Wind Engineering Joint Usage/Research Center
FY2023 Research Result Report

Research Field: Wind Hazard Mitigation/Wind Resistant design
Research Year: FY2023
Research Number: 23235002
Research Theme: Revisit to reference longitudinal wind speed for tall building design

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Budget [FY2023]: Yen

*There is no limitation of the number of pages of this report.
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1. Research Aim

The dynamic interplay between wind-induced pressures exerted on buildings and structures and their resultant reactions is profoundly influenced by the approaching wind. Within the realm of practical building design, the longitudinal component of wind velocity, specifically at the mean roof height, serves as the pivotal parameter, embraced by numerous wind loading codes and standards (e.g., AIJ, 2015; ASCE7-16, 2016; AS/NZS 1170.2, 2021). Nevertheless, within wind tunnel experiments targeting tall structures, there exists a prevalent practice of utilizing either the longitudinal wind speed or the velocity pressure at the building's height or the boundary layer gradient height as the benchmark wind velocity. Although this approach carries certain advantages such as its simplicity, the nuanced impact of wind speed at the reference height on wind pressures, forces, and ensuing responses of tall buildings remains inadequately scrutinized.

Given that the correlation between longitudinal wind speed and various parameters such as building pressure, force, and response can unveil similarities within their fluctuating components, it becomes imperative to ascertain the optimal wind speed at which height exhibits the highest correlation with these aforementioned dynamic factors. In this study, the correlation of the incoming wind and the wind effects on tall buildings have been examined. This exploration is pivotal for advancing our understanding of how wind dynamics influence tall structures and refining the methodologies used in their design and assessment. Next, Section 2 of this study introduces simultaneous measurement of approaching longitudinal wind speed and wind pressures on tall building models with square-section in a boundary layer wind tunnel. Section 3 illustrates the experimental results for the correlation between incoming wind and the building forces.

2. Experimental setup

Wind tunnel tests on a rigid tall building model were conducted in a large-scale boundary-layer wind tunnel with a test section 2.2m wide, 1.8m high and 19m long, in Tokyo Polytechnic University. Urban area terrain was simulated with power-law exponent α = 0.27, which is illustrated in Fig. 1. Both of the profiles of mean wind speed and turbulence intensity matched the ABL flow of urban terrain very well (AIJ, 2015).

To ensure the applicability of the research, this paper tested two representative models for tall building, with aspect ratios of 8 and 4, respectively, as illustrated in Fig. 2. The geometric size of the tested model was Breadth (B)×Depth (D)×Height (H_1) = 80mm ×80mm ×640mm and Breadth (B)×Depth (D)×Height (H_2) = 80mm ×80mm ×320mm, and there are 256 and 128 pressure taps for the two models, respectively. In order to synchronize acquire the wind pressures of tall building model and the incoming wind, an X-type probe was set at the upstream direction of the models to measure the longitudinal and lateral wind speeds.

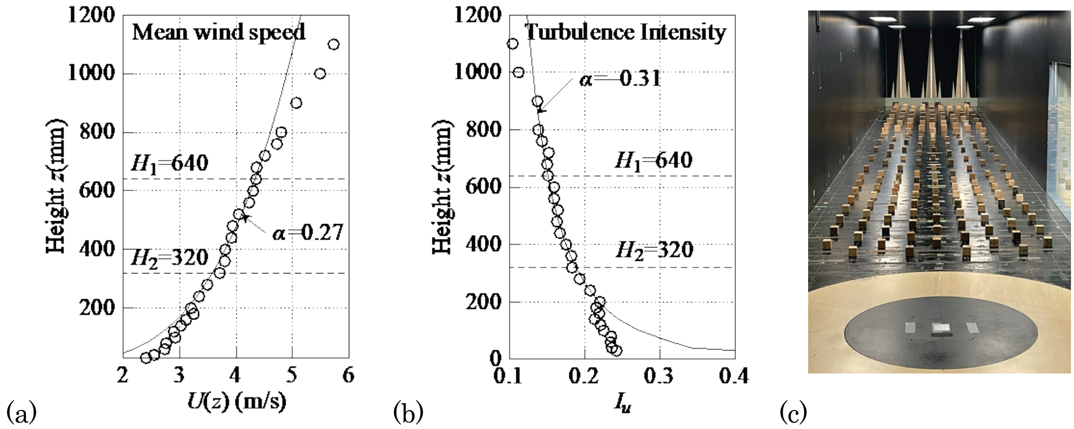

Fig. 1 Wind field measurement at the center of turntable: (a) Mean wind speed; (b) Turbulence intensity; (c) Spires and roughness elements in wind tunnel.

