TORNADO-INDUCED WIND PRESSURES ON A COOLING TOWER

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ABSTRACT

Although wind-resistant design of structures is usually carried out with respect to synoptic boundary-layer-type strong winds, tornado-induced wind effects on important structures like a cooling tower is necessary to be investigated. This paper presents wind pressures acting on a cooling tower caused by stationary and translating tornados by utilizing a moving tornado-like vortex simulator developed at Tongji University, China. For the stationary tornado, the wind pressure is measured at different radial distances between the cooling tower and stationary tornado-like vortex. For the translating tornado, three different translation speeds are considered. The results show that tornado vortex can produce high negative wind pressure coefficients on the cooling tower surface due to combined effects of pressure drop accompanying the tornado and aerodynamic flow-structure interaction. The wind pressure caused by a translating tornado is not significantly different than those of a stationary tornado.

KEYWORDS: TORNADO-LIKE VORTEX, COOLING TOWER, WIND PRESSURES

Introduction

Although tornadoes in China are not as strong as those in the USA, they do occur in eastern China. Golden and Snow (1991) reported that China experiences about 10 to 100 tornadoes per year. As featured by a three-dimensional funnel-shape vortex, the wind characteristics of a tornado is quite different than those of conventional boundary-layer winds, which indicates the necessity to investigate the tornado-induced wind loads on structures.

Many case studies have been conducted to investigate the tornado-induced wind force on structures, the majority of which considered stationary tornados [Jischke and Light (1983); Bienkiewicz and Dudhia (1993); Mishra et al. (2008); Sabareesh et al. (2013)] while some studies considered the effects of translating motion of a tornado [Sarkar et al. (2006); Sengupta et al. (2008); Haan et al. (2010)]. The increasing development of economy, people's consciousness and expectations of the structure safety promote the attention on tornado effects on structures in China. The most significant feature of a tornado is its three-dimensional funnel-shape vortex structure, which creates different wind velocity and pressure fields from those of straight-line winds. A cooling tower is usually an important component part of a power plant, whose wind-resistant performance attracts more attentions than before in China because it is becoming more wind sensitive due to its continuous increase in structure height. Similar as other structures, the wind-resistant design of a cooling tower is usually performed with respect to the straight-line boundary-layer-type strong winds, and accordingly the wind load effects on a cooling tower are often investigated in a boundary-layer-type wind tunnel [Zhao and Ge (2010)]. However, wind load characteristics of a cooling tower exposed to a tornado are necessary to be investigated if it is located at a tornado-prone region.

In the present study, both stationary and translating tornado-like vortices are modeled in a tornado-like vortex generator. The swirl ratio of the tornado is S=0.54. For the stationary tornado, the wind pressure is measured at different radial distances between the cooling tower and stationary tornado. For the translating tornado, three different translating velocities (u=0.04m/s, 0.12m/s and 0.2m/s) are considered. The characteristics of tornado-induced wind pressures on a cooling are studied, while the effects of translating motion is clarified by comparing the wind pressures in a translating tornado with quasi-steady pressure data.

Experimental Setup

Fig. 1 shows the schematic diagram of tornado-like vortex simulator at Tongji University whose mechanism to generate a tornado-like flow is similar to that at Iowa State University, USA [Haan et al. (2008)]. A circular duct of 1.5m in diameter and 1.009m in height is suspended overhead with a 0.5m-diameter updraft hole (r_o=250mm) holding a controlling fan to generate a strong updraft. The simulator floor could be adjusted up and down, enabling a range of heights for the inflow layer (H=150mm~550mm). Both the fan and guide vanes are placed on the top of the simulator, which allows more spaces to conduct model tests to determine the tornado effects. In addition, this tornado vortex simulator can translate along the ground plane at a given speed (maximum translation speed is 0.4m/s).

The cooling tower model is fitted with a total of 36 pressure taps distributed evenly over external surface at three layers as shown in Fig. 2. On each layer, twelve pressure taps are distributed uniformly with 30^o angle between two adjacent pressure taps.

