Wind Engineering Joint Usage/Research Center
FY2024 Research Result Report

Research Field: Outdoor Environment
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Research Number: 24242012
Research Theme: Wind tunnel investigation of the pedestrian level wind (PLW) environment within oppositely faced high-rise buildings

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Budget [FY2024]: Yen 390,000

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*Figures can be included to the report and they can also be colored.
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1. Research Aim

Pedestrian-level wind (PLW) speed in the built environment is an important measure for assessing wind comfort and safety during certain wind events. The speed of PLW is greatly affected by individual buildings or clusters of buildings, particularly when high-rise buildings are present. In modern times, the growing population has sped up the development of tall residential complexes to maximize land utilization. Buildings are created with diverse shapes to fulfill the residents' needs while prioritizing functionality, safety, and comfort. High-rise residential buildings typically have an outside common area with a swimming pool, playground, amenities, and parks to help residents keep a healthy lifestyle. This space serves as a multipurpose zone where residents can spend their time. In Malaysia, common areas are often located at elevated positions due to the architecture of buildings, which feature a podium underneath for parking and shops (see Fig. 1). The common area is situated on top of the podium, nestled between the two buildings facing one another.

Numerous investigations have examined how changes in the shape of high-rise buildings, like canopies, podiums, balconies, and permeable floors, impact the PLW environment. Most studies concentrate on individual high-rise buildings, with a particular focus on the pedestrian level area at ground level. This study aims to examine the PLW environment in the common area situated at an elevated height between two high-rise residential buildings facing each other. Various characteristics to be assessed include aspect ratio (distance between two buildings), podium height, and wind directions.

Fig. 1 Residential structures: (a) conventional designs without a podium and (b) contemporary design featuring an elevated structure at a lower level of the buildings.

2. Research Method

Fig.2 (a) shows the wind tunnel configurations featuring various sizes of roughness elements organized in the upstream region, with the building model placed in the downstream area. The experiments are conducted in a wind tunnel at Tokyo Polytechnic University, Japan, measuring 19 m in length, 2.2 m in width, and 1.8 m in height. Furthermore, the model employed in the present investigation encompasses two different building configurations designated as Model 1 and Model 2, illustrated in Fig. 2 (b) and (c), respectively. The model (1:400) consists of two buildings with dimensions of $0.5H$ x H x $0.75H$ (length x width x height) each are built over a podium that is $2H$ x $1.5H$ x $0.25H$ at the bottom. Here, $H = 0.2$ m represents the model's overall height, measured from the wind tunnel floor to the top of the building, including the podium. Both models are assigned in accordance with the distance between the two opposing buildings, defined as H for Model 1 and 0.5H for Model 2, respectively indicating the intervening space size.
The I-type hot wire anemometer (HWA) measures the approaching flow profile at a position $5H$ upstream from the center of the turntable, whereas incidental flow is evaluated in the center of the turntable in the absence of the building model. Furthermore, thermistor anemometers are positioned within the intervening space to measure the mean wind speed, as the probe's frequency response is insufficient to capture the fluctuating component. The thermistors are positioned 5 mm above the podium's top (2 m at full scale), signifying the height of the occupants. Four wind directions, θ = 0º, 30º, 60º, and 90º, are evaluated by rotating the turntable in a clockwise direction. For reference, the building's position depicted in Fig. 2 (a) is at θ = 0º.

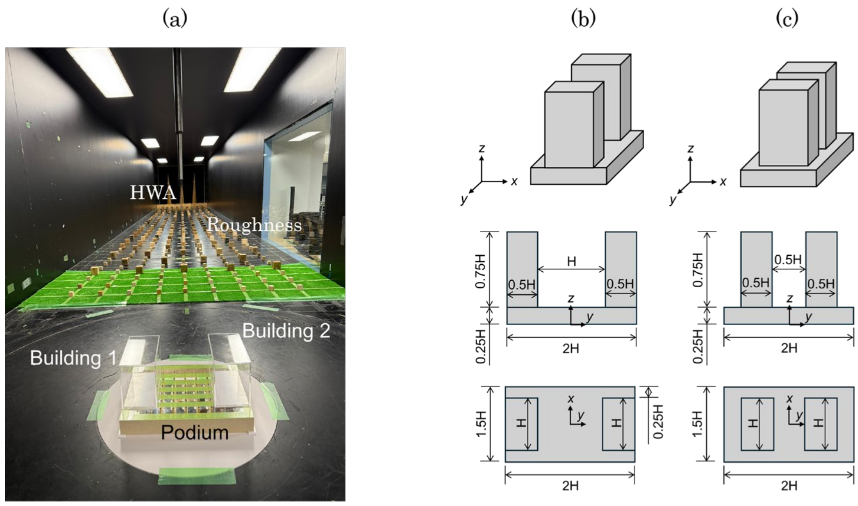

Fig. 2 Building model employed in the experiment (a) position in the wind tunnel, (b) Model 1 and (c) Model 2.

