Experimental study of interference effect on super large cooling towers exposed to tornado-like vortices

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SUMMARY:
This paper physically investigates the interference effects on aerodynamics and wind pressure distribution patterns considering various swirl ratios, cooling tower layouts, and relatively distance between cooling towers and tornado based on a tornado-like vortex simulator. Two kind of rigid models were constructed for wind force measurement tests and wind pressure measurement tests respectively, and the experimental results demonstrate that the interference effects on aerodynamics and local wind pressure are significantly related to the swirl ratios, relatively distance between the cooling tower and tornado, and cooling tower layouts. Moreover, the tornado located at the side of two adjacent towers is the most unfavourable layout compared with the single tower and other one scenario (i.e., the tornado located at the middle of two adjacent towers), which could result in greater amplification effects on total wind forces and local wind pressure of the studied towers. This investigation aims to contribute to the better understanding on the wind-resistant behaviours of cooling towers exposed to non-synoptic winds, especially tornadic vortex impacts.

Keywords: Tornado-like vortices, Cooling tower, Interference effect

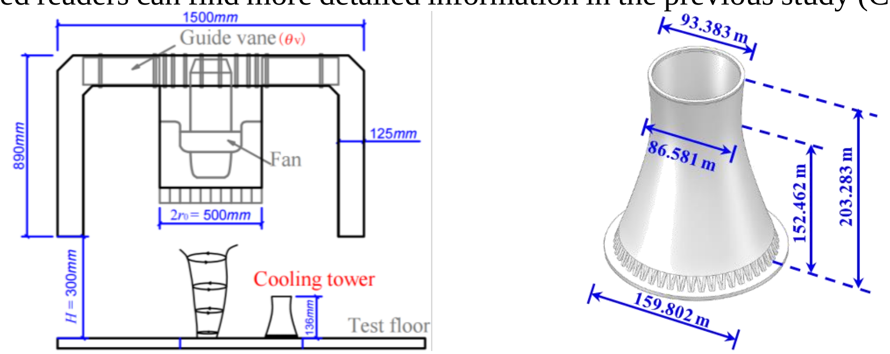
1. INTRODUCTION

Owing to the significant height (over 200 m) and thin-walled features (the minimum thickness is only about 0.25 m), super large cooling towers (SLCTs) with low and dense frequencies are typical wind-sensitive structures. Currently, most available knowledge of the wind load characteristics for an isolated cooling tower or interference effects is considered only conventional boundary-layer-type strong winds. It is well-known that tornadoes have specific swirling effects with tangential, radial and vertical velocity components, which are quite different from those of conventional straight-line boundary-layer winds. Compared with synoptic winds, relatively few investigations (Wang et al, 2016; Liu et al, 2018; Chen et al, 2022) have been conducted on SLCTs exposed to tornado-like vortices with the aid of a tornado-like vortex simulator (TVS). However, these abovementioned studies only aim at an isolated cooling tower, and ignored interference effects on SLCTs. It should be note that the cooling towers in most of thermal and nuclear plants exist in the form of group tower combinations, and there is a trend of increasing the scale of group tower combinations. The objective of this study was to physically investigate the interference effects on aerodynamics and tornadic wind pressure distribution patterns considering various swirl ratios, cooling tower layouts, and relatively distance between cooling towers and the tornado.

2. EXPERIMENTAL SETUP

2.1. Tornado-like vortex and prototype cooling tower

The three-dimensional wind field of target tornado-like flow in present studies were modeled by the TVS constructed at Tongji University. The Schematic diagram of the TVS are introduced in Figure 1(a). Furthermore, the prototype cooling tower and main dimensions of the structure are introduced in Figure 1(b). The swirl ratios *S* are set as 0.15, 0.35, and 0.72, respectively. For concise consideration, the detailed introductions of the genetared wind field are not illustrated here, and concerned readers can find more detailed information in the previous study (Chen et al, 2022).

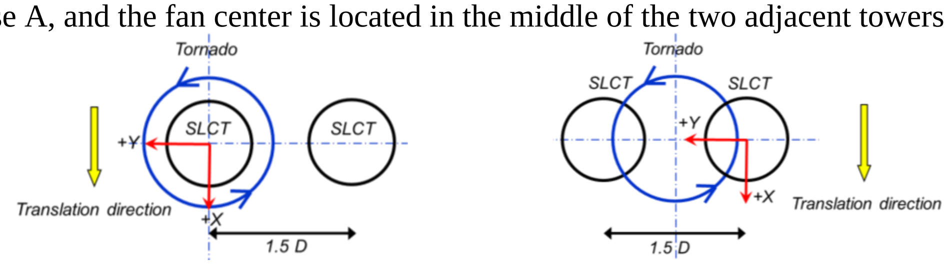


(a) TVS (b) Prototype SLCT

Figure 1. Schematic diagram of TVS and prototype SLCT.

