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Spatiotemporal correlations of aerodynamic load and flow structures of buildings with different heights exposed to twisted wind profile

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SUMMARY: (10 pt)
This study systematically investigates the spatial-temporal correlation of aerodynamic characteristics of buildings with different heights specifically for twisted wind. Surface pressure and flow field of square cross-section buildings with aspect ratio (AR=1:1, 1:4 and 1:6) under conventional wind profile (CWP) and twisted wind profile (TWP) are quantitatively measured by wind tunnel test and Large-eddy simulation. The correlation of wind loads and flow structures in time-frequency domain is examined. The results show that TWP largely modifies correlation of aerodynamic characteristics both spatially and spectrally, and this effect is dependent on the aspect ratio. For tall building, out-of-plane and in-plane correlation analysis indicates wake vortex under TWP results in stronger moment exchange along building height. Yet, TWP suppresses all correlations associated with Karman vortex. For low-rise building, TWP is more resembling the condition of CWP with certain attack angle. Thus, its correlation of wind load under TWP is amplified along all building height. Proper orthogonal decomposition (POD) analysis is further utilized to capture coherent structure and the spatial-temporal features of its correlation, which is expected to explain the potential mechanism of twisted-wind effect on correlation of wind load.

Keywords: Twisted flow; spatiotemporal correlation; coherent structure; POD

1. INTRODUCTION

Twisted wind flow is frequently observed in the mountainous terrain, especially in Hong Kong, which exhibits the wind speed and wind direction both continuously varying with the height (as shown in Fig. 1). Previous study conducted by our research group have found that the resultant flow fields, wind load and wind environment around/of a building in twisted flows can be greatly different from CWP with a certain angle of attack (Tse et al., 2016; Zhou et al., 2021). However, various simplified methods to obtain wind load combination specified in current building standards are all targeted for conventional straight wind profile (CWP) (Architectural Institution of Japan 2014, Australian/New Zealand Standard, 2009). Moreover, Tamura et al., (2008, 2014) demonstrated that aspect ratio (AR) of building has significant impacts on the correlation feature of wind loads. Therefore, to accurately evaluate TWP-induced response and ensure wind safety of buildings with different heights frequently subjected to twisted wind flows, it is of paramount importance to conduct a systematic study on the effect of twisted wind on the spatiotemporal

correlation for buildings with different aspect ratios.

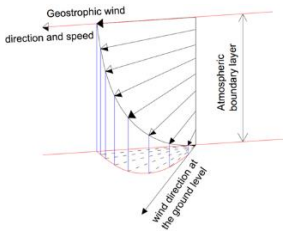


Figure 1. Schematics of twisted wind profile.

2. METHODOLOGY

Both wind tunnel test and numerical simulation method is adopted in this study to facilitate a comprehensive perspective to understand the effect of twisted wind on buildings with different height. The global layout, technical setting and local details in the experimental and numerical test (as shown in Fig. 2) is basically consistent with our previous study (Zhou et al., 2021, 2022). As one of the classic statistical method, proper orthogonal decomposition (POD) has obtained widespread application on both fundamental fluid mechanics and practical engineering application (Carassale et al., 2007; Solari et al., 2007). In this study, POD is used to capture the coherent structure and its correlation.

