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Can wind loads of a twisted building in the untwisted wind field be equivalent to those of an untwisted building in the twisted wind field?

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SUMMARY:
The wind direction in the atmospheric boundary layer will twists with height due to the Coriolis force; this phenomenon is called the Ekman spiral, which may have a significant effect on the building wind loads. At present, many researchers have studied the wind load characteristics of buildings under twisted wind fields, but the process of simulating twisted wind profiles is undoubtedly complex and difficult. This paper investigates whether the wind load results of a twisted building, which is twisted by Ekman spiral, in the conventional untwisted wind field can be equivalent to those of an untwisted square-section building in the twisted wind field. Based on ANSYS Fluent, large eddy simulation (LES) is used to analyze and calculate the difference between the two cases. It is proved that the mean wind pressure coefficient and the wind force coefficient are equivalent approximately, but the fluctuating wind pressure coefficient, local wind streamlines and vortex shedding of the two cases are much different, especially the vortex shedding of the untwisted building in the twisted wind field is more distinct.

Keywords: Twisted building, Twisted wind flow, Large eddy simulation

1. GENERAL INSTRUCTIONS

In the actual atmospheric boundary layer, due to the Coriolis force, the wind direction will twist with the height, causing the bottom and top areas of the super high-rise building to be in different wind directions, which may have a significant impact on the building wind loads. This phenomenon is called Ekman spiral phenomenon. In fact, several researchers did related studies on the twisted wind flow through wind tunnel tests and numerical simulations. Liu et al. (2019) and Zhou et al. (2022) simulated the twisted wind field in a wind tunnel and analyzed the wind load of super high-rise buildings under the twisted wind field. Feng et al. (2019) analyzed the wind pressure distribution and the wind-induced response of super high-rise buildings under a twisted wind field via LES. Yuan et al. (2022) analyzed the aerodynamic forces on high-rise buildings under twisted winds through different turbulence models. They have proven that the influence of the twisted wind flow on the wind load and wind-induced response of kilometer super high-rise buildings is apparent. However, the process of simulating the twisted wind profile is difficult, especially in the wind tunnel. In this paper, a twisted square-section building, which is twisted along the height by the form of the Ekman spiral, is designed to compare the wind loads of the twisted building in the conventional untwisted wind field and those of the untwisted square-section building in the twisted wind field. Based on LES, this paper compares the differences between the two cases to investigate whether the method of twisting buildings can be equivalent to the results of the twisted wind field. This issue is systematically investigated by CFD simulations based on the commercial software ANSYS Fluent 17.0 in this paper.

2. CASE SETTINGS, COMPUTATIONAL SETTINGS, AND PARAMETERS

2.1. Case settings and building models

The untwisted square-section building model (Fig. 1) for comparison in this paper is consistent with Feng et al. (2019), and the length, width, and height are 0.1×0.1×0.91 m. The twisted angle at the building height is about 24.60° (the twisted wind profile simulated by Feng et al., 2019), so the twisted building model in this paper twists 24.60° along the height, where the twisting curve is consistent with the twisted angle profile. Based on the two models of twisted building and untwisted square-section building, the corresponding conventional untwisted wind profile and twisted wind profile are set respectively, which are Case 1 and Case 2 investigated in this paper. The specific case settings are shown in Table 1.

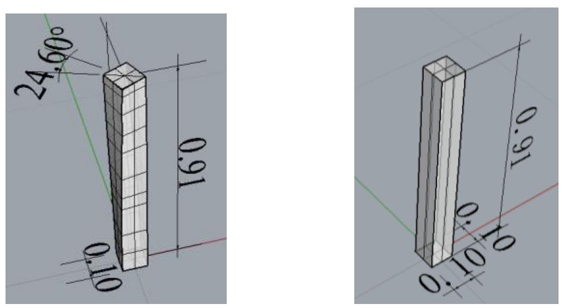


Figure 1. Twisted building and untwisted building models.

Table 1. Case settings.

