MODAL ANALYSIS OF MULTISTOREY RECTANGULAR BUILDINGS WITH 1:2:2.5 PLAN RATIOS

Geetha D

Department Of Civil Engineering, Karunya University, TamilNadu, India

Abstract - The natural frequencies and mode shapes are important parameters in the evaluation of design loads for buildings subjected to dynamic loading condition. They are also required for spectrum analysis or a mode superposition harmonics or transient analysis. In the present study, the effect of bay width on the fundamental time period of 30 storey tall rectangular buildings (1:2 side ratios in plan) with Moment Resisting Frame is studied. Free vibration analysis of the rectangular buildings is carried out to get the dynamic characteristics of the structure in terms of natural frequencies and mode shapes. In the present study, number storeys of 30 and storey height of 3.28 m are considered to study the influence of bay width of Moment Resisting Frame on the fundamental Time period and fundamental natural frequency (1st sway mode) of the building. The free vibration analysis of the building is carried out by using STAAD Pro.

Key Words: NATURAL FREQUENCY, TIME PERIOD, BAY WIDTH, FREE VIBRATION ANALYSIS, MOMENT RESISTING FRAME

1. INTRODUCTION

Framed structure is most widely used structural system in building practice. The design of tall building and structure are governed by lateral loads such as wind load and seismic load. Since, the wind loads and seismic loads are dynamic in nature; the proximity of natural frequencies of all buildings to these dynamic loads can cause resonance effects. To consider these dynamic effects due to wind and seismic loads on design of tall buildings, the natural frequency of the building is required for the evaluation of design loads. Both IS: 875 (Part 3) and IS: 1893 (Part 1) provide empirical expressions for the evaluation of fundamental time periods of tall building. The calculated time period of the building is used to evaluate the natural frequency, \( f_o = \frac{1}{T} \), which is used to obtain Gust Factor as provided under Clause 8.3 of IS: 875 (Part 3) – 1987 and as indicated below:

\[
G = \frac{\text{Peak Load}}{\text{Mean Load}}
\]

Where, \( S \) (Size Reduction Factor) and \( E \) (Gust Energy Factor) depend upon the natural frequency of the building \( f_o \) as shown below.

\[
G = 1 + g_H \sqrt{\frac{B (1 + \phi)^2 + SE}{\beta}}
\]

In which the value of \( S \) (Size Reduction Factor) and \( E \) (Gust Energy Factor) depend upon the natural frequency of the building \( f_o \) as shown below.
IS: 1893 (Part 1) – 2002 provides empirical expressions for the evaluation of fundamental time period under Clause 7.6 as given below:

**Fundamental Natural Period**

The approximate fundamental natural period of vibration \( (T_a) \), in seconds, of a moment-resisting frame building without brick infill panels may be estimated by the empirical expression:

\[
T_a = \begin{cases} 
0.075 \frac{h^{0.75}}{d} & \text{for RC frame building} \\
0.085 \frac{h^{0.75}}{d} & \text{for steel frame building}
\end{cases}
\]

Where,

\( h \) = Height of building, in m. This excludes the basement storeys, where basement walls are connected with the ground floor deck or fitted between the building columns.

But, it includes the basement storeys, when they are not so connected.

The approximate fundamental natural period of vibration \( (T_a) \), in seconds, of all other buildings, including moment-resisting frame buildings with brick infill panels, may be estimated by the empirical expression:

\[
T_a = \frac{0.09}{\sqrt{d}} \left( h^{0.75} \right)
\]

Where,

\( h \) = Height of building, in m, and

\( d \) = Base dimension of the building at the plinth level, in m, along the considered direction of the lateral force."

The calculated time period of the building is used to obtain \( (S_a/g) \) as provided in empirical expressions for \( (S_a/g) \) under Clause 6.4.5 and in Fig. 2 of IS:1893 (Part 1) – 2002 and as indicated below:

![Chart 3: Spectral Acceleration Coefficient (Fig. 2 of IS: 1893 (Part 1) – 2002)](chart3.png)

**2. FREE VIBRATION ANALYSIS OF RECTANGULAR BUILDING**

The natural frequencies and mode shapes of buildings are considered in the evaluation of design load for buildings subjected to dynamic loading conditions. Free vibration analysis of buildings is carried out to get the dynamic characteristics of the building in terms of natural frequencies and mode shapes, which are used for the computation of dynamic responses.