2.2. Location of tornado with respect to SLCTs

Two scenarios (the tornado located at the side of two adjacent towers, i.e., Case A; the tornado located at the middle of two adjacent towers, i.e., Case B) according to the location of the tornado-like vortices relative to the rigid models (seeing Figure 2) are designated to investigate the interference effects on wind-load characteristics of SLCTs. It should be note that the *D* represents the shell base diameter, and yellow arrows represent the translation direction of the tornado for investigating the variation of structural wind loads when the tornado is different distances from the cooling towers. Moreover, the fan center of the TVS is consistent with the center of the target tower in Case A, and the fan center is located in the middle of the two adjacent towers in Case B.



(a) Case A (b) Case B

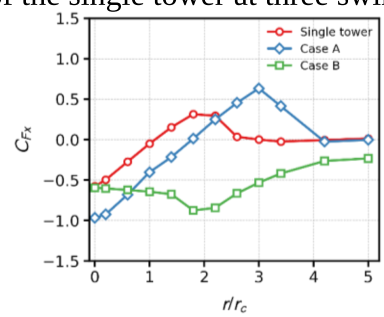
Figure 2. Location of tornado-like vortices with respect to rigid models.

3. RESULTS AND DISCUSSION

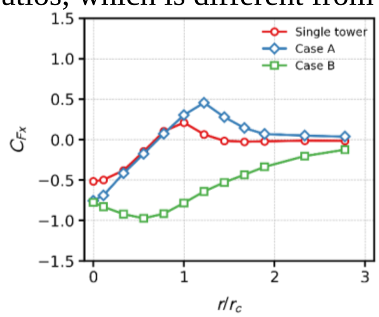
3.1. Total wind force

Due to space limitations, only the tornado-induced total wind forces include three basement forces F_X, F_Y, and F_Z were investigated, and the direction definition is introduced in Figure 2. Figure 3 shows the variations in the mean total wind force coefficients (defined as C_{Fx}, C_{Fy} and C_{Fz}, respectively) with respect to the relative distance *r* between the SLCTs and tornado, where *r* is normalized by the radius of vortex core r_c. Compared with the single tower, the C_{Fx} in Case A is significantly enlarged in special conditions at both three swirl ratios. Specifically, the maximal absolute value of the C_{Fx} decreases with increasing S, and the location correspond to the extremum of the C_{Fx} in the positive direction, is getting closer to the radius of the vortex core. For Case B, inconsistent with other two combinations, C_{Fx} has no reverse phenomenon with increasing distance from tornado. Interestingly, when the S=0.15, the maximal absolute value of the C_{Fx} is similar to that in case A, but with increasing S, the maximal absolute value of the C_{Fx} is significantly greater than those of the single tower and Case A.

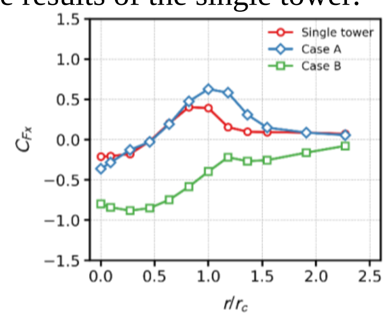
As shown in Figures 3(d)-(f), the C_{Fy} near the center of the vortex core for Cases A and B is opposite to those of the single tower at both three swirl ratios, due to the interference effects from the adjacent tower. When S=0.15, wind load amplification only occur in the special conditions (i.e., r/r_c=3 and 3.4 in Case A), and the wind loads in Cases A and B are smaller than those of the single tower when r/r_c is less than 2.6, indicating that the adjacent tower has beneficial effects on reducing the wind load of the SLCTs. When S=0.35 and 0.70, the C_{Fy} varies with the distance from the tornado similarly. Moreover, the structural wind loads within the radius of the vortex core are smaller than those of the single tower, while outside the radius of the vortex core, the C_{Fy} is basically close to those of the single tower. As shown in Figures 3(g)-(i), the C_{Fz} first increases and then decreases in Cases A and B, and the largest uplift force is significantly smaller than that of the single tower at three swirl ratios, which is different from the results of the single tower.



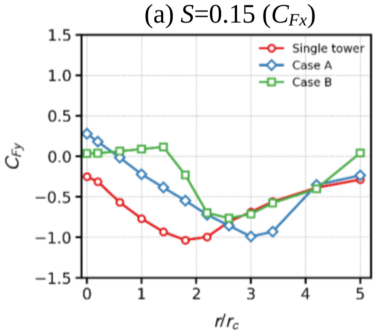
(a) S=0.15 (C_{Fx})



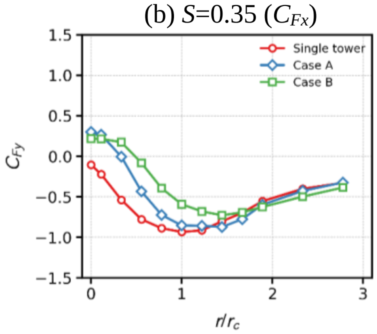
(b) S=0.35 (C_{Fx})



