Study of Neighboring Interference on the Along-Wind Response of a Building

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Abstract. As structures increase in height, the complexity of their design and structural analysis also increases. Specifically, the impact of wind becomes a crucial consideration in construction. This study aimed to examine how the distances between adjacent buildings affect the along-wind response of a standardized tall building, known as CAARC, under the influence of wind. Wind effect analysis was conducted in two main directions, with the wind acting at 0° and 90°, considering the presence of a interfering building in four distinct positions. Using force and moment data, computational analyses were performed using MATLAB software, combined with the High-Frequency Pressure Integration (HFPI) method, as well as factors from the Brazilian standard and the Davenport Method. The results revealed that as the distance between interfering buildings increases, the impact of this proximity on wind action decreases.

Keywords: along-wind response, Dynamic analysis, Wind action, HFPI.

1 Introduction

By the mid-1960s, most buildings were low-rise, had a high self-weight, and were highly rigid, characteristics that, according to Blessmann [1], helped resist wind action. However, the current construction scenario is characterized by increasingly tall and slender buildings, which naturally leads to more complex structural analyses, thereby increasing the need for innovations and optimization studies from the perspective of Wind Engineering (WE). A thorough analysis of buildings under wind action is essential to ensure structural safety and design requirements, especially in the realm of dynamic actions, a topic that is still not widely covered in the training of Brazilian civil engineers. Wind action varies over time, resulting in dynamic stresses, a characteristic that increases its complexity. Dynamic effects are determined by the kinetic energy contributing to fluctuations and depend on how this energy is distributed across various frequencies, a fundamental structural parameter in dynamic wind analysis (Blessmann [2]).

Another point of study is the interference caused by the presence of nearby buildings. Several researchers (Vieira [3] [4], Gu et al. [5], Fontes et al. [6], Lavôr [7] [8] [9]) have dedicated themselves to analyzing factors arising from this situation, such as the quantity and positioning of interfering buildings, wind angle of incidence, terrain roughness, modal shapes, among others.

The complexity of such interactions leads standards such as ABNT NBR 6123 [10] and the Indian IS-875 to provide parameters to guide engineers in considering the effects of wind action, covering both mean and fluctuating responses.

In order to expand on Vieira's [4] scope of work, building upon Lavôr's [9] studies, this research sought to enhance the understanding of dynamic aspects induced by wind action on buildings, analyzing the response of a tall building. Results were compared with and without the presence of nearby buildings using normative procedures, Davenport's theory, and experimental findings. The aim was to obtain the response of a standardized tall building under wind action in the direction of its incidence. Based on the values of forces and moments obtained, the neighborhood interference factor will be calculated.

2 Research Method

2.1 Wind tunnel

The data used in this study were obtained from tests conducted by Vieira (2016) at the wind tunnel of the Federal University of Rio Grande do Sul. The tunnel is a closed-circuit type with a test section cross-sectional area of 1300 mm in width by 900 mm in height and a length of 9320 mm. The simulated wind, whose characteristics are presented in Figure 1, was of the sliding and turbulent type, over terrain with roughness produced by numerous and closely spaced obstacles, a common situation in small towns and suburbs of large cities. The mean velocity (V) is expressed by a power law (Equation 1) and the turbulence intensity (I) by the mathematical expression presented in Equation 2. The mean velocity is measured along the height 'z' in the test section of the tunnel; V_{ref} represents the reference velocity at height 'z_{ref}'; and the exponent $p = 0.23$ is responsible for representing the type of terrain considered in the velocity power law, corresponding between Categories III and IV of the Brazilian standard NBR 6123 [10]. In the tunnel, this condition is replicated by the insertion of a grid immediately after the convergent section and by the positioning of blocks along the floor between the convergent section and the test section (Figure 2).

$$\frac{V}{V_{ref}} = \left(\frac{z}{z_{ref}}\right)^p \tag{1}$$

$$I(z) = \frac{\sigma_V(z)}{V(z)} \tag{2}$$

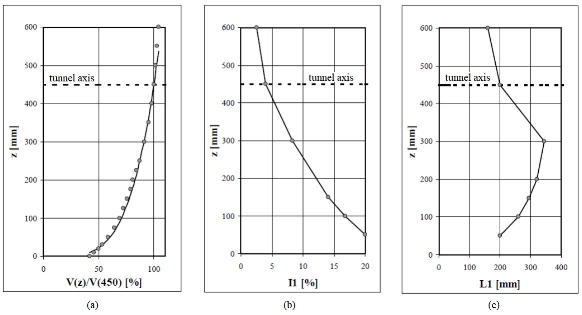

Figure 1. Characteristics of simulated turbulent wind with exponent p = 0.23: (a) Mean velocity profile; (b) Longitudinal turbulence intensity; (c) Longitudinal turbulence macro-scale