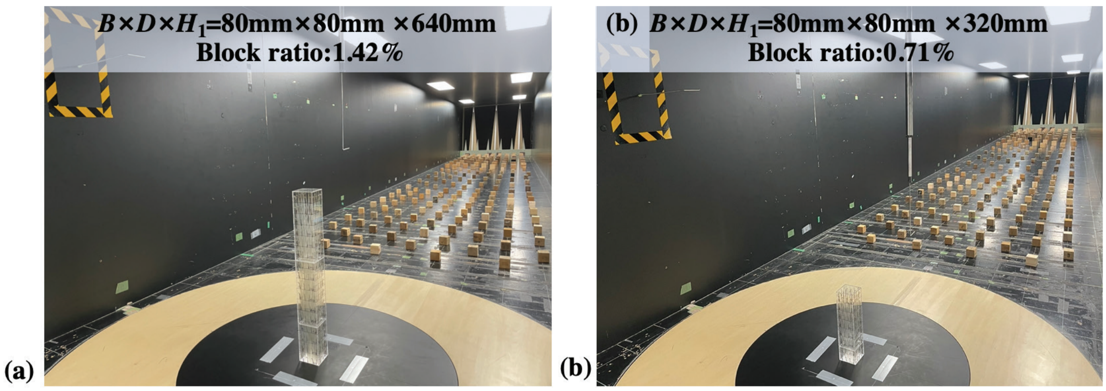

Fig. 2 Wind tunnel tests on tall building models: (a) Aspect ratio = 8; (b) Aspect ratio = 4.

3. Research Result

3.1 development of the wind profiles

Attentionally, there are some points to make sure the effectiveness of the measured data for building pressures and wind speeds. Firstly, the support system for the X-probe shouldn't influence the building pressure. Secondly, the building model shouldn't influence the upstream wind speed. So, there should be enough space between the windward building face and the support system of the X-probe. Thirdly but importantly, the wind speed measurement point should have quite similar wind speed when there is an experimental or not. To satisfy the above points, the profiles for longitudinal wind speed has been measured, when the upstream X-probe and the windward building face has a distance L=2B, 5B, 8B and 10B, where B is the building breadth, for both of the cases with a model or without a model. The measurement strategy is shown as Fig. 3. It is also should be noticed that 10B is almost at the middle of the roughness end and the building model, the profile of the incoming wind at this point is developed to be steady.

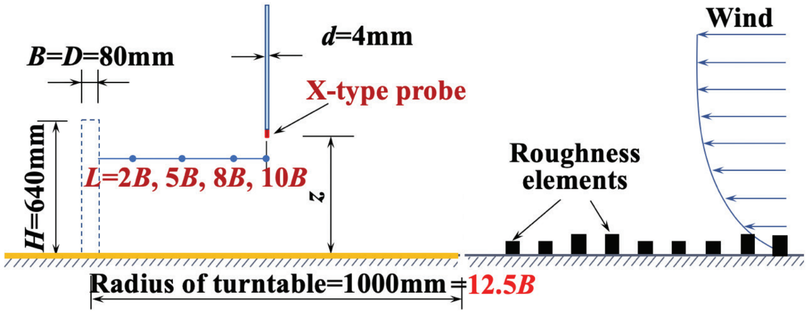

Fig. 3 Wind field measurement in front of the building model

Figure 4 shows the development of the mean wind speed profiles in front of the building model with aspect ratio 8, when the distance L = 2B, 5B, 8B and 10B, where B is the building breadth. The blue diamond illustrates the mean wind speed profile when there isn't a building model, and the red diamond indicates the mean wind speed profile when there is a tall building model with the aspect ratio 8 and whose height is 640mm. It is shown from the results that, the mean wind speed profiles are strongly affected by the building model when the distance L = 2B. As the distance increases, the effects of the building model on the mean wind speed profile decreases. At L = 10B, the mean wind speed profiles are almost not affected by the building model, moreover, the mean wind speed profile is close to that at the center of turntable when there isn't a building model. The development of the mean wind speed profiles in front of the building model with aspect ratio 4 has the same tendency as that with the aspect ratio 8, as illustrated in Fig. 5.

