

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

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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 be constant 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 (Size 11 , cambria font)

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 tall 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. In the case of Moment Resisting Frames without brick infill panels, without bracings/shear walls, the empirical expressions are observed to be function of either number of storeys (IS: 875(Part 3)) or the height of the building (IS: 1893 (Part 1)) only as highlighted in the following sections.

1.1 IS: 875 (Part 3) – 1987

IS: 875 (Part 3) – 1987 provides empirical expressions for the evaluation of fundamental time period under Note 1 of Clause 7.1 as given below:

- (a) For moment resisting frames without bracing or shear walls for resisting the lateral loads

$$T = 0.1 n$$

Where n = number of storeys including basement storeys; and

- (b) For all others

$$T = \frac{0.09 H}{\sqrt{d}}$$

Where,

H = total height of the main structure of the building in metres, and

d = maximum base dimension of building in metres in a direction

Parallel to the applied wind force.”

The calculated time period of the building is used to evaluate the natural frequency, ($f_0 = 1/T$), which is used to obtain Gust Factor as provided under Clause 8.3 of IS: 875 (Part 3) – 1987 and as indicated below:

G = Gust factor (Peak Load / Mean Load) and it is given,

$$G = 1 + g_f r \sqrt{\left[B (1 + \phi)^2 + \frac{SE}{\beta} \right]}$$

In which the value of S (Size Reduction Factor) and E (Gust Energy Factor) depend upon the natural frequency of the building (f_0) as shown below.

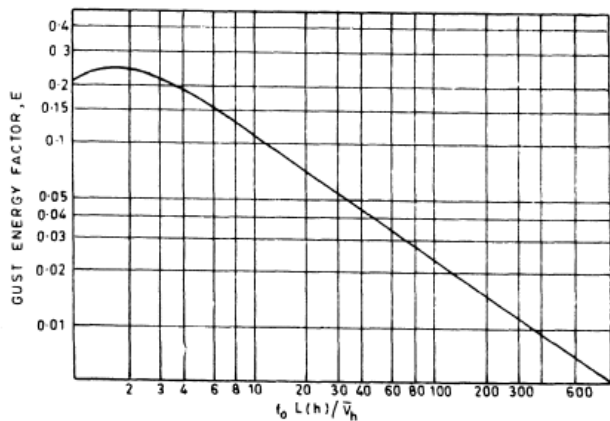


Chart-1: Size Reduction Factor (Fig. 10 of IS: 875 (Part 3) - 1987)

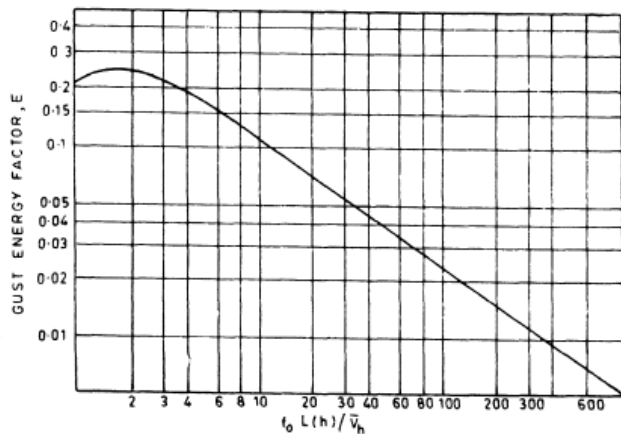


Chart-2: Gust Energy Factor (Fig. 11 of IS: 875 (Part 3) - 1987)

1.2 IS: 1893 (Part 1) - 2002

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:

$$T_a = 0.075 h^{0.75} \text{ for RC frame building}$$

$$= 0.085 h^{0.75} \text{ for steel frame building}$$

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:

$$T_a = \frac{0.09 h}{\sqrt{d}}$$

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:

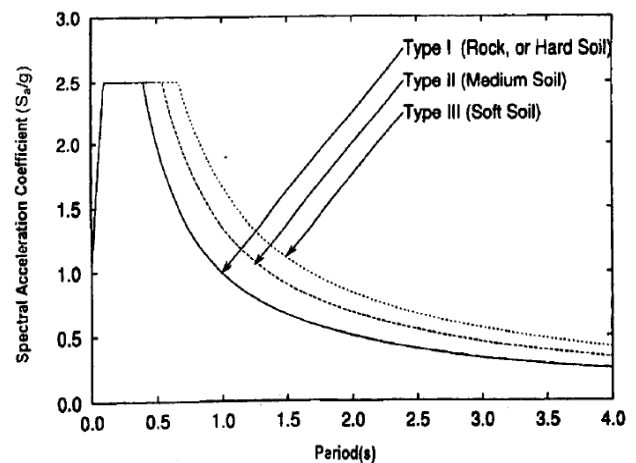


Chart-3: Spectral Acceleration Coefficient (Fig. 2 of IS: 1893 (Part 1) - 2002)

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 -1: Output viewer from STAAD Pro

Mode	Frequency (cycle/sec)	Period (sec)
1	0.308	3.24290
2	0.320	3.12178
3	0.321	3.11538
4	0.937	1.06684
5	0.970	1.03105
6	0.970	1.03069

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)

Plan Dimension (m)	Natural Frequency of 1 st Sway Mode (Hz)
40	0.308
60	0.315
80	0.321
120	0.323

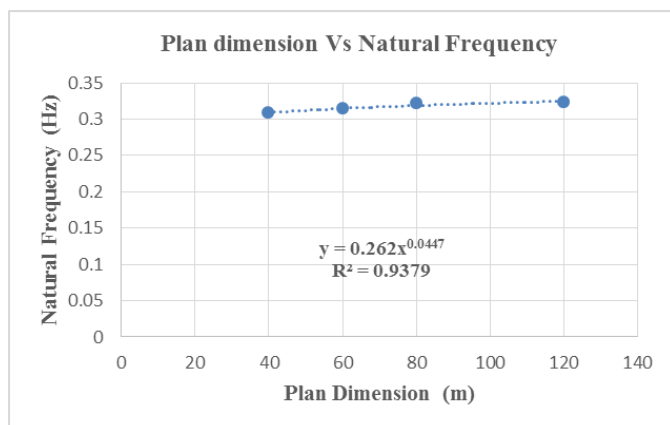


Chart -4: Comparison of Natural Frequency values for plan dimension

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

B_x	B_z	$B_x^{-0.6} B_z^{-0.3}$	n_x	$B_x^{-0.3} B_z^{-0.6}$	n_z
3.000	4.000	0.341	0.368	0.313	0.346
5.000	4.000	0.251	0.278	0.269	0.307
6.000	4.000	0.225	0.252	0.254	0.295
10.00	4.000	0.166	0.199	0.218	0.266
4.000	3.000	0.313	0.338	0.341	0.380
4.000	5.000	0.269	0.299	0.251	0.280
4.000	6.000	0.254	0.287	0.225	0.257
4.000	10.00	0.218	0.257	0.166	0.201
3.000	3.000	0.372	0.390	0.372	0.401
4.000	4.000	0.287	0.315	0.287	0.323
5.000	5.000	0.235	0.262	0.235	0.268
6.000	6.000	0.199	0.223	0.199	0.229
10.00	10.00	0.126	0.138	0.126	0.141

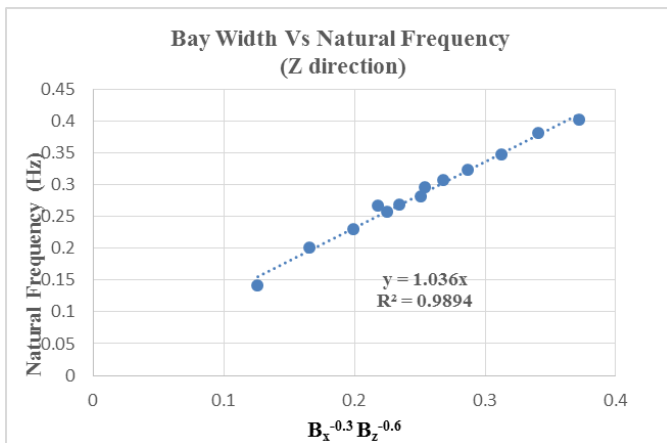


Chart -5: Variation of Natural Frequency values of 1st sway mode in Z-direction for Building 2