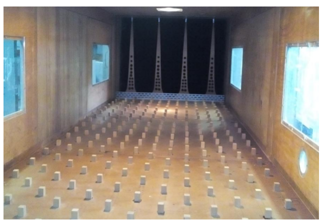

Figure 2. Device used to simulate natural wind profile

The tunnel analysis system employs an electronic sensor from Scanivalve Corp, specifically the ZOC33 model. This sensor consists of 6 sets of modules, each with 64 channels, enabling high-frequency data capture with a maximum acquisition rate of 20 kHz. The associated inaccuracy of this sensor is 0.12%. For the purposes of this research, the sensor recorded a total of 8192 pressure measurements per channel over a period of 16 seconds, resulting in an acquisition rate of $512Hz$.

The modules were connected to the standard building model available in the wind tunnel for research, using measurement taps. The model itself was constructed from acrylic plates with a height of $450mm$ and a cross-sectional area with dimensions of $112.5mm$ by $75mm$. The length scale employed was $1 : 406.4$. The measurement points were distributed around the perimeter of the model at 10 different levels, with each level containing 28 measurement points (7 points per facade). In total, 280 pressure taps were used, distributed as illustrated in Figure 3, with dimensions corresponding to full scale.

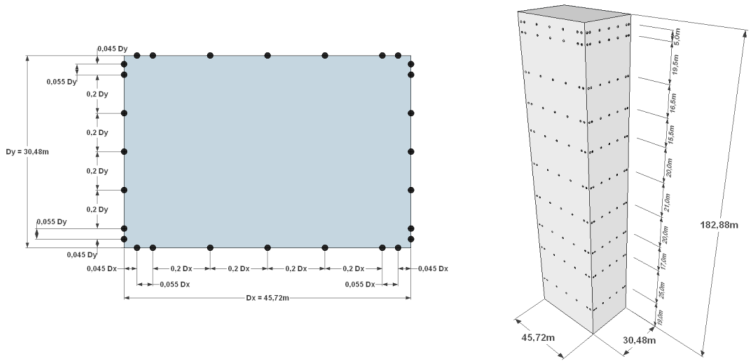

Figure 3. Layout of the pressure taps and dimensions

2.2 Proposed Neighborhoods

To meet the objectives outlined in this study, an investigation was proposed using two buildings of identical dimensions. The chosen building was the standard model of the Commonwealth Advisory Aeronautical Research Council (CAARC), with dimensions presented in Figure 3. One of the building models was equipped with pressure taps connected to data reading equipment, while the interfering building was not instrumented. The interfering building was positioned in front of the instrumented model in four distinct positions, with a distance related to the total height of the buildings (Figure 4). This positioning was chosen based on the parameter used by the NBR 6123 standard, which relates the distance to be considered for the effect of a interfering building to the height of the building under evaluation. Wind incidence angles of 0° and 90° relative to the axes of the building under analysis were considered, angles also taken into account in the calculation of NBR 6123.

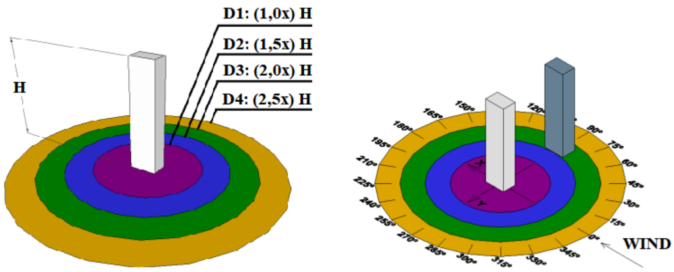

Figure 4. Evaluated neighborhood

2.3 Data analysis

Based on the data collected in the experiment, these are processed to obtain the resultant force and moment, according to Equations 3 and 4, respectively, per measurement level, considering in each case the areas of influence of each measurement.

$$F_i = c_{p_i} A_i q \tag{3}$$

$$M_i = c_{p_i} A_i q\, d \tag{4}$$

Where F_i and M_i represents the force and moment acting at point "i", respectively, c_{p_i} is the pressure coefficient, A_i is the area of influence, q is the calculated pressure, and d is the distance between the line of action of the force and the considered axis.