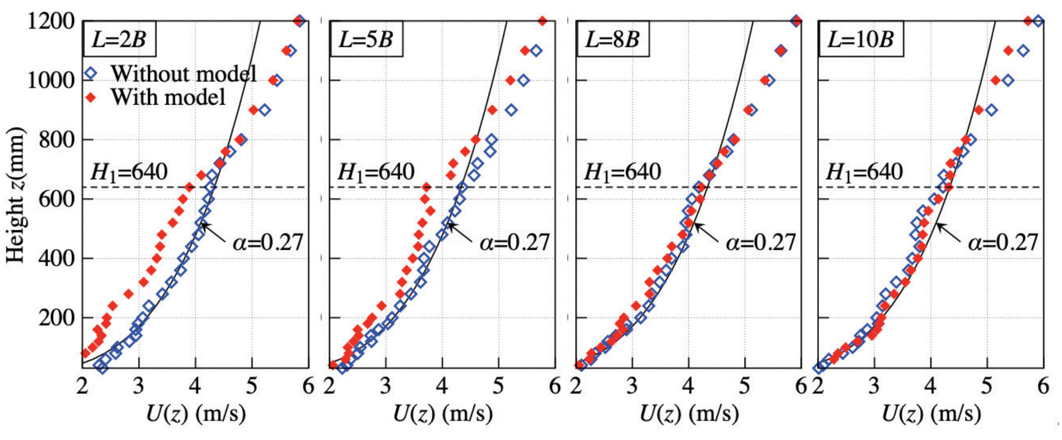

Fig. 4 The development of mean wind speed profiles
in front of the building model with aspect ratio 8

It should be noticed that, the development of the turbulence intensity profiles, the power spectral densities of the longitudinal wind speed have also been examined, though they haven't been listed here. Based on all of the research results, it can be concluded that when L, the distance of the X-probe and the windward building face, is equal to $10B$, the properties of the upstream wind have the minimum effects of the building model. Thus, all wind-building pressure correlation discussions are based on the distance $L=10B$, as shown in the following subsection 3.2.

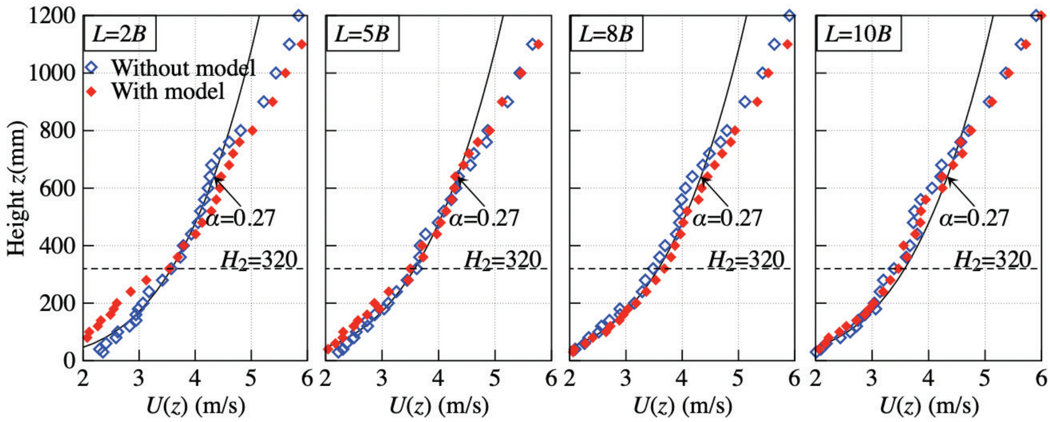

Fig. 5 The development of mean wind speed profiles in front of the building model with aspect ratio 4

3.2 Wind-building force correlation

Current section discusses the correlation between longitudinal and lateral wind speed at various heights and wind-induced base shear forces and overturning moments of tall building models when the wind direction θ is 0°.

Fig. 6(a) illustrates the correlation coefficients between approaching longitudinal wind speed at height z (u_z) and base shear forces (F_X and F_Y), and generalized forces (M_Y, M_X and M_Z) of the tall building with aspect ratio 8, where height z varies from $0.1H$~$1.2H$. Time lags between the fluctuations of wind speed and wind forces are ignored in this study. Only the maximum values of the correlation functions are considered, which are written as correlation coefficients as follows. The corresponding correlation coefficients between longitudinal wind speed and wind forces and moments are indicated by $[u_z–F_X]$, $[u_z–F_Y]$, $[u_z–M_Y]$, $[u_z–M_X]$ and $[u_z–M_Z]$.