Case No.	Case settings
Case 1	Twisted Building under a conventional untwisted wind profile with an inflection point (CWPP)
Case 2	Untwisted square-section Building under a twisted wind profile (TWP)

2.2. Computational settings and parameters

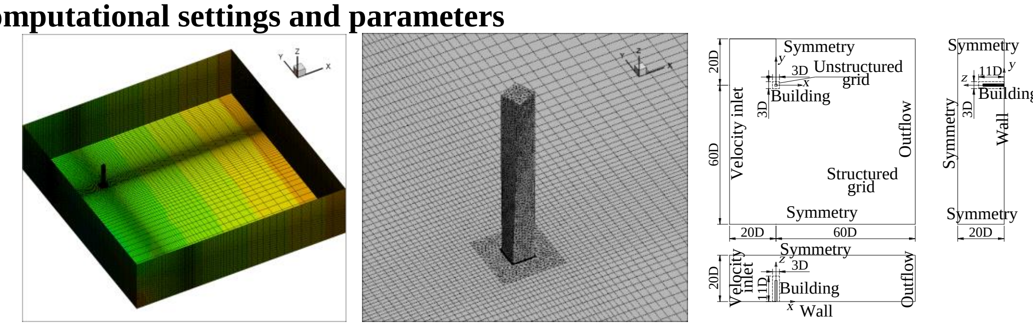


Figure 2. Hybrid mesh of twisted building and computational domains.

As shown in Fig. 2, the length of the computational domain in the x, y, and z directions are 80D×80D×20D, respectively. The building is located in the center of the coordinate axis. The area of 3D×3D×11D around the building is set as unstructured tetrahedral grids with a global size of 0.2D, and the boundary layers are set around the building. The peripheral area is set as structured grids. The boundary conditions of the computational domain are set as shown in Fig. 2. The zero-mean fluctuating velocity series generated by an improved inflow turbulence generator, the NSRFG (Yu et al., 2018), are superimposed on the mean wind profiles as the inflow boundary conditions for LES. For comparison and verification, other settings are consistent with those in Feng et al. (2019).

3. RESULTS AND DISCUSSIONS

3.1. Wind pressure coefficients

Fig. 3 shows the comparison of wind pressure coefficients of Case 1 and Case 2 buildings when z=1/2H and 2/3H. It can be seen that the mean wind pressure coefficients of Case 1 and Case 2 on most sections are roughly the same, but on the left side (Tap 8-14), the mean wind pressure coefficients are not the same, and the results of the untwisted square-section building are slightly smaller than those of the twisted building. For fluctuating wind pressure coefficient, it is obvious that the fluctuating wind pressure coefficient of the untwisted square-section building is slightly larger.

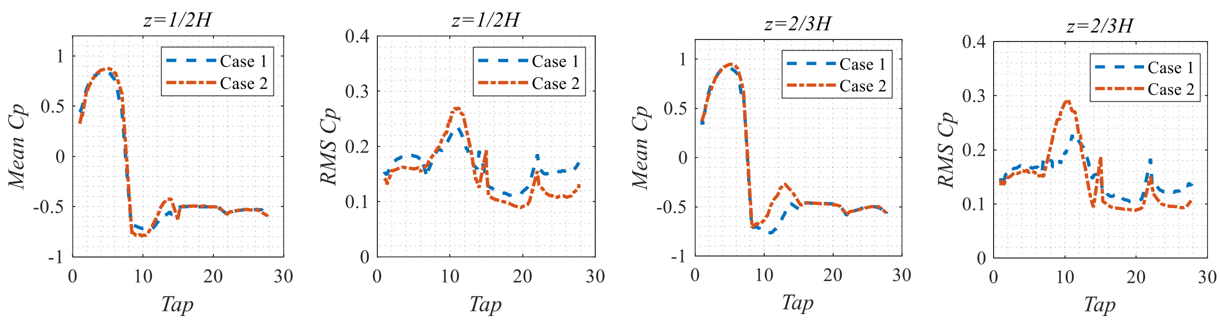


Figure 3. Comparisons of the pressure coefficients of Case 1 and Case 2 (z=1/2H and 2/3H).