For the consideration of the fluctuating wind component for the isolated model, the results obtained by the simplified method of NBR 6123:2023, the Davenport Method, and the High-Frequency Pressure Integration (HFPI) Method were compared.

Since the studied building has a constant section, NBR 6123:2023 [10] presents Equation 5 for the calculation of the dynamic pressure at a defined height '$q(z)$'. In the expression, the basic calculated dynamic pressure (q_0), the meteorological parameter (b_m), the building height (h), the elevation above the ground (z), the reference elevation (z_r), the exponent representing the modal shape of the first vibration mode (γ), and the dynamic factor (ξ) are considered. The first term in brackets represents the mean response, while the second term represents the maximum amplitude of the fluctuating response.

$$q(z) = \overline{q_0}\, {b_m}^2 \left[\left(\frac{z}{z_r}\right)^{2p} + \left(\frac{h}{z_r}\right)^{p} \left(\frac{z}{h}\right)^{\gamma} \frac{1+2\gamma}{1+\gamma+p} \xi \right] \tag{5}$$

The Davenport Method [11] takes into account the influence lines, variation of drag coefficients ($C_a(z)$), building geometry, mass, wind velocity profile, and exposed area index. The mean and fluctuating wind forces on the structure at a normalized height, z, are obtained by Equations 6 and Equation 7, respectively.

$$\overline{F}(z) = [q_H D_H H]\phi(z)\, C_a(z)\, {\phi_U}^2(z)\, \phi_D(z) \tag{6}$$

$$\tilde{F}(z) = [q_H D_H H] C_a(z)\, \phi_U(z)\, \phi_D(z)\, 2 I_u(z) \tag{7}$$

Where q_H is the dynamic pressure, D_H is the width, and H is the height of the building. $\phi(z)$ represents the exposed area index, ${\phi_U}^2(z)$ is the wind velocity profile, ${\phi_D}^2(z)$ denotes the width variation, and $I_u(z)$ stands for turbulence intensity.

For the application of the HFPI Method, data obtained from tests are used to determine the resultant force ($F(t)$) and moment ($M(t)$) over time, using Equation 8 and Equation 9 respectively.

$$F(t) = \int_S p(t)\, dA \tag{8}$$

$$M(t) = \int_S p(t)\, L_i\, dA \tag{9}$$

Where $\vec{p}(t)$ represents the local pressure and L_i represents the orthogonal distance from the pressure action axis to the origin of the reference system.

Once the resultant forces and moments are obtained, the dynamic response is calculated through modal superposition.

Computational routines were developed using spreadsheets as well as Python and MATLAB programs to perform all the calculations presented above.

3 Results and discussions

The following presents the calculated results of force and resultant moment when the wind incident angle was 0° (Figure 5), as considered for this work. In both the force and moment results, it is possible to observe that the

Davenport Method and the NBR 6123 present very similar values. These results show some noticeable deviation from the height of 90m onwards. In the case of the HFPI Method, the value is significantly different from lower heights.

Regarding the fluctuating part of the analyzed actions, the results obtained through the Davenport and HFPI methods were very close, while the results obtained by NBR 6123 showed a strong discrepancy in relation to the former, overestimating the fluctuation of the along-wind response. When considering the sum of the average and fluctuating results, it is observed that the Davenport method presents the lowest values along with the results of NBR 6123 in the case of the force.