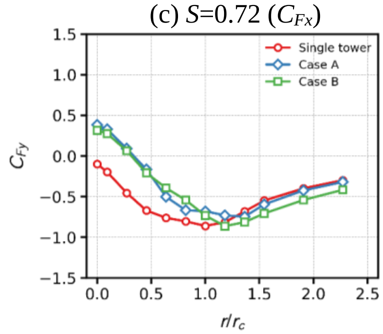
(c) S=0.72 (C_{Fx})



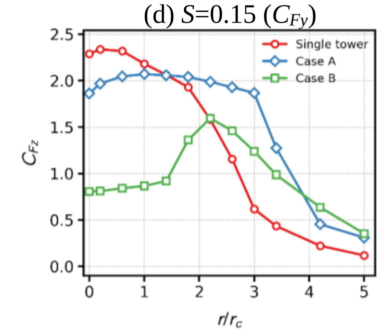
(d) S=0.15 (C_{Fy})



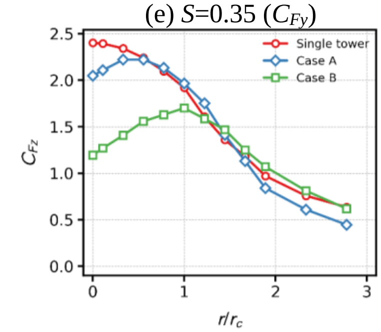
(e) S=0.35 (C_{Fy})



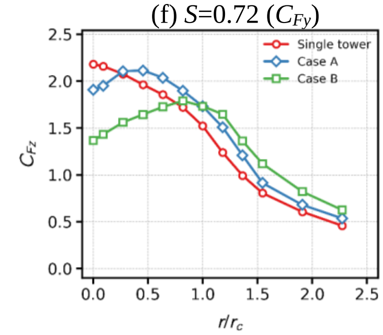
(f) S=0.72 (C_{Fy})



(g) S=0.15 (C_{Fz})



(h) S=0.35 (C_{Fz})

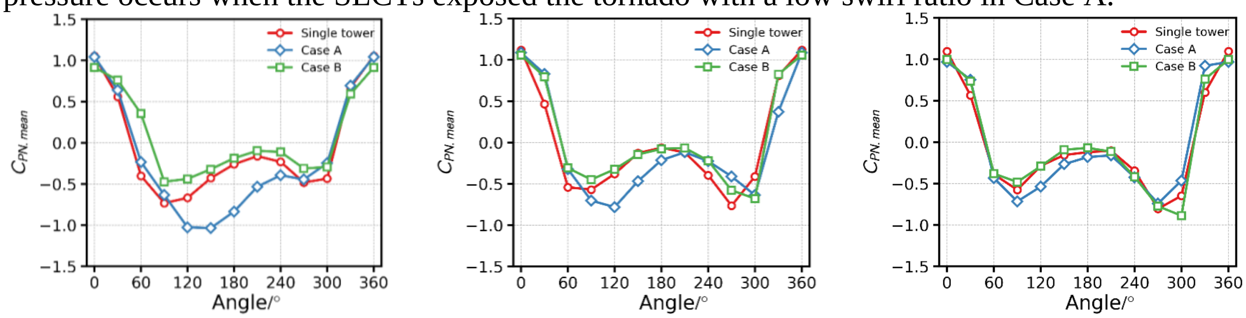


(i) S=0.72 (C_{Fz})

Figure 3. Mean total wind force coefficients at various distances and swirl ratios

3.2. Local wind pressure

The net pressure (i.e., the difference between the external and internal pressures), which is the predominant load in the structural design, is selected as the research objective. Figure 4 shows the envelope curves of the net mean pressure coefficients (defined as $C_{PN.mean}$) on the throat level at various distances between the SLCTs and tornado. Moreover, three swirl ratios and three cooling tower layouts are also considered in present studies. The results indicate that the $C_{PN.mean}$ exhibits asymmetrical W-shaped distributions, which is analogous to that under synoptic winds. For Case A, the interference effects on wind pressure distributions mainly manifested in the sideward and leeward faces of the studied tower, and the amplification effects of local wind pressure decay gradually with increasing S. For Case B, the wind pressure distributions are basically consistent with those of the single tower at both three swirl ratios. Notably, the SLCT suffers the critical negative pressure on the sideward side when S=0.15, indicating that the most unfavourable local pressure occurs when the SLCTs exposed the tornado with a low swirl ratio in Case A.



(a) S=0.15 (b) S=0.35 (c) S=0.72

Figure 4. Distribution of the net mean pressure coefficient at various swirl ratios.

4. CONCLUSIONS

The interference effects on aerodynamics and local wind pressure are related to the swirl ratios, relatively distance between the SLCTs and tornado, and SLCTs layouts. The tornado located at the side of two adjacent towers (i.e., Case A) is the most unfavourable layout compared with the single tower and the Case B, which could result in greater amplification effects on total wind forces and local wind pressure of the SLCTs. Moreover, the most unfavourable local pressure occurs when the SLCTs exposed the tornado with a low swirl ratio in Case A.

ACKNOWLEDGEMENTS

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