3. Research Result

3.1 Approaching flow conditions

Fig. 3 shows the vertical profiles of wind speed and estimated turbulent kinetic energy (TKE) for the approaching and incidental flows. Fig. 3 (a) illustrates the normalized approaching wind speed generated by adhering to the power law with an exponent of 0.25, applicable to urban regions characterized by mid-rise buildings (category IV). The mean wind speed is represented by U, whereas U_{ref} denotes the reference mean wind speed at height H. Despite a small acceleration observed near the wind tunnel surface due to the absence of roughness elements, the profile above $0.5H$ coincided closely with the approaching flow. The TKE is approximated based on the assumption that $k \sim \sigma_u$, where σ_u represents the standard deviation of the streamwise velocity, as the I-type HWA is inadequate for measuring multiple velocity components (Fig. 3 (b)). In addition, both profiles are well expressed by the exponential equation.

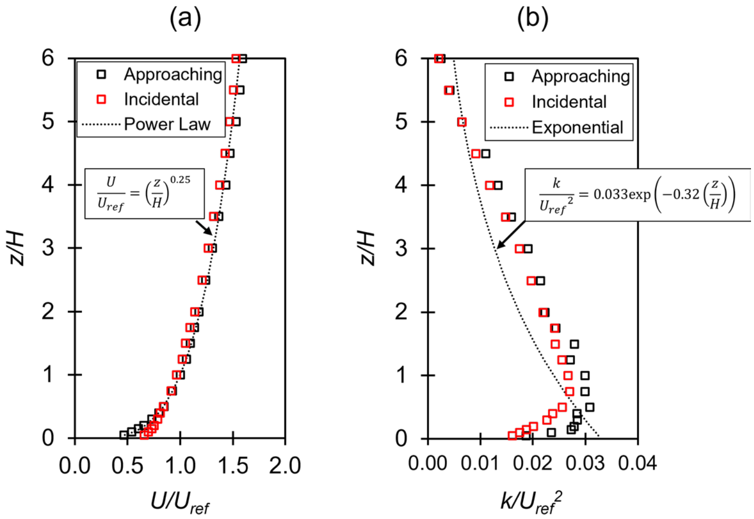

Fig. 3 Vertical profiles (a) wind speed and (b) estimated turbulent kinetic energy for approaching flow; *empty black square* at x/H = -5.0 and incidental flow; *empty red square* at x/H = 0.0.

3.2 Speed-up ratio

Fig. 4 illustrates the speed-up ratio R for Model 1 across four wind directions. The speed-up ratio is defined as

$$R = \frac{U_i}{U_{i0}} \quad (1)$$

U_i represents the mean wind speed at pedestrian level at point i, measured around the two opposing buildings, while U_{io} denotes the mean wind speed at the same location in the absence of the buildings, specifically under podium-only conditions. At a wind direction of θ = 0º (Fig. 4(a)), a substantial wind speed-up ratio is observed in the central area between the buildings due to a combination of corner streams. Moreover, it is evident that in the intervening area between the buildings, the speed-up ratio exceeding 1, signifying local acceleration attributable to the channeling effect. At θ = 30º (Fig. 4(b)), there is a noticeable reduction in the speed-up ratio, approximately 40% lower R_{max} than that observed in the parallel wind direction, due to the flow being partially obstructed and deflected around the buildings, leading to a weakened channeling effect. The flow becomes asymmetric, with increased velocities concentrated at the Building 2 (B2) façade, while an area of low speed-up ratio develops around Building 1 (B1).

A further reduction of the speed-up ratio is evident as the wind direction increases to θ = 60º (Fig. 4(c)) as no significant acceleration zones are observed. Under this condition, flow separation occurs at the corner of B2, resulting in a reduced speed-up ratio compared to the case of θ = 30º, prior to the formation of a broader jet in the intervening space, accompanied by an essentially symmetrical weak flow region in front of B1. When the wind direction is normal to the building axis (θ = 90º) as shown in Fig. 4(d), the B1's blocking effect becomes significant as the speed-up ratio decreases further and the low acceleration zone is concentrated in the middle position in the space between the buildings.

Fig. 5 illustrates the speed-up ratios for Model 2 across different wind directions. For a parallel wind direction of θ = 0º, as seen in Fig. 5(a), the narrow gap between the buildings promotes compressed airflow, resulting in significant local acceleration in the upstream region of the model. As the wind approaches the model at an oblique angle (θ = 30º), the flow is deflected by both buildings, generating a tilted high-speed path with a weakened channeling effect, resulting in a modest speed-up ratio near the B2 façade. For $\theta = 60^{\circ}$ (Fig. 5(c)), the distribution of the speed-up ratio throughout the building's gap is comparable to that of $\theta = 30^{\circ}$, nevertheless with a higher reduction in the former case. Moreover, when $\theta = 90^{\circ}$ (Fig. 5(d)), the blockage effect becomes apparent as no distinct acceleration zone is observed within the building's gap.