In the present study, the free vibration analysis of the buildings is done by using STAAD Pro.
2.1 Modeling of building

The following are steps involved in the Finite Element Modeling of the building:

- Creation of members (beams, columns and slabs)
- Assigning material properties
- Assigning member properties
- Support specifications
- Adding load cases

Building frame model was created by using following typical plan requirement:

- Plan dimension : 40 m x 80 m (for Building 1) : 60 m x 120 m (for Building 2)
- Height of the building: 98.4m , Typical Bay width: 4m,
- Storey height: 3.28m, No. of Storeys : 30

2.2 Output File

The calculated natural frequencies for Building 1 are given below

<table>
<thead>
<tr>
<th>Mode</th>
<th>Frequency (cycle/sec)</th>
<th>Period (sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.308</td>
<td>3.24290</td>
</tr>
<tr>
<td>2</td>
<td>0.320</td>
<td>3.12178</td>
</tr>
<tr>
<td>3</td>
<td>0.321</td>
<td>3.11538</td>
</tr>
<tr>
<td>4</td>
<td>0.937</td>
<td>1.06684</td>
</tr>
<tr>
<td>5</td>
<td>0.970</td>
<td>1.03105</td>
</tr>
<tr>
<td>6</td>
<td>0.970</td>
<td>1.03069</td>
</tr>
</tbody>
</table>

3. RESULTS AND DISCUSSIONS

In the present study, the influence of bay width on the natural frequencies of two tall buildings with 1:2 side ratios in plan is studied. In the present study the fundamental frequency of the building for sway mode in X and Z directions are considered. The following values are considered constant while varying the bay width of the frame in X-direction and Z-direction in plan:

- No. of Storeys = 30, Storey height = 3.28m,
- Column size = 0.6x0.6m, Beam size = 0.25x0.45m.

**Building 1**

For Building 1, the following building dimensions in plan have been chosen: 40 m (in X-direction) x 80 m (in Z-direction).

- **Varying Bay width in X-direction (Case 1)**
  
  In this case, the bay width of the frame in X-direction is varied between 4 m and 10 m while keeping the bay width in Z-direction as constant as 4 m.

- **Varying Bay width in Z-direction (Case 2)**

  In this case, the bay width of the frame in Z-direction is varied between 4 m and 10 m while keeping the bay width in X-direction as constant as 4 m.

- **Varying Equal Bay widths in X-direction and Z-direction (Case 3)**

  In this case, the bay width of the frame in both X-direction and Z-direction is varied between 4m and 10m.

**Building 2**

For Building 2, the following building dimensions in plan have been chosen: 60 m (in X-direction) x 120 m (in Z-direction).

- **Varying Bay width in X-direction (Case 1)**

  In this case, the bay width of the frame in X-direction is varied between 3 m and 10 m while keeping the bay width in Z-direction as constant as 4 m.
Varying Bay width in Z-direction (Case 2)

In this case, the bay width of the frame in Z-direction is varied between 3 m and 10 m while keeping the bay width in X-direction as constant as 4 m.

Varying Equal Bay widths in X-direction and Z-direction (Case 3)

In this case, the bay width of the frame in both X-direction and Z-direction is varied between 3 m and 10 m.

3.1 INFLUENCE OF BUILDING PLAN DIMENSION ON NATURAL FREQUENCY

Further, the influence of building plan dimension on natural frequency of 1st sway mode of the building has been studied.

Table 2-Natural frequency values (Hz) for Plan dimension. (For reference case ie. Equal Bay width of 4 m in both directions)

<table>
<thead>
<tr>
<th>Plan Dimension (m)</th>
<th>Natural Frequency of 1st Sway Mode (Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>40</td>
<td>0.308</td>
</tr>
<tr>
<td>60</td>
<td>0.315</td>
</tr>
<tr>
<td>80</td>
<td>0.321</td>
</tr>
<tr>
<td>120</td>
<td>0.323</td>
</tr>
</tbody>
</table>

3.2 REGRESSION ANALYSIS OF RESULTS

Based on the variation of the natural frequency (1st sway mode) of the building in a particular direction with respect to the bay width in the same direction of sway mode and the bay width in the perpendicular direction of sway mode, the following relationship has been formulated based on regression analysis carried out by using the all the values of natural frequency of 1st sway mode in X-direction and Z-direction from cases 1 to 3 of Building 1 and Building 2,

\[
    n_x \propto B_x^{-0.6} B_z^{-0.3}
\]

\[
    n_z \propto B_x^{-0.3} B_z^{-0.6}
\]

Where

- \( n_x \) = Natural frequency of building 1st sway mode in X-direction
- \( n_z \) = Natural frequency of building 1st sway mode in Z-direction
- \( B_x \) = Bay width of frame of building in X-direction
- \( B_z \) = Bay width of frame of building in Z-direction

