 bays respectively. By increasing the number of bays in length, the required values of aspect ratios can be obtained.

For example, the structural model shall contain 2 bays on both directions on base (12mx12m) to obtain the value of an aspect ratio as one. In this way, a total of 6 building models is formulated by assigning different aspect ratio for every 10 storeys and 15 storey tall buildings. All the structures are symmetrical, non-twisting and without infill walls. Two types of configurations are used in this study:

- **Square Building Frames**: When the value of aspect ratio is one
- **Rectangular Building Frames**: When the value of aspect ratio is more than one.

The typical size of the beam is 0.3x0.4 m² and the typical size of the column is 0.5x0.5 m². Each bay is 6.0 metre in length and each storey is 3.0 metre in height. The depth of the foundation is 2.4 metre for both 10 and 15 storeys building. The wind load is applied both along and across the building frame.

Analysis of modelled structures is carried on STAAD PRO. It is a user-friendly interface which allows modelling the frames and applying loads of varying dimensions. This software helps in modelling the building frames, analysing different parameters and changing the properties of all materials which are used for building structures.
Fig. 3: Live load applied on the frame

Fig. 4: Wind Load Applied on the Frame

Fig. 5: Deflection of the Building

6. RESULTS AND DISCUSSIONS
The effect of wind load is more considerable in modern times due to the heavy construction of tall structures across the globe. Wind load is more predominant in case of tall slender frames. The safety and stability of structure may become a critical factor as tall slender frames interact with the wind. Hence, a thorough study of wind effects is much necessary for the design of tall buildings.

Fig. 6: Aspect ratio vs. displacement
In figure 6 aspect ratios 1(12x12), 2(12x24), 3(12x36) are taken on the X axis and displacement values are taken on the Y axis. The graphs are drawn for 10 storeys and 15 storeys. The wind load is applied along the length of the frame. The variation of displacement at different aspect ratios is increasing at a low rate. The same trend is observed at different storey heights.

In figure 7 aspect ratios 1(12x12), 2(12x24), 3(12x36) are taken on the X axis and displacement values are taken on the Y axis. The graph is drawn for 10 storeys and 15 storeys. The wind load is applied across the length of the frame. The variation of displacement at different aspect ratios is decreasing i.e. when the wind is applied across (along the smaller side) with an increase in aspect ratio displacement decreases.

![Fig. 7: Aspect ratio vs. displacement](image)

In figure 8 the number of storeys are taken on X-axis and displacement values are taken on Y-axis. In the below graph aspect ratio is constant 1, with variation in length and breadth: 6mx6m and 12mx12m at different storey heights. The variation of displacements at the same aspect ratio is an increasing function.

![Fig. 8: Number of storeys vs. displacement](image)

In figure 9 the number of storeys are taken on the X axis and displacement is taken on the Y axis. The above graph is drawn for aspect ratio 2 but two cases are considered in one case length and breadth are 6m x 12m, in other case length and breadth are 12mx24m. The wind load is applied along the length of the frame. The variation of displacement at different storey heights is increasing.

![Fig. 9: Storey vs. displacement](image)
7. CONCLUSIONS

After performing the analysis of the building frames using STAAD PRO software, the conclusions obtained are:

- When wind load is applied along the length of the building, the displacement is very high for 15 storied frames when compared to 10 storied frames.
- When wind load is applied across the length of the building frame, as aspect ratio increases, displacement gradually decreases. This displacement reduction is high in case of 15 storied frames compared to 10 storied frames.
- For aspect ratio 1, displacement is high for 6x6 frame compared to 12x12 and 18x18 frames.
- For aspect ratio 2, displacement is more when wind load is applied along the length of the building frame. The displacement decreases when wind load is applied across the building frame.
- As the stiffness of the member increases the displacement of the frame decreases. The aspect ratio plays a major role in affecting the displacements up to a certain height. Further research can be carried out for more accurate results.

8. REFERENCES