The along-wind base shear forces and overturning moments show high correlation with the longitudinal wind speed, as indicated by $[u_z–F_X]$ and $[u_z–M_Y]$ in Fig. 6. For the correlation between longitudinal wind speed and along-wind base shear forces, the maximum correlation coefficient $[u_z–F_X]_{max}$ = 0.71 occurs at wind speed height z = $0.7H$. The correlation of $[u_z–F_X]$ at wind speed height $0.5H \leq z \leq 0.7H$ shows larger amplitude than other wind speed heights. For the correlation between longitudinal wind speed and along-wind overturning moment, the maximum correlation coefficients $[u_z–M_Y]_{max}$ = 0.75 occurs at wind speed height z = $0.7H$. As a result, both the along-wind base shear forces and overturning moments show remarkably high correlation with longitudinal wind speed at around 0.7*H*.

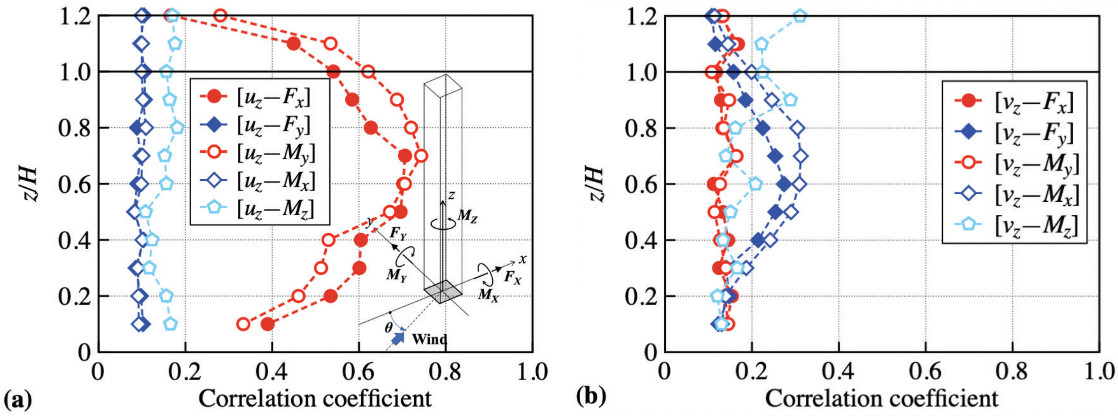

Fig. 6 Wind – building force correlation for the building model with Aspect ratio = 8:
(a) Correlation of *u*-component and building force;
(b) Correlation of *v*-component and building force.

When wind speed height $z < 0.5H$, correlations [u_z–F_X] and [u_z–M_Y] decrease with decrease in wind speed height z. When wind speed height z is close to building height H, correlations [u_z–F_X] and [u_z–M_Y] slightly decrease but remain relatively high. Since the along-wind overturning moments M_Y are mainly composed of pressures on the upper part of the building, their correlation with longitudinal wind speed at around 0.7*H* are higher than the correlation between along-wind base shear forces F_X and longitudinal wind speed. The across-wind base shear forces and across-wind overturning moments are not correlated with longitudinal wind speed at any height, as indicated by correlation coefficients [u_z–F_Y] and [u_z–M_X]. And the torsional moment has slightly higher correlation with the longitudinal wind speed, indicated as [u_z–M_Z], compared to [u_z–F_Y] and [u_z–M_X].

Fig. 6(b) illustrates the correlation coefficients between approaching lateral wind speed at height z (v_z) and base shear forces (F_X and F_Y), and generalized forces (M_Y, M_X and M_Z) of the tall building with aspect ratio 8, where height z varies from 0.1*H*~1.2*H*. It is shown that, the lateral wind speed is correlated with the across-wind shear force and overturning moment at 0.5*H*~0.8*H*, indicated as [v_z–F_Y] and [v_z–M_X]. Moreover, the lateral wind speed at around the building height H shows slightly higher correlation with the torsional moment, indicated as [v_z–M_Z]. And the lateral wind speed at all height has no correlation with the along-wind shear force and overturning moment, indicated as [v_z–F_X] and [v_z–M_Y].

Figure 7 (a) and (b) illustrates the correlation coefficients between approaching longitudinal wind speed at height z (u_z), lateral wind speed at height z (v_z), and base shear forces (F_X and F_Y), and generalized forces (M_Y, M_X and M_Z) of the tall building with aspect ratio 4, where height z varies from 0.1*H*~1.2*H*, respectively.

