Study on the Effect of Vegetation on Wind Load Characteristics of High-Rise Buildings (Post-print)

Authors: Wang Shengde

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Abstract

Vertical greening on the exterior walls of fourth-generation high-rise buildings alters, to some extent, the original architectural form, and the interference mechanism between the structure and the vegetation under strong wind becomes more complex. At present, research on the wind resistance of fourth-generation high-rise building structures is still in its infancy, and there is no clear consensus on the applicability of existing wind-resistant design codes for high-rise structures to fourth-generation high-rise buildings. Taking the Tongyou Building in Changsha as the research background, this study employs a rigid pressure-measuring model to analyze the wind pressure coefficients and shape coefficients on the building façades under four greening ratios of 0%, 6.8%, 13.5%, and 20.3%, thereby revealing the influence patterns of vegetation on the wind load characteristics of building façades. The results show that the coherence of fluctuating wind pressure on the side and leeward façades is relatively low, and the presence of vegetation reduces the coherence of fluctuating wind pressure on the windward façade. Vegetation can effectively reduce the minimum wind pressure coefficients on the side and leeward façades and has a significant suppressing effect on localized strong winds acting on the building façades. The shape coefficients for the windward façade specified in the code are overly conservative, whereas those for the side and leeward façades tend to be unsafe. When the angle between the building windward façade and the incoming flow is 45°–60°, the vegetation produces the greatest reduction in the windward façade shape coefficient, with a maximum reduction of 70%.

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Study on the Influence of Vegetation on Wind Load Characteristics of High-Rise Buildings

SHEN Lian^{1,2}, HAN Yan^{1}, DENG Shuwen^{3}, CAI Chunsheng^{4}, WANG Peijie^{1}

^{1}Hunan Province Engineering Technology Research Center for Safety Control Technology and Equipment of Bridge Engineering, Changsha University of Science and Technology, Changsha, China
^{2}College of Civil Engineering, Changsha University, Changsha, China
^{3}College of Water Resources and Civil Engineering, Hunan Agricultural University, Changsha, China
^{4}School of Transportation, Southeast University, Nanjing, China

Abstract

The vegetation on the facades of fourth-generation high-rise buildings significantly alters the original aerodynamic shape of the structures. The interaction mechanism between the structure and vegetation under strong winds becomes more complex. Currently, research on wind resistance of fourth-generation high-rise buildings is still in its infancy, and there is no conclusive evidence regarding the applicability of existing wind resistance specifications to these buildings. This study focuses on the Tongyou Building in Changsha as a case study. Through rigid pressure measurement model tests, the wind pressure coefficients and shape coefficients of the building facade under three greening rates (6.8%, 13.5%, and 20.3%) were analyzed to reveal the influence of vegetation on wind load characteristics. The results indicate that the coherence of fluctuating wind pressure on the side and leeward surfaces is relatively low, while vegetation reduces the coherence of fluctuating wind pressure on the windward surface. Vegetation can effectively reduce the minimum wind pressure coefficients on the side and leeward surfaces, exerting significant inhibitory effects on local strong winds on the building facade. The shape coefficients specified in current codes for the windward surface are conservative, while those for the side and leeward surfaces are potentially unsafe. The reduction in shape coefficients on the windward surface is maximized when the building windward surface forms an angle of 45°–60° with the incoming flow, with a maximum reduction of 10.6%.

Keywords: high-rise building; wind tunnel test; wind pressure coefficient; shape coefficient; correlation

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1. Model Description

This study employs rigid model pressure measurement wind tunnel tests conducted in the high-speed test section of the Wind Engineering and Wind En-

Figure 1

Figure 1: Figure 1

vironment Research Center at Changsha University of Science and Technology. The wind tunnel has a cross-section of 3.0 m (width) × 2.5 m (height) with a wind speed regulation range of 1.0–45.0 m/s. The test model has a geometric scale of 1:100 with structural dimensions of 45.2 m × 32 m × 100 m (prototype dimensions), resulting in a blockage ratio of less than 1%.