Table 2-Bay widths and Natural Frequency values for Building 2

<table>
<thead>
<tr>
<th>( B_x )</th>
<th>( B_z )</th>
<th>( B_x^{-0.6} B_z^{-0.3} )</th>
<th>( n_x )</th>
<th>( B_x^{-0.3} B_z^{-0.6} )</th>
<th>( n_z )</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.00</td>
<td>4.00</td>
<td>0.341</td>
<td>0.268</td>
<td>0.269</td>
<td>0.307</td>
</tr>
<tr>
<td>5.00</td>
<td>4.00</td>
<td>0.251</td>
<td>0.278</td>
<td>0.269</td>
<td>0.295</td>
</tr>
<tr>
<td>6.00</td>
<td>4.00</td>
<td>0.225</td>
<td>0.252</td>
<td>0.254</td>
<td>0.295</td>
</tr>
<tr>
<td>10.00</td>
<td>4.00</td>
<td>0.166</td>
<td>0.199</td>
<td>0.218</td>
<td>0.266</td>
</tr>
<tr>
<td>4.00</td>
<td>3.00</td>
<td>0.313</td>
<td>0.338</td>
<td>0.341</td>
<td>0.380</td>
</tr>
<tr>
<td>4.00</td>
<td>5.00</td>
<td>0.269</td>
<td>0.299</td>
<td>0.251</td>
<td>0.280</td>
</tr>
<tr>
<td>4.00</td>
<td>6.00</td>
<td>0.254</td>
<td>0.287</td>
<td>0.225</td>
<td>0.257</td>
</tr>
<tr>
<td>4.00</td>
<td>10.00</td>
<td>0.218</td>
<td>0.257</td>
<td>0.166</td>
<td>0.201</td>
</tr>
<tr>
<td>3.00</td>
<td>3.00</td>
<td>0.372</td>
<td>0.390</td>
<td>0.372</td>
<td>0.401</td>
</tr>
<tr>
<td>4.00</td>
<td>4.00</td>
<td>0.287</td>
<td>0.315</td>
<td>0.287</td>
<td>0.323</td>
</tr>
<tr>
<td>5.00</td>
<td>5.00</td>
<td>0.235</td>
<td>0.262</td>
<td>0.235</td>
<td>0.268</td>
</tr>
<tr>
<td>6.00</td>
<td>6.00</td>
<td>0.199</td>
<td>0.223</td>
<td>0.199</td>
<td>0.229</td>
</tr>
<tr>
<td>10.00</td>
<td>10.00</td>
<td>0.126</td>
<td>0.138</td>
<td>0.126</td>
<td>0.141</td>
</tr>
</tbody>
</table>
4. CONCLUSIONS

In the present study, the effect of bay width on the fundamental time period of two 30 storey tall rectangular buildings (1:2 side ratio in plan) with Moment Resisting Frame is studied. With a storey height of 3.28 m, the total height of both the buildings is 98.4 m. The plan dimensions of the two rectangular buildings are 40 m x 80 m for Building 1 and 60 m x 120 m for Building 2. The modal analysis of the buildings with Moment Resisting Frames without infill has been carried out using STAAD PRO software by using BEAM and PLATE elements to model beams, columns and slabs. For both the buildings, three cases of bay width variation is carried out to study their effect on the natural frequency of 1st sway mode of the building in X-direction and Z-direction as given below:

Case 1: In X-direction: Bay width ($B_x$) is varied between 4 m and 10 m for Building 1 and between 3 m and 10 m for Building 2 while bay width in Z-direction ($B_z$) is kept constant of 4 m.

Case 2: In Z-direction: Bay width ($B_z$) is varied between 4 m and 10 m for Building 1 and between 3 m and 10 m for Building 2 while bay width in X-direction ($B_x$) is kept constant of 4 m.

Case 3: In both X-direction and Z-direction: Bay widths ($B_x$ and $B_z$) are varied between 4 m and 10 m for Building 1 and between 3 m and 10 m for Building 2.

The modal analysis of the buildings is carried out using the finite element software Staad Pro. In the present study, the
natural frequency of the building for 1st sway mode in X and Z direction (in plan) are studied.

Based on the modal analysis and the results obtained, the following observations have been made:

i) For constant \( B_x \) natural frequency of 1st sway mode of the building in X-direction is proportional to \( B_x^{-0.5} \). Whereas natural frequency of 1st sway mode of the building in Z-direction is proportional to \( B_z^{-0.2} \).

ii) For constant \( B_x \) natural frequency of 1st sway mode of the building in X-direction is proportional to \( B_x^{-0.2} \). Whereas natural frequency of 1st sway mode of the building in Z-direction is proportional to \( B_z^{-0.5} \).

iii) For equal bay width case of \( B_x = B_z = B \), both natural frequencies of 1st sway mode of the building in X-direction and Z-direction are proportional to \( B^{-0.5} \).

iv) Based on regression analysis of the relationship between natural frequencies (\( n_x \) and \( n_z \)) and bay widths (\( B_x \) and \( B_z \)), the following relations have been obtained:

\[
\begin{align*}
  n_x & \propto B_x^{-0.6} B_z^{-0.3} \\
  n_z & \propto B_x^{-0.3} B_z^{-0.6}
\end{align*}
\]

v) Further, the influence of building plan dimensions on the natural frequency of 1st sway mode is observed to be less than the influence of bay width.

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