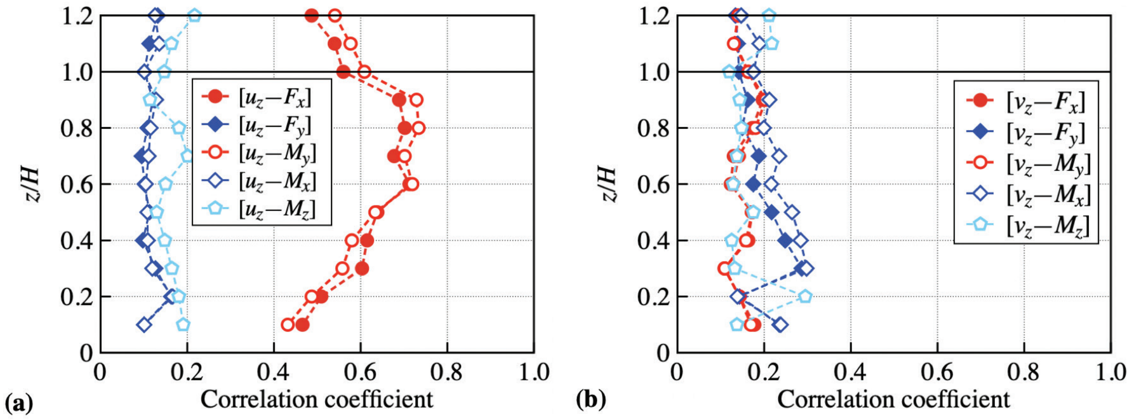

Fig. 7 Wind – building force correlation for the building model with Aspect ratio = 4:
(a) Correlation of u-component and building force;
(b) Correlation of v-component and building force.

Similar to the case of the building model with aspect ratio 8, the along-wind base shear forces and overturning moments show high correlation with the longitudinal wind speed, as indicated by $[u_z–F_X]$ and $[u_z–M_Y]$ in Fig. 7. For the correlation between longitudinal wind speed and along-wind base shear forces, the maximum correlation coefficient $[u_z–F_X]_{max}$ = 0.71 occurs at wind speed height $z = 0.6H$. The correlation of $[u_z–F_X]$ at wind speed height $0.6H \leq z \leq 0.9H$ shows larger amplitude than other wind speed heights. For the correlation between longitudinal wind speed and along-wind overturning moment, the maximum correlation coefficients $[u_z–M_Y]_{max}$ = 0.74 occurs at wind speed height $z = 0.8H$. As a result, both the along-wind base shear forces and overturning moments show remarkably high correlation with longitudinal wind speed at around $0.6H \leq z \leq 0.9H$. The across-wind base shear forces and across-wind overturning moments are not correlated with longitudinal wind speed at any height, as indicated by correlation coefficients $[u_z–F_Y]$ and $[u_z–M_X]$. And the torsional moment has slightly higher correlation with the longitudinal wind speed, indicated as $[u_z–M_Z]$, compared to $[u_z–F_Y]$ and $[u_z–M_X]$.
Different from the case of the building model with aspect ratio 8, the lateral wind speed at the height $0.3H \leq z \leq 0.5H$ shows higher correlation with the across-wind shear force and the overturning moment of the tall building with aspect ratio 4. And the lateral wind speed at all height almost has no relation with the across-wind shear force, overturning moment and torsional moment, indicated as $[v_z–F_X]$, $[v_z–M_Y]$ and $[v_z–M_Z]$.
As a conclusion, for both of the tall buildings with aspect ratios of 8 and 4, the best reference longitudinal wind speed height is at $0.6H \leq z \leq 0.9H$.

4. Published Paper etc.
[Underline the representative researcher and collaborate researchers]
[Published papers]
1.
2.

[Presentations at academic societies]
1.
2.

[Published books]

1.
2.

[Other]
Intellectual property rights, Homepage etc.

5. Research Group
1. Representative Researcher
   1. Qingshan Yang

2. Collaborate Researchers
   1. Yong Chul Kim
   2. Yukio Tamura
   3. Wenshan Shan

6. Abstract (half page)

Research Theme: Revisit to reference longitudinal wind speed for tall building design
Representative Researcher (Affiliation): Qingshan Yang (Chongqing University)
Summary・Figures

This research revisits the reference longitudinal wind speed for tall building designs, by checking the correlation between the incoming wind and wind-induced pressures, forces and responses of tall-building, through wind tunnel tests performance at the large-scale wind tunnel in Tokyo Polytechnic University. The experimental results shows that the best correlation height between incoming wind and wind-induced effects on tall buildings are 0.6*H*~0.9*H*, where *H* is the building height.