The model design includes cylindrical vegetation elements with a height of 10 m (prototype) on the building' s exterior walls. The balcony parapet walls have a height of 1.5 m (prototype). A total of 331 pressure taps were arranged on the facade, with 60 taps on each floor. The pressure measurement system utilizes an Initium electronic pressure scanning valve with a sampling frequency of 331.5 Hz and a sampling duration of 60 s. Wind direction angles ranging from 0° to 180° were tested. The scaled model is shown in

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2. Parameter Definitions

To analyze the surface wind pressure under different vegetation coverage areas, the wind pressure coefficient is defined as:

$$C_{pi} = \frac{p_i - p}{\rho U_H^2}$$

where p_i is the wind pressure at measurement point i, p is the static pressure at the reference point, ρ is air density (1.225 kg/m^3), and U_H is the wind speed at the reference height.

The extreme wind pressure coefficient is defined as:

$$C_{pi,\mathrm{extreme}} = C_{pi,\mathrm{mean}} \pm g \times C_{pi,\mathrm{rms}}$$

where $C_{pi,\mathrm{mean}}$ is the mean wind pressure coefficient, $C_{pi,\mathrm{rms}}$ is the fluctuating wind pressure coefficient, and g is the peak factor (taken as 3.5).

To investigate local wind loads, the building facade is divided into blocks, with the block shape coefficient defined as:

$$\mu_s = \frac{\sum \mu_{si} A_i}{A}$$

where μ_{si} is the shape coefficient at measurement point i, and A_i is the corresponding area. For uniform incoming flow conditions, $\mu_{si} = C_{pi,\mathrm{mean}}$.

3. Results and Analysis

3.1 Extreme Pressure Distribution The envelope nephograms of extreme pressure coefficients under different greening rates are shown in [FIGURE:2]. As the greening rate R increases, the maximum pressure coefficient region on the windward surface is divided into left and right portions. The minimum value in the upper-left corner decreases from 0.1, indicating that vegetation reduces the maximum positive pressure coefficient and alters the distribution pattern of extreme pressure values.

The envelope nephograms of minimum pressure coefficients on the facade are presented in FIGURE:2. As R increases, the minimum pressure coefficient decreases from -1.6 to -0.9, with the negative pressure region gradually expanding to cover one-third of the entire facade area. The pressure distribution for $R = 13.5\%$ shows the most extensive negative pressure region, suggesting that the shielding effect of vegetation has a nonlinear relationship with greening rate. Vegetation not only reduces the maximum negative pressure but also mitigates the impact of local strong winds on the building facade.

The envelope nephograms of extreme pressure coefficients on the side surfaces are shown in FIGURE:3. The upper region values originate from the side surface, while the lower region values are from the leeward surface. The extreme pressure on the lower leeward surface decreases with increasing greening rate, whereas the extreme pressure on the upper side surface is less affected by vegetation.

The envelope nephograms of minimum pressure coefficients on the side surfaces are presented in FIGURE:3. As R increases, the minimum pressure coefficient decreases from -1.5 to -0.9. The negative pressure region reaches its maximum extent at $R = 13.5\%$ when the wind direction angle is between 0°-60°, indicating that the arranged vegetation provides the greatest reduction in pressure within the vortex shedding zone. When the windward surface forms an angle with the incoming flow, vegetation most effectively reduces the negative pressure.

3.2 Mean Pressure Variation The vertical axes of measurement points on the building facade are numbered sequentially from 1 to 9. To study the influence of vegetation on mean wind pressure coefficients, only the symmetrical axes 1–9 are presented for typical wind direction angles of 0° and 45°.