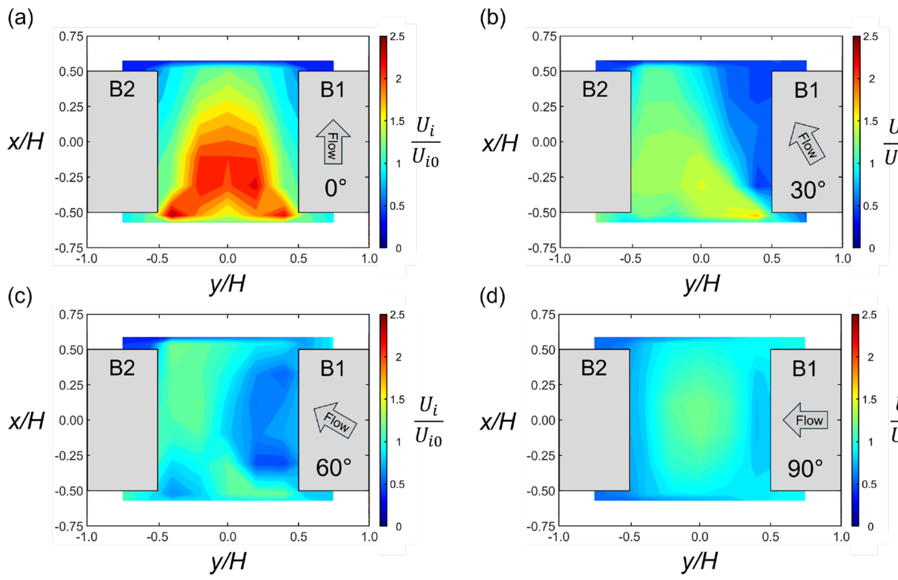

Fig. 4 Speed-up ratios R for Model 1 in the intervening space for wind directions (a) $\theta = 0^{\circ}$, (b) $\theta = 30^{\circ}$, (c) $\theta = 60^{\circ}$, and (d) $\theta = 90^{\circ}$

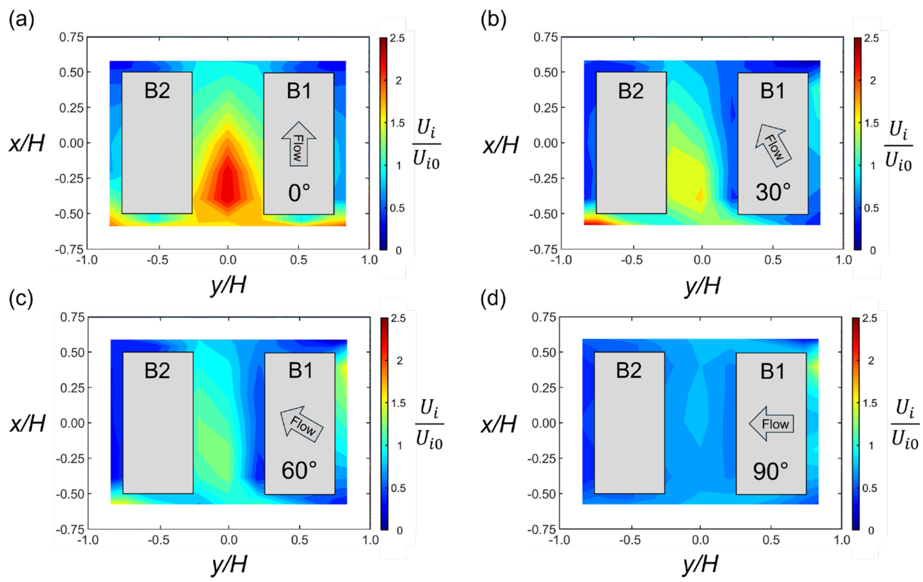

Fig. 5 Speed-up ratios R for Model 2 in the intervening space for wind directions (a) $\theta = 0^{\circ}$, (b) $\theta = 30^{\circ}$, (c) $\theta = 60^{\circ}$, and (d) $\theta = 90^{\circ}$

4. Published Paper etc.
[Underline the representative researcher and collaborate researchers]
[Published papers]
1. Not available
2. Not available

[Presentations at academic societies]
1. The 10th Asia-Pacific Conference on Wind Engineering (APCWE10) (Abstract accepted)

[Published books]
1. Not available
2. Not available

[Other]
Intellectual property rights, Homepage etc.

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6. Abstract (half page)

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Summary・Figures

This study performed a series of wind tunnel experiments to evaluate the wind environment in the intervening space above the podium between two opposing high-rise buildings. Two models, designated as Model 1 and Model 2, are employed based on the inter-building distance, with four different incoming wind directions: $\theta = 0°$, $30°$, $60°$, and $90°$. The main findings and recommendations for the future can be summarized as follows:

- The largest speed-up ratios were observed with parallel wind direction ($\theta = 0°$), as the airflow is compressed, leading to a channeling effect between the buildings.
- The speed-up ratio significantly decreases under oblique wind directions ($\theta = 30°$, $60°$, $90°$) due to the obstruction and deflection of the flow around the buildings, leading to a diminished channeling effect.
- It is recommended that the various building configurations and shapes should be considered in future research.