3.2. Wind force coefficients

Fig. 4 shows the difference between the local wind coefficients of the building of Feng et al. (2019), Case 1 and Case 2. The simulation results of Case 2 are in good agreement with those of Feng et al. (2019), indicating that the simulation in this paper is accurate. Moreover, the along-wind local wind force of Case 1 can be equivalent to the results of Case 2, but the across-wind local wind force is a little different.

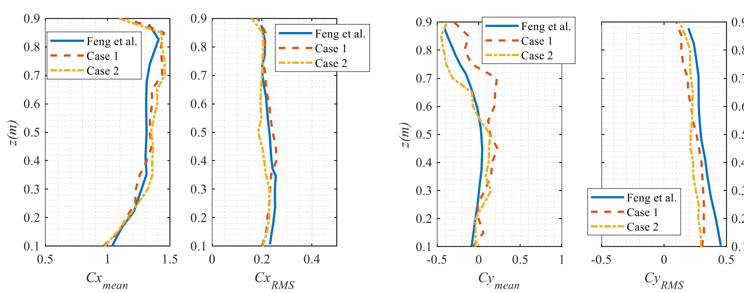
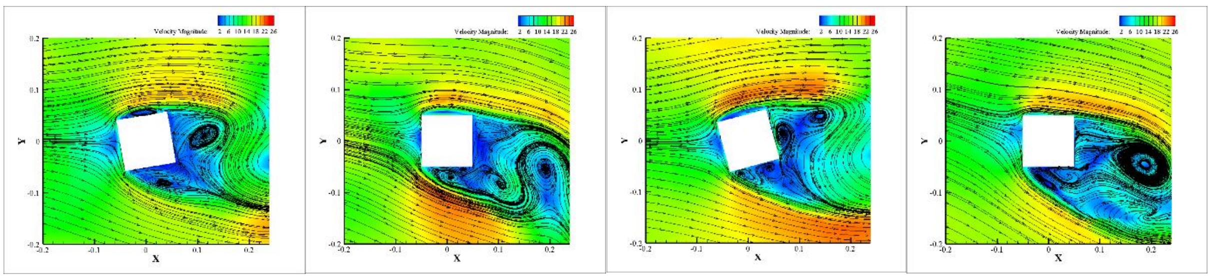


Figure 4. Comparisons of the local wind force coefficients of Case 1 and Case 2 (C_x and C_y).

3.3. Mean velocity characteristics of the simulated fluid

Fig. 5 can reflect the distribution of the flow field and vortex around the building. Although the wind speed distribution around the building is basically the same (the color distribution is roughly the same), the vortices around the building are quite different. For example, when z=2/3H, there are obvious vortices on the leeward side and right side of the twisted building, but there is no obvious vortex around the untwisted building and the vortex occurs in the far area behind the building. The twisted wind field will change the flow field distribution around the building, and the position of vortex shedding and reattachment will be different from that of the untwisted wind field.



(a) z=1/2H (Case 1) (b) z=1/2H (Case 2) (c) z=2/3H (Case 1) (d) z=2/3H (Case 2)

Figure 5. Mean velocity magnitude contours with time-average streamlines on the horizontal planes of Case 1 and Case 2 (z=1/2H and 2/3H).

4. CONCLUSION

To investigate whether the wind load results of a twisted building in an untwisted wind field can be equivalent to those of an untwisted building in a twisted wind field, this paper calculated the wind loads on a square-section building in these two cases with the CFD method. Through comparison, it can be seen that the maximum mean wind pressure coefficient, local wind force coefficient, and other macroscopic results can be approximately equivalent, but the fluctuating wind pressure, the correlation of local wind coefficient, vortex shedding, surrounding flow field distribution, and other microscopic results are different, and the influence of twisted wind field and untwisted wind field still have a large difference. For Case 2, the fluctuating wind pressure coefficient of the left side is larger, and the vortex shedding around the building is more distinct.

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