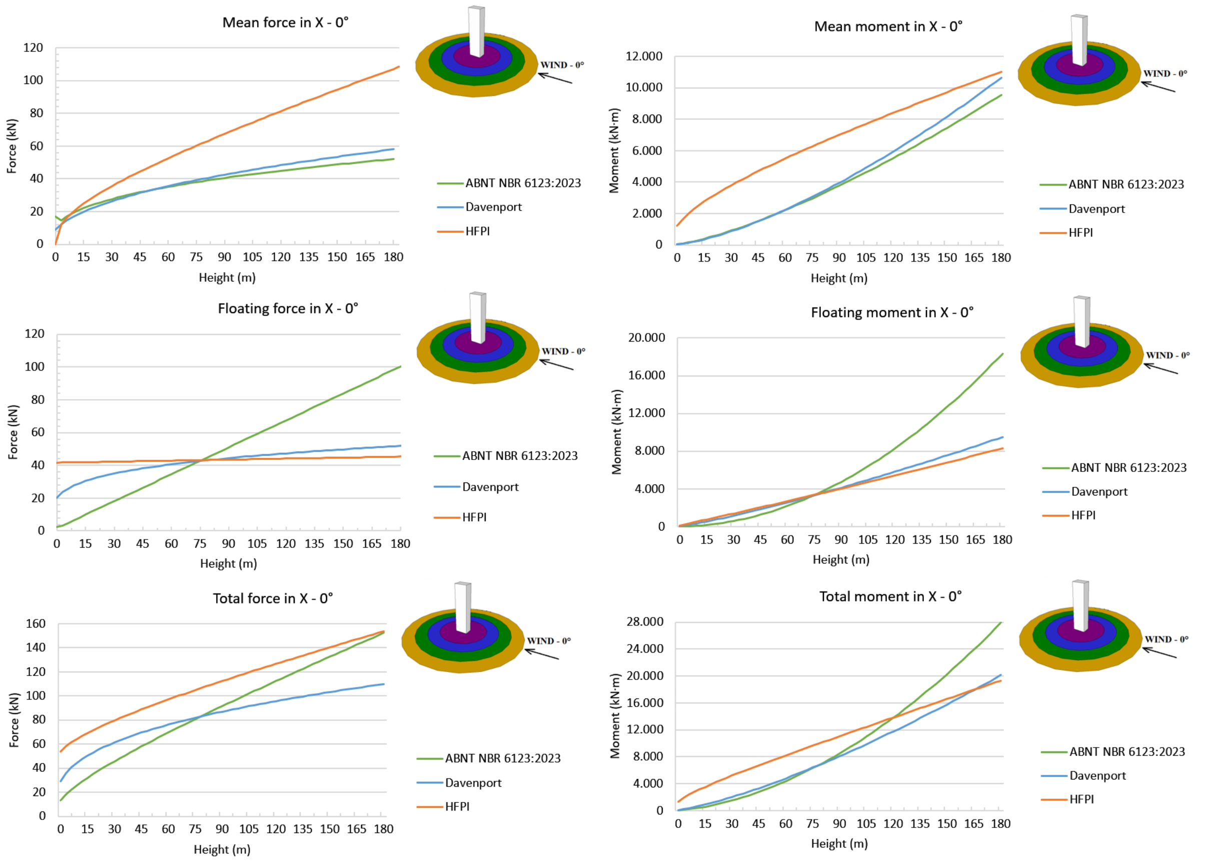

Figure 5. Along-wind forces and moments under wind at 0º

When analyzing the cases where the wind is incident at 90° (Figure 6), a similar behavior to the 0° case is observed. The presence of the interfering building in the same direction as the wind incidence did not alter the behavior of the results. The results obtained by the Davenport method and the NBR 6123 methods are very close when only considering the mean wind-induced force, and both are significantly lower than the results of the HFPI method. In the case of the fluctuating response, similar to the wind incident at 0°, practically without interference from the interfering building, from a height of 90m, the results obtained with the NBR 6123 method are much higher than those found in the other methods.

Analyzing the IF for wind in the 90° direction (Figure 7), it is observed that the interfering building provides protection in the case of the mean response. The redirection of the incident wind has little effect on the building under study the closer the buildings are to each other. In the case of the fluctuating component, it is observed that the effects more than double at low speeds and remain above 25%. Thus, it can be inferred that the influence of the vortices produced on the leeward facade of the interfering building, combined with the reattachment of the wind redirected from the windward facade, significantly influences the fluctuating response of the force acting on the analyzed building.