The variation curves of mean pressure coefficients for each axis at 0° wind direction are shown in [FIGURE:5]. The mean pressure coefficient at the windward edge (axis 1) decreases monotonically with increasing R, with vegetated cases showing lower values than the non-vegetated case. This demonstrates the strong shielding effect of vegetation on airflow diffusion toward the edges. The mean pressure coefficient on the side surface initially increases then decreases with height, and shows a similar trend with increasing greening rate R, reaching maximum values at $R = 13.5\%$.

The variation curves for the 45° wind direction are shown in [FIGURE:6]. The mean pressure coefficient on the windward surface increases monotonically with height, while the side surface shows a decreasing trend. The reduction effect of vegetation on side and leeward surface negative pressures increases with greening rate. At $R = 13.5\%$, the mean pressure coefficient is significantly larger than other greening rates, indicating that vegetation enhances vortex shedding on the facade.

3.3 Fluctuating Pressure Correlation Characteristics For spatial building structures, the spatial correlation of fluctuating wind pressure can be represented by the coherence function that varies with distance and frequency:

$$\gamma^2_{xy}(f) = \frac{|S_{xy}(f)|^2}{S_x(f) \times S_y(f)}$$

where $\gamma^2_{xy}(f)$ is the coherence function, f is the fluctuating wind pressure frequency, $S_{xy}(f)$ is the cross-power spectrum, and $S_x(f)$ and $S_y(f)$ are the auto-power spectra.

The coherence functions between different measurement points at 3/4H height in the horizontal direction are shown in FIGURE:7. The coherence function of windward surface pressure coefficients decays exponentially with dimensionless frequency fz/U, where z is the horizontal distance between measurement points and U is the incoming flow velocity. The horizontal decay exponent ranges from 4 to 9.8, consistent with previous square cylinder studies.

The coherence functions for crosswind pressure coefficients are presented in [FIGURE:8]. The decay exponent absolute value is smallest near the horizontal centerline, with other measurement point pairs showing similar decay rates. The decay exponent is approximately 8.3, with horizontal coherence functions generally lower than vertical ones and showing delayed attenuation frequency.

The coherence functions for leeward surface pressure coefficients are shown in [FIGURE:9]. The vertical coherence is relatively low, with different height measurement points showing identical variation patterns. The leeward surface is located in the vortex shedding zone where fluctuating pressure variations are complex.

The envelope values of coherence functions between measurement points at different spacings under various greening rates are presented in [FIGURE:10]. The horizontal coherence function decay exponent absolute value initially increases then decreases with greening rate, reaching a maximum of 8.3 at $R = 6.8\%$, indicating that vegetation causes the greatest disturbance to fluctuating wind pressure coherence on the windward surface. The decay exponent increases monotonically with greening rate, while the vertical decay exponent is less affected by vegetation.

3.4 Influence of Vegetation on Building Shape Coefficients The building windward surface is divided into upper and lower sections, numbered as blocks A1 and A2. Corresponding sections on the side surfaces are numbered B1, B2, B3 and C1, C2, C3, as shown in [FIGURE:11].

The shape coefficient variation patterns for these blocks are analyzed in [FIGURE:12] through [FIGURE:14]. The maximum shape coefficients for blocks A1, A2 range from 0.4–0.5, 0.7–0.8, and 0.5–0.7, respectively. The minimum values range from -0.8 to -0.6, -0.8 to -0.7, and -1.0 to -0.7, respectively. The windward surface shape coefficient initially increases then decreases with height, while the leeward surface shape coefficient gradually decreases.

The shape coefficients for blocks B1–B3 are shown in [FIGURE:13]. The shape coefficients are smaller for vegetated cases than non-vegetated cases, demonstrating that vegetation effectively reduces wind loads. The reduction effect increases gradiently with greening rate, particularly in the upper building region. The shape coefficients reach maximum values at wind direction angles of 60°–120°.

The shape coefficients for blocks C1–C3 are presented in [FIGURE:14]. At $R =$ 20.3%, the shape coefficients are significantly smaller than the code-specified value of -0.62, indicating that vegetation substantially reduces suction on the lower side surfaces. The maximum reduction occurs when the windward surface is perpendicular to the incoming flow.