In this study, the inflow height is fixed at H=400mm below the exit of the outer duct. Swirl ratio which is defined as $S=\tan\theta/2a$, where θ and a are guide vane angle and aspect ratio $a=H/r_o$, respectively [Mitsuta and Monji (1984); Matsui and Tamura (2009)], is chosen to be S=0.54 by setting the guide vane angle at $\theta=60^o$. The rotational speed of fan is fixed at 1500rpm and data are acquired at a sampling frequency of 300Hz for both stationary and translating tornados.

External wind pressures

Fig. 3 shows the external wind pressure coefficient acting on the cooling tower model exposed to a stationary tornado (S=0.54) at different radial locations. Wind pressures at three layers are presented. When the tornado vortex is located at different radial distances to the cooling tower, wind pressures exhibit different characteristics. The pressure decreases from

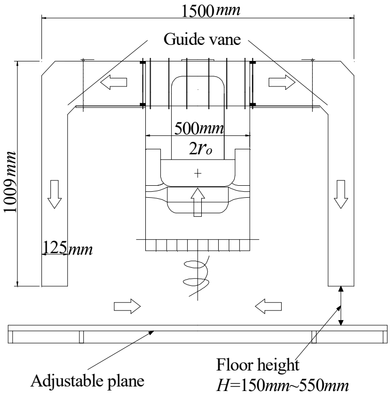

Fig. 1 Schematic diagram of tornado-like vortex simulator

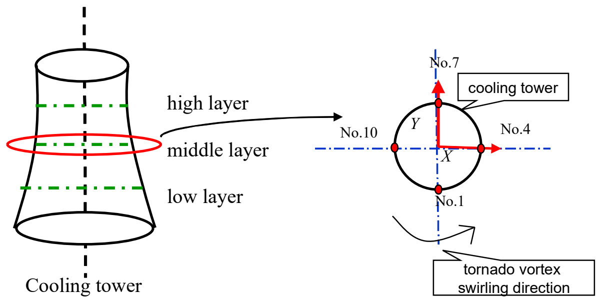

Fig. 2 Cooling tower model

pressure tap No.6 to pressure tap No.10 and then recovers a little until pressure tap No.12 (base point) at r/r_o=0. At other radial locations (i.e. r/r_o=0.28, 0.52 and 0.84), the pressure coefficient decreases from pressure tap No.7 to pressure tap No.10 or No.11 and then recovers a little until pressure tap No.1 (base point). These characteristics of wind pressure distribution mean that the pressures acting on a cooling tower are influenced by combined effects of negative pressure drop accompanying the tornado and aerodynamic force acting on the cooling tower model.