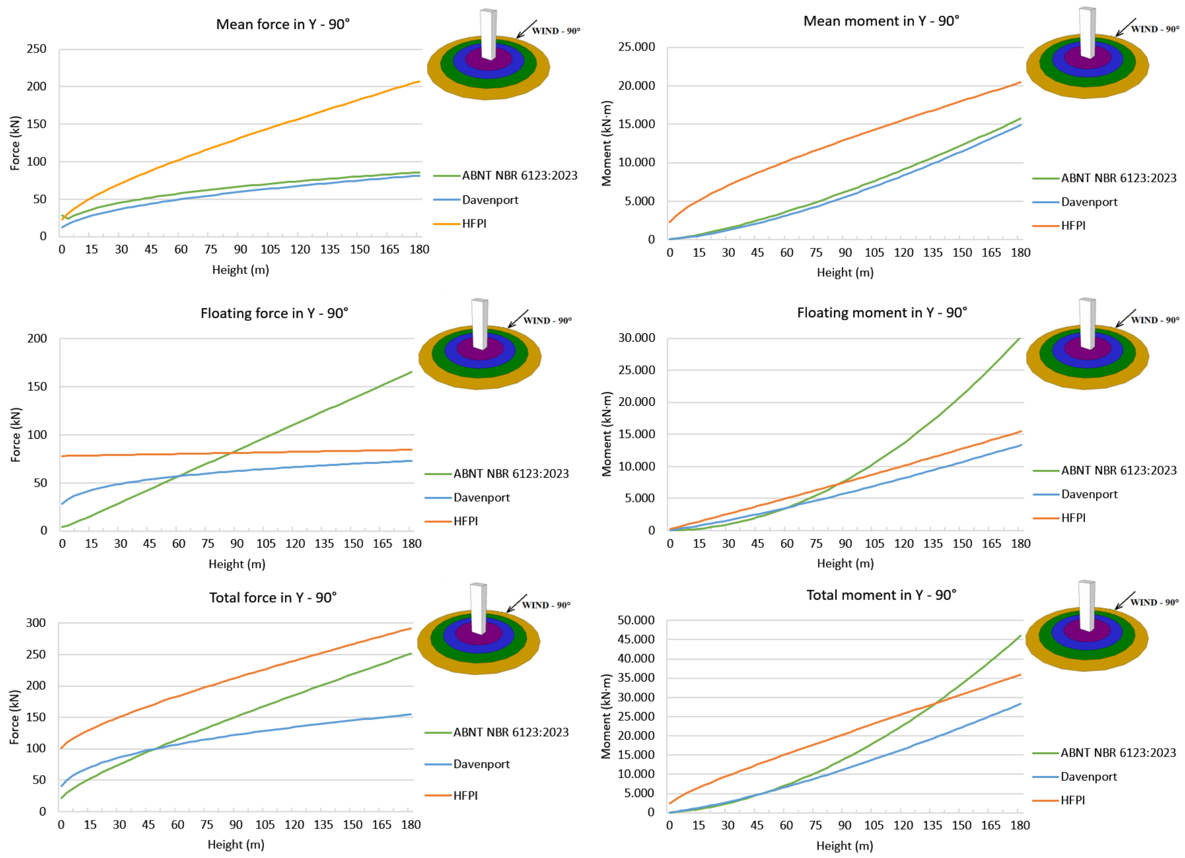

Figure 6. Along-wind forces and moments under wind at 90º

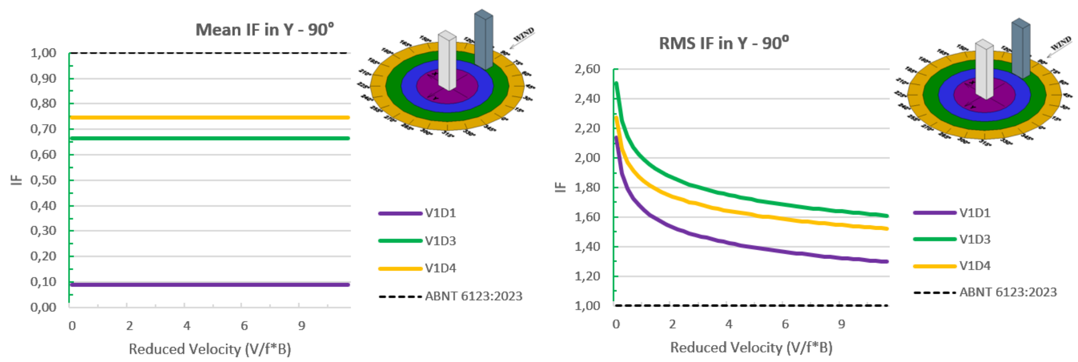

Figure 7. Along-wind forces and moments under wind at 90º

4 Conclusions

Based on the data collected throughout this work, it is concluded that:

1. For the mean responses of both force and moment, the standard parameters need to be revised, as they presented significantly lower results than those obtained through experimental results. Since these are analyses most frequently performed by engineers, it is of fundamental importance that standard recommendations represent results more consistent with experimental data, which, in general, are closer to real outcomes.
2. In the case of fluctuating responses, NBR 6123 should be revised, especially for buildings exceeding 90 m in height, as the results showed that, above this height, the standard values are evidently higher than those obtained with experimental data. The adoption of higher values may lead to incorrect considerations of the fluctuating effects on buildings.
3. Although the presence of upwind buildings may lead to lower mean forces, the fluctuating response in these same situations can more than doubled. Therefore, it is essential to consider these variations for proper

design.

4. The increase in mean forces in the situation where there were no upwind buildings shows that more studies should be conducted to better understand the reasons for this occurrence. To confirm the phenomenon, it would be important to conduct wind tunnel experiments using smoke, which would allow visualization of the flow in such a situation.

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