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# Evaluation of Tornado Uplift Pressure Adjustment Factor Based on Tornado Simulator and Boundary Layer Wind Tunnel Experiments

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## INTRODUCTION

Tornadoes are considered one of the most destructive windstorms around the globe. Post-damage surveys show significant damage to roofs, which has been postulated to be due to additional uplift forces caused by the vertical winds in tornadoes. To account for the additional uplift force in building codes against tornadoes, a tornado pressure coefficient adjustment factor for vertical winds ($K_{vT}$) was introduced in ASCE 7-22. In this study, a series of comprehensive experimental tests were conducted in both the VorTECH tornado simulator and Atmospheric Boundary Layer (ABL) wind tunnel at Texas Tech University (TTU), measuring pressures on a low-rise building model. The pressure coefficients ($C_p$) from the tornado-like loading are compared to the $C_p$ from ASCE 7-22 and the ABL wind tunnel study to evaluate the accuracy of the current $K_{vT}$ factor for both the main wind force resisting system (MWFRS) and components and claddings (C&C).

## EXPERIMENTAL TESTS

Two types of tornado-like vortices were generated in the tornado simulator: 1) a single-celled vortex with a swirl ratio ($S$) of 0.17 and 2) a multi-celled vortex with an $S$ of 0.83. The single-celled and multi-celled vortices have a core radius ($r_c$) of 8 cm and 46 cm, respectively. The building model used in this study is a 1:100 scale of the TTU Wind Engineering Research Field Laboratory (WERFL). The dimensions of the building model and the schematic of a test configuration are shown in Figure 1. Various test configurations (shown in Table 1) were tested where the tornado-like vortex passed over or near the building. Due to the non-stationary and non-gaussian nature of the tornado-like loading, each configuration was repeated at least 100 times, providing more reliable ensemble statistics of the loading. To make a direct comparison between the tornado-like and ABL wind loading, the same WERFL building model was tested in the ABL wind tunnel for a mean along wind speed of 11.64 m/s at mean eave height and mean wind directions ranging from 0° to 180° with 15° increments.

Table 1. Tornado simulator test configurations

| Swirl Ratio ($S$) | Translation path ($y/r_c$) | Model orientation ($\beta$) | Translation speed $U$ (m/s) |
|---|---|---|---|
| 0.17 | 0, 0.5, 1.0, 1.5 | 0°, 45°, 90° | 0.25, 1.25 |
| 0.83 | 0, 0.5, 1.0, 2.0 | 0°-180° with 15° increments | 0.25, 0.75, 1.25 |

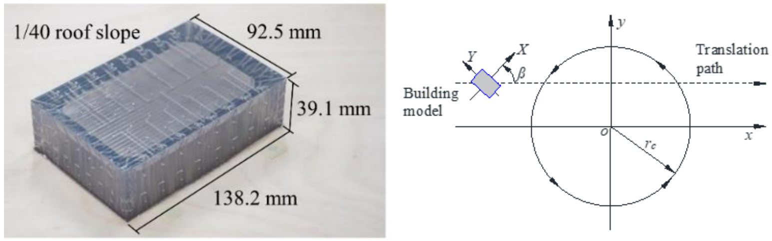


Figure 1. WERFL building dimensions and schematic drawing of the test configuration.

## COMPARISON METHODS

The $K_{vT}$ factor is defined as the ratio of the maximum value of the tornado-induced wind pressure, including the effects of the vertical wind component, to the maximum pressure without the effects of the vertical wind component. In this study, the maximum tornado-induced pressure is established with data from the experiments in the tornado simulator, and two different methods are employed to determine the maximum pressure induced by ABL winds, including 1) $C_p$ or ($GC_p$) from ASCE 7-22 and 2) $C_p$ or ($GC_p$) estimated from ABL wind tunnel study. In addition, as the $K_{vT}$ factor exclusively accounts for wind-induced pressure, the static pressure deficit from the vortex was subtracted from the total pressure, and only the aerodynamic pressure caused by the wind velocity was compared.

## PRELIMINARY RESULT

Figure 2 shows a preliminary comparison of the pressure coefficients caused by (a) the tornado-like vortex and (b) ABL wind from the tunnel tests. The tornado pressure coefficient ($\langle C_{p,T} \rangle$) in Figure 2(a) and (c) represent the ensemble average of the instantaneous pressure coefficient over 100 repetitions when the building model is located at $x/r_c$ = 0.75 and 1.2, respectively, for test configuration of $S$ = 0.83, $y/r_c$ = 0, $\beta$ = 0°, and $U$ = 1.25 m/s. Figure 2(b) and (d) show the contour plots of the mean ABL pressure coefficient ($\bar{C}_{p,A}$) with corresponding mean wind direction. The four figures show an evident increase in the magnitudes of the mean aerodynamic tornado pressure coefficient from the mean ABL pressure coefficient at different locations. Preliminary results suggest that ASCE 7-22 $K_{vT}$ values may be underestimating the additional tornado uplift pressures on the roof. Moreover, a significant increase in pressure is also shown on the windward walls, whereas the pressure adjustments for walls are not considered (i.e., $K_{vT}$ = 1.0) in the current building codes. A comprehensive analysis with more test configurations is currently underway to assess the accuracy of the $K_{vT}$ values in ASCE 7-22.

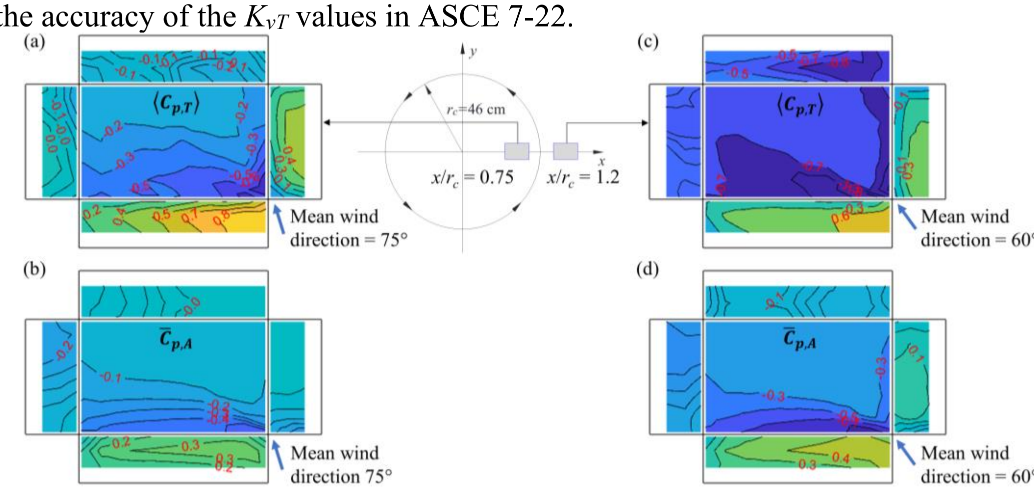


Figure 2. Contour plots of the (a) ensemble averaged tornado $C_p$ at $x/r_c$ = 0.75, (b) mean ABL $C_p$ at wind direction of 75°, (c) ensemble averaged tornado $C_p$ at $x/r_c$ = 1.2, and (d) mean ABL $C_p$ at wind direction of 60°.