To analyze the magnitude of wind load reduction by vegetation at different greening rates, the shape coefficient reduction β is defined as:

$$\beta = \frac{\mu_{s,R} - \mu_{s,0}}{\mu_{s,0}} \times 100\%$$

where $\mu_{s,R}$ is the shape coefficient at greening rate R (6.8%, 13.5%, or 20.3%), and $\mu_{s,0}$ is the shape coefficient without vegetation.

The adjustment values of shape coefficients under different greening rates are shown in [FIGURE:15]. The adjustment coefficient for the windward surface decreases with increasing greening rate, with a maximum reduction of 12.6% at $R = 13.5\%$. The side surface adjustment coefficient shows the greatest reduction, while the leeward surface adjustment coefficient remains essentially unchanged. Vegetation can effectively reduce wind loads on windward and side surfaces, with the maximum reduction occurring when the incoming flow is perpendicular to the building.

The maximum reduction of shape coefficients for each block and corresponding wind direction angles are summarized in Table 1. The results show that $R = 13.5\%$ produces the most prominent reduction effect, with maximum reductions of 64.6% for block C and 12.6% for block A. The reduction effect is more pronounced on narrow surfaces, with the maximum reduction occurring when the windward surface forms a 45°–60° angle with the incoming flow.

4. Conclusions

This study obtained wind pressure data on building facades under different greening rates through rigid pressure measurement model wind tunnel tests. The variation patterns of wind pressure coefficients and shape coefficients on exterior facades under typical wind direction angles were investigated. The main conclusions are:

1. Vegetation has minimal impact on mean wind pressure on the windward surface. As greening rate increases, vegetation strongly suppresses wind pressure at windward edges and side surfaces, reducing maximum negative pressure while improving local strong wind effects on the building facade.
2. The coherence of fluctuating wind pressure on side and leeward surfaces is relatively low. The coherence function on the windward surface shows exponential decay, and vegetation reduces the coherence of fluctuating wind pressure on the windward surface.
3. The adjusted shape coefficients for side and leeward surfaces are significantly larger than code-specified values. The shape coefficients in current specifications are conservative for windward surfaces but potentially unsafe for side and leeward surfaces.
4. Building wind loads are closely related to wind direction angles. The maximum reduction in windward surface shape coefficients occurs when the windward surface forms a 45°–60° angle with the incoming flow. Vegetation provides the greatest reduction in side surface wind loads when the incoming flow is perpendicular to the building.

These research results can provide references for wind-resistant design of similar high-rise buildings.

References

[1] LIN W E, LETCHFORD C, TAMURA Y. Characteristics of wind forces acting on high-rise buildings [J]. Journal of Wind Engineering and Industrial Aerodynamics, 2005, 93(3): 151-164.

[2] LI Q S, CHEN F B. Probability characteristics and extreme estimation of wind pressure coefficients on high-rise building envelopes [J]. Journal of Vibration and Shock, 2023, 42(1): 224-231 (in Chinese).

[3] FENG Y, LI Q S. Numerical simulation of wind veering effects on super high-rise buildings with different length-width ratios [J]. China Civil Engineering Journal, 2022, 55(11): 1-10 (in Chinese).

[4] LI Y L, ZHANG W. Experimental study on wind load characteristics of high-rise buildings with opening [J]. The Structural Design of Tall and Special Buildings, 2020, 29(9): e1734.

[5] CAO S, TAMURA Y, YOSHIDA A. Wind tunnel study of aerodynamic characteristics of trees [J]. Journal of Wind Engineering and Industrial Aerodynamics, 2012, 111: 6-16.

[6] WANG X K, CHENG C M. Characteristics of pressure distribution and global aerodynamic forces on vertical forest buildings [J]. Journal of Central South University (Science and Technology), 2023, 54(3): 987-996 (in Chinese).