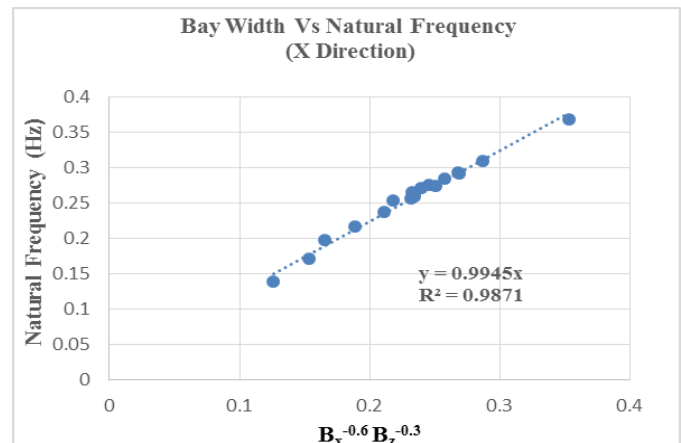


Chart -6: Variation of Natural Frequency values of 1st sway mode in X-direction for Building 1.

Table 3-Bay widths and Natural Frequency values for Building 1

B_x	B_z	$B_x^{-0.6} B_z^{-0.3}$	n_x	$B_x^{-0.3} B_z^{-0.6}$	n_z
10.00	4.000	0.166	0.197	0.218	0.267
8.000	4.000	0.189	0.216	0.233	0.278
6.666	4.000	0.211	0.236	0.246	0.288
5.714	4.000	0.232	0.255	0.258	0.297
5.000	4.000	0.251	0.274	0.269	0.306
4.444	4.000	0.270	0.291	0.278	0.314
4.000	10.00	0.218	0.252	0.166	0.201
4.000	8.000	0.233	0.264	0.190	0.222
4.000	7.272	0.240	0.284	0.201	0.232
4.000	6.666	0.246	0.284	0.211	0.242
4.000	5.714	0.258	0.284	0.232	0.263
4.000	5.000	0.269	0.293	0.251	0.283
4.000	2.000	0.354	0.367	0.435	0.462
4.000	4.000	0.287	0.308	0.287	0.321
8.000	8.000	0.154	0.170	0.154	0.175
10.00	10.00	0.126	0.138	0.126	0.142
5.000	5.000	0.235	0.258	0.235	0.267

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_z , 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 $B_x^{-0.2}$.

ii) For constant B_x , natural frequency of 1st sway mode of the building in X-direction is proportional to $B_z^{-0.2}$. 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 $B^{-0.9}$.

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:

$$n_x \propto B_x^{-0.6} B_z^{-0.3}$$

$$n_z \propto B_x^{-0.3} B_z^{-0.6}$$

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.

ACKNOWLEDGEMENT

At the outset I express my gratitude to the **ALMIGHTY GOD** who has been with me during each and every step that I have taken towards the completion of this project.

I thank our beloved founder **Late Dr. D.G.S Dhinakaran** and our Honorable Chancellor **Dr. Paul Dhinakaran** for providing me the educative infrastructure and learning ambience, which motivated me to a greater extent.

I wish to thank with deep sense of gratitude to the management of Karunya University and to our Vice Chancellor **Dr. S. SUNDAR MANOHARAN** and our respected registrar **Dr. C. JOSEPH KENNADDY** for extending all facilities.

I express my sincere thanks to Director **Dr. D. TENSING**, School of Civil Engineering for his full support and valuable guidance.

I express my sincere gratitude to my internal guide **Dr. G HEMALATHA**, Head of Department, School of Civil Engineering, for her wholehearted support right from the beginning for successful completion of this project.

I am grateful to **Dr. NAGESH R IYER**, Director, Structural Engineering Research Centre (SERC) and **Dr. P HariKrishna**, Senior Principal Scientist and my project leader, Wind Engineering Lab to take up the Project.

My Sincere thanks to **D. S SELVIRAJAN**, Head of Wind Engineering Lab for her guidance and suggestion for my project.

This project would not have been completed in full shape without the efforts taken by **Mr. A JOSEPH ANDREW PRASAN** (Project Assistant) at SERC including various testing laboratories and civil engineering staffs of Karunya University and thank them profusely.

I would also like to thank my **Beloved Parents and all my Friends** who prayed and helped during the project work.

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