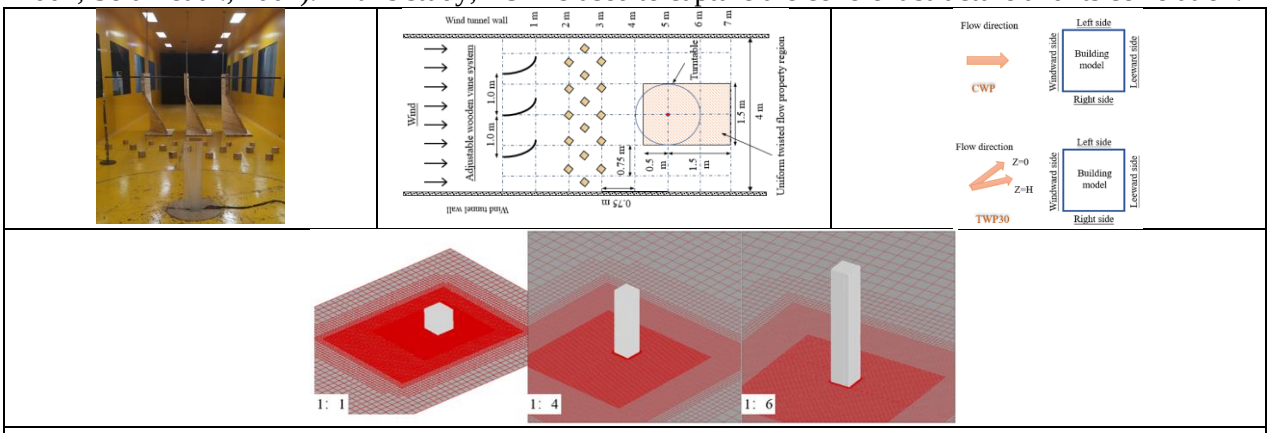
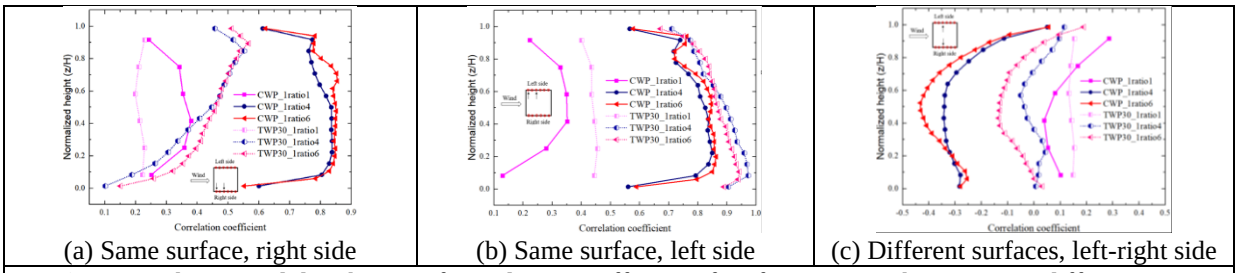


Figure. 2 Global layout and local details of the experimental and numerical test

3. RESULTS AND DISCUSSION

3.1. Correlation of wind pressure

Fig. 3 shows the vertical distribution of correlation coefficients of pressures on the same/ different building surface. Compared with CWP, the streamwise correlation distribution on the two side surfaces exhibit distinctive discrepancy for TWP30 case. specifically, correlation of pressure on the right-side surface is obviously reduced, conversely, that on the left-side surface is largely boosted especially for low-rise building AR=1:1. As illustrated in Fig. 3 (c), the heterolateral correlation of pressures of the left-side and right-side surface could reflects the vortex shedding characteristics. Thus, under CWP, the correlation coefficient is negative for tall buildings, which decreases with the increase of AR of building, however, TWP reduces this pressure correlation particularly for the middle height of building.



(a) Same surface, right side (b) Same surface, left side (c) Different surfaces, left-right side

Figure. 3 The vertical distribution of correlation coefficient of surface pressure between two different taps

3.2. Correlation of flow field

Wake velocity field of five horizontal planes at the height of $Z_i=i/6H$ (i=1, 2, 3, 4, 5) are monitored. Fig. 4 shows the correlation distribution of the longitudinal velocity components u of two points located on two different heights of horizontal planes but with the same (x, y) coordinates for case AR=1:6. Compared with CWP, the correlation of longitudinal under TWP30 is always less correlated, notably, the out-of-plane correlation of u changes from a symmetrical distribution under CWP to the distribution that deflects toward the side of the oncoming wind twist. As two planes are isolated farther, the large correlation region is significantly reduced or even disappears, A possible reason attributes to this finding is that the projection overlap area of the wake vortex structure at different height is reduced for TWP30 case, indicating that the three-dimensional wake structure is largely distorted by the twisted flow.