[7] SANZ A, RODRIGO J, BEECK J V, et al. Wind tunnel simulation of wind conditions inside bidimensional forest clear-cuts: Application to wind turbine siting [J]. Journal of Wind Engineering and Industrial Aerodynamics, 2007, 95(7): 609-638.

[8] MOLINA-AIZ F D, VALERA D L, ÁLVAREZ A J. Wind tunnel study of airflow through horticultural crops: Determination of the drag coefficient [J]. Biosystems Engineering, 2006, 93(4): 447-457.

[9] DUMAN T, KATUL G, SIQUEIRA M. A velocity-dissipation Lagrangian stochastic model for turbulent dispersion in atmospheric boundary-layer canopy flows [J]. Boundary-Layer Meteorology, 2014, 152(1): 73-99.

[10] WANG Y C. Mathematical model for effect of trees on wind-induced responses of vertical forest buildings [J]. Journal of Wind Engineering and Industrial Aerodynamics, 2018, 182: 1-13.

[11] YU Z. Wind tunnel test study on wind load characteristics of vertical forest buildings [D]. Changsha: Changsha University of Science and Technology, 2020 (in Chinese).

[12] WANG L, SHEN L, CHUN Z. Study on drag effects of vegetation on neighborhood wind fields [J]. Engineering Mechanics, 2021, 38(5): 88-97 (in Chinese).

[13] WANG Y C, CHENG C M. Characteristics of pressure distribution and global aerodynamic forces on vertical forest buildings [J]. Journal of Wind Engineering and Industrial Aerodynamics, 2018, 182: 1-13.

[14] YANG H, LI Q S. Numerical simulation of wind environment in neighborhoods under multiple factors [J]. Engineering Mechanics, 2021, 38(5): 88-97 (in Chinese).

[15] KANG G. Computational fluid dynamics simulation of effects of trees on pedestrian comfort in urban areas [J]. Sustainable Cities and Society, 2020, 63: 102456.

[16] KANG G. Development of computational fluid dynamics model parameterizations: Application to pedestrian comfort in urban area [J]. Building and Environment, 2017, 125: 129-139.

[17] LIN L, LETCHFORD C, TAMURA Y. Characteristics of wind forces acting on high-rise buildings [J]. Journal of Wind Engineering and Industrial Aerodynamics, 2005, 93(3): 151-164.

Figure 16

Figure 2: Figure 16

[18] YUAN C, NORFORD L K. A semi-empirical model for urban environment [J]. Landscape and Urban Planning, 2017, 167: 198-207.

[19] QI S, ISHIHARA T. Numerical study of turbulent flow fields around trees and isolated buildings using a modified k-ϵ model [J]. Journal of Wind Engineering and Industrial Aerodynamics, 2018, 182: 1-13.

[20] HEFNY M M, SALIM S M, HEINKE S, et al. Including trees in numerical simulations of urban areas: Should we care? [J]. Journal of Wind Engineering and Industrial Aerodynamics, 2015, 144: 84-95.

[21] BALCZÓ M, GROMKE C. Numerical modeling of pollutant dispersion in street canyons with planting [J]. Meteorologische Zeitschrift, 2009, 18(2): 197-206.

[22] KANG G. Effects of trees on scalar dispersion in an urban street canyon [J]. Atmosphere, 2015, 25(4): 435-454.

[23] LI Q S, CHEN F B. Probability characteristics and extreme estimation of wind pressure coefficients on high-rise building envelopes [J]. Journal of Vibration and Shock, 2023, 42(1): 224-231 (in Chinese).

[24] Ministry of Housing and Urban-Rural Development of the People's Republic of China. Load Code for the Design of Building Structures: GB 50009—2012 [S]. Beijing: China Architecture & Building Press, 2012.

[25] LIU Z L, TONG Y, ZHI Y, et al. Optimization analysis of wind-induced vibration responses of building structures with arbors on roofs [J]. Industrial Construction, 2021, 51(3): 121-127 (in Chinese).

Figures

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