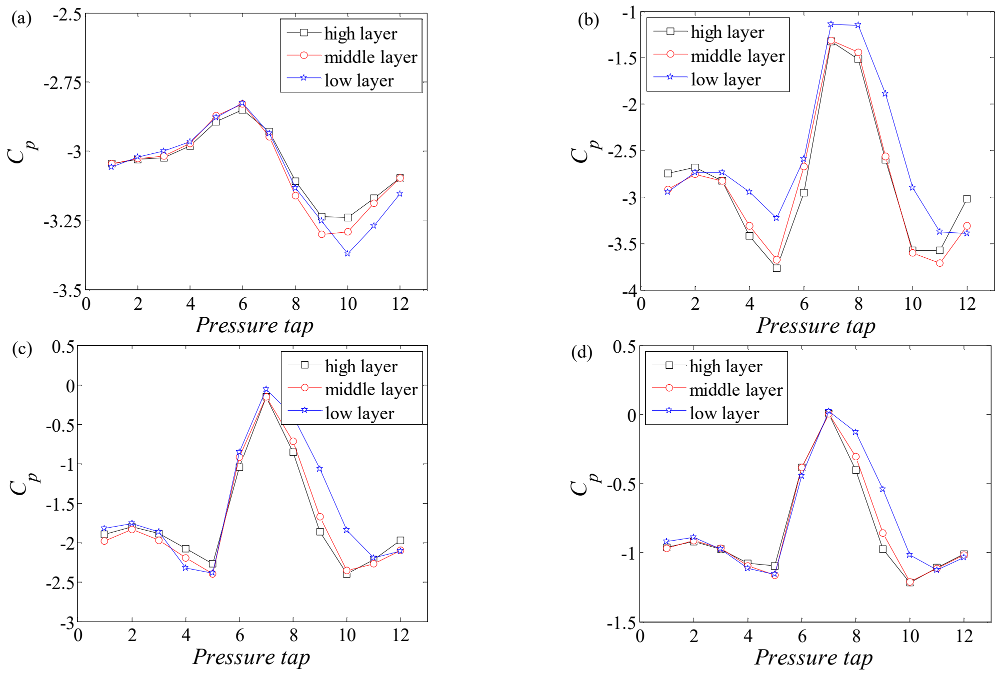

Fig. 3 Wind pressure coefficients on the cooling tower at different radial locations (a) r/r_o=0; (b) r/r_o=0.28; (c) r/r_o=0.52; (d) r/r_o=0.84

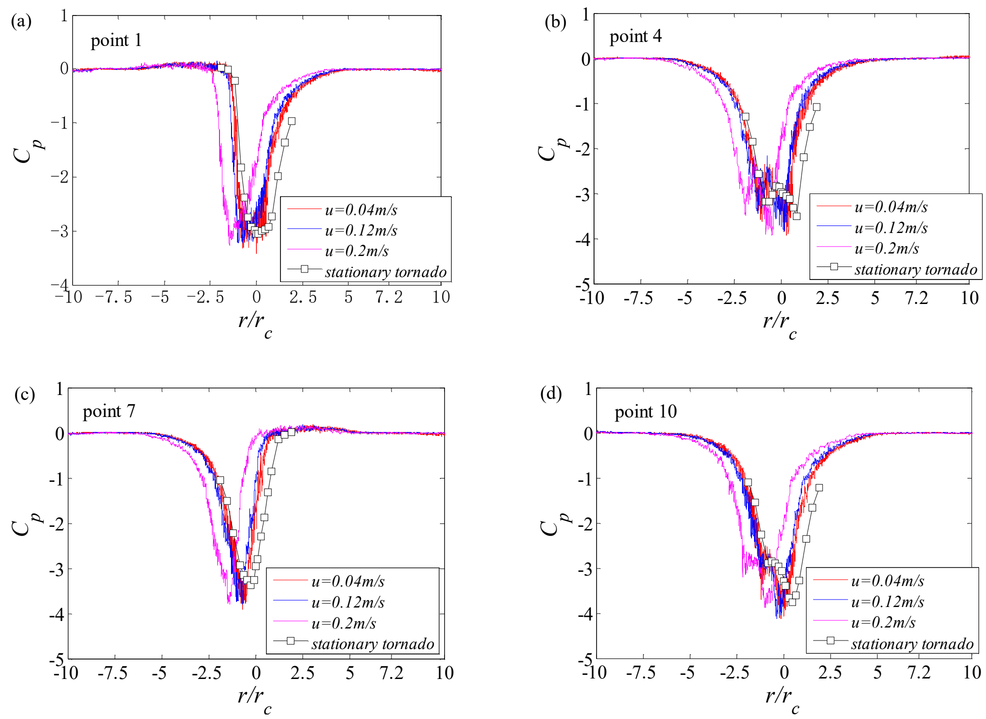

Fig.4 Time histories of pressure coefficient at different translating speeds

Fig.4 presents time history of wind pressure coefficient on a cooling tower exposed to a translating tornado-like vortex with different translating speeds (*u*=0.04m/s, 0.12m/s and 0.2m/s). The quasi-steady pressure data obtained at stationary tornado vortices are shown together for comparison. The negative and positive radial distances *r* mean the tornado vortex is located at the left side and right side of the cooling tower, respectively. The magnitude of peak pressure generally decreases slightly with the increase in translation speed. It is interesting to notice that the peak pressure exists before the tornado reaches the model center, which is different with that reported by Haan et al. (2010).

Conclusions

The pressure distribution around the cooling tower exhibits characteristics that are quite different than those in atmospheric boundary layer flows. High negative pressure is produced on the external surface due to the pressure drop accompanying a tornado and the flow-structure interaction. The pressure drop accompanying the tornado dominates the pressure coefficient magnitudes compared to the pressure variations due to wind-structure interaction when the cooling tower is located at the tornado core center. The magnitude of peak pressure generally decreases slightly with the increase in translation speed of tornado and the peak pressure exists before the tornado reaches the model center. However, the difference is not significant.

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