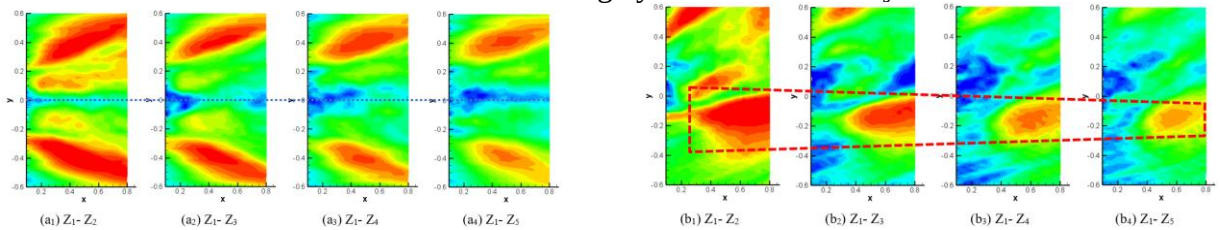


Figure. 4 Distribution of out-of-plane correlation coefficients between two horizontal plane of u velocity component for building AR=1:6 under different flow conditions (a) CWP; (b) TWP30

3.3. Correlation of coherent structure

Coherent structure is extracted by POD. Due to limitation of paper length, only the correlation of temporal evolution of coherent structure is investigated. Fig. 5 compares the coherence between the main mode coefficients of the same order but at different horizontal planes (Z_1=1/6H and Z_3=1/2H) for two building models. Under CWP, for low-rise building of AR=1:1, coherence of the first two modal coefficients peak at frequency of 0.07 with the magnitude close to 1, while for tall building of AR=1:6, the coherence reaches the peak value of 0.1. This phenomenon suggests the dominant coherent structures of low-rise building and tall building are controlled by the arch-type vortex and Karman vortex respectively, and thus the modal coefficients at planes Z_1=1/6H and Z_3=1/2H are almost completely correlated with each other. Moreover, the coherence peak of the third mode appears within the extremely low frequency region both for the low-rise building and tall building, which signifies the coherence of the third modal coefficients at two different planes is mainly influenced by the shift mode. Under TWP30, twisted flow increases the coherence in the low frequency region and most high frequency regions for two building models. A notable finding is that the correlation of the tall building caused by the Karman vortex structure within the frequency range of around 0.1 is clearly suppressed.

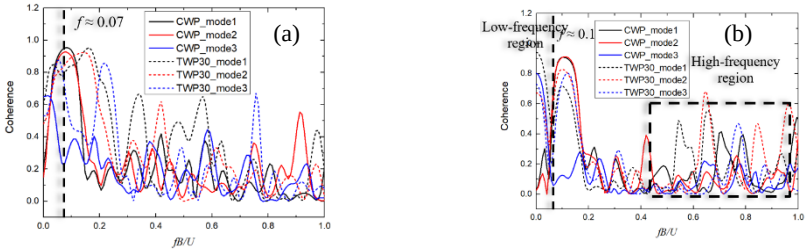


Figure. 5 The coherence between the main mode coefficients of the same order at different horizontal planes (z=1/6H and z=1/2H) for (a) AR=1:1; (b) AR=1:6

4. CONCLUDING REMARKS

In this study, the effect of twisted wind on the spatiotemporal correlation of the aerodynamic characteristics of different height of buildings is systematically investigated. Pressure measurement experiment, large eddy simulation and POD analysis are conducted. Results show that twisted wind has significant effect on the correlation of wind pressure distribution, and this twisted-wind effect on correlation is dependent on aspect ratio. For low-rise building AR=1:1, TWP is more resembling the condition of the conventional straight wind with certain attack angle; while for tall building, the pressure distribution is clearly deviated with the deviation degree that decreases with the height of building. The out-of-plane correlations of longitudinal velocity under TWP30 all becomes less correlated because the flow twisting results in much less projection overlap area compared to CWP. POD mode analysis well captures the the flow pattern and the correlation of coherence structure. Although TWP30 reduces the correlation caused by the Karman vortex structure, it genuinely increases the coherence in the low frequency band dominated by the shift mode as well as that in most high frequency regions.

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