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Assessment of Tornado loading on A Building Considering Transient Internal Pressure

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SUMMARY

Tornadoes cause extensive damage to buildings. Due to the significant pressure drop in tornadoes, the loading that causes the damage is significantly influenced by the openings in the building envelop, which affects the internal pressure. Currently, the transient internal pressure caused by a sudden breach of the building envelop due to either wind loading or impact by wind-borne debris is not understood. In this study, a building model was tested in a tornado simulator to investigate the characteristics of transient internal pressure resulting from a suddenly appearing dominant opening in a wall of the model. The results of the study suggest that the wind loading with contribution from the transient internal pressures is not significantly different from that with contribution from the internal pressure of a building model with a permanent dominant opening.

Keywords: low-rise building, tornado loading; transient Internal pressure

1. INTRODUCTION

Wind loading on a building can have a significant contribution from the pressure inside the building (internal pressure). For this reason, numerous studies have been conducted to understand the characteristics of the internal pressure and the dependence of these characteristics on the major factors, including the size(s) and location(s) of the dominant opening(s) in the building envelope, the amount of background leakage, the compartmentalization of the internal space of the building, and the flexibility of the building envelope (e.g., Ginger et al, 1997; Holmes, 1979; Kopp et al, 2008). However, only a limited number of studies investigated the internal pressure of buildings in tornadoes. Rajasekharan et al (2013) measured the internal pressure of a building model in tornado-like vortices generated by a tornado simulator and examined the dependence of the internal pressure on the porosity of the building envelope with background leakage, the size of the dominant opening, the location of the building relative to the vortex, and the roughness of the surroundings. Experiments like these did not simulate the translation of the vortex relative to the building model. Consequently, their outcomes do not address the performance of buildings in full-scale translating tornadoes. A few other experimental studies have investigated the internal pressure of building models exposed to translating tornado-like vortices (e.g., Roueche et al, 2020; Sabareesh et al, 2019). It is revealed that the translation of the vortex can indeed significantly affect the internal pressure in low-rise building models. Regardless of whether the experiments were conducted in stationary or translating tornado-like vortices, however, the previous studies of the internal pressure of buildings in tornadoes dealt with the scenario in which the major opening is permanently built into the building envelope and does not address the situation in which a large opening is suddenly created in the building envelope to cause transient pressure inside the building. The following presents an experimental study to characterize the transient internal pressure of a low-rise building model that translates relative to a tornado-like vortex.

2. EXPERIMENTAL SET-UP

The experiments were performed in a large-scale Ward-type simulator(Ward, 1972), ”VorTECH”, at Texas Tech University, which has a testing chamber of 10.2 m in diameter and an updraft hole of 4 m in diameter. It has been shown in previous studies that this simulator can generate vortices which cause surface pressures that are similar in characteristics to the surface pressures measured in full-scale tornadoes (Tang et al, 2018). The center section of the simulator floor is mounted on an aluminum truss system, which can be driven by an electrical motor to move relative to the other parts of the floor and the generated vortex at constant velocities up to 1.47 m/s over a distance of at least 5 m.

In the experiments, a 1:200 model of a building (Figure 1) with an augmented internal volume that satisfies the volume scale specified in Holmes (1979) was tested in a vortex with a swirl ratio of 1.88, a maximum mean tangential velocity of 12.88 m/s and a core radius (distance between the location of the maximum mean tangential velocity and the axis of the vortex) of 0.88 m. The model has holes of 1 mm built into its envelope to represent the background leakage in a building. In addition, a large opening representing a failed large overhead door is also built into a wall of the model. A mechanical shutter system similar to that used in Stathopoulos and Luchian (1989) was used to enable the sudden appearance of this opening in the wall. The building model was mounted on the moving section of the simulator floor and translated along various paths relative to the tornado-like vortex. The speed of the translation was varied to enable an assessment of this factor on the loading. The pressures at 216 taps on the external surface of the building and 2 taps on the internal surface of the building were measured by a Scanivalve pressure scanner during the translation of the model. Because the wind velocity and pressure fields in the tornado-like vortex are spatially inhomogeneous, the loading on the translating model is nonstationary. For this reason, 200 repeat test runs for each experimental configuration, and a combination of ensemble averaging and adaptive Gaussian kernel regression was used to estimate the position varying mean, standard deviation, skewness and kurtosis of the pressures and resultant forces.

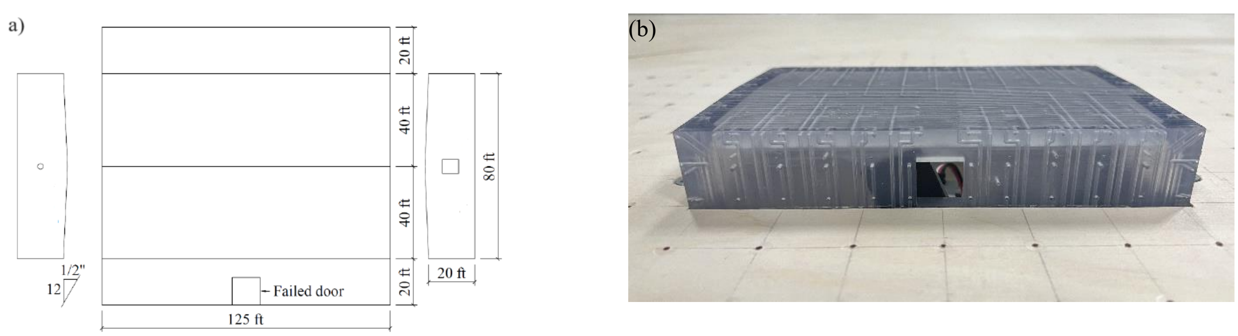


Figure 1 a) Dimension of prototype building; (b) building model

3. EXPERIMENTAL RESULT

Figure 2 shows the mean wind velocity field of the vortex, which is normalized by the maximum mean tangential velocity. The arrows represent the resultant of the axial and radial components of the mean wind velocity and the color represents the mean tangential component of the velocity. To characterize the loading on the model, all the pressures, which are reference to the far field static pressure, are normalized by $0.5\rho V_{\theta,\max}^2$ to yield the corresponding pressure coefficients and the estimated resultant uplift force are normalized by $0.5A\rho V_{\theta,\max}^2$ to yield the corresponding force coefficient. Here ρ is air density, $V_{\theta,\max}$ is the maximum mean tangential velocity and A is projected roof area. Figure 3 a), b), c), and d) show the position varying mean value, variance, skewness, and kurtosis of the internal pressure coefficient when the tornado translated at 1.25m/s through the center of the vortex. The legends "PDO+BL", "SDO035+BL", and "SDO089+BL", represent the model with background leakage and a permanent door opening, background leakage and the door suddenly opening at the location of 0.35 core radius before reaching the vortex center, and background leakage and the door suddenly opening at the location of 0.89 core radius before reaching the vortex center, respectively. It is observed that the mean value and the variance of the internal pressure coefficient suddenly change when the dominant opening appears and that after the appearance of the dominant opening, these two statistics of the internal pressure are very close to the corresponding characteristics of the internal pressure when the dominant opening is permanently present during the translation of the model. Similarly, the uncertainty in the estimates of the statistics notwithstanding, the skewness and kurtosis of the internal pressure after the sudden appearance of the dominant opening are similar to those of the internal pressure over this region when the dominant opening was always present. Table 1 presents the estimated mean peak uplift force. It is apparent again that the transient effect of the internal pressure due to sudden appearance of the dominant opening does not cause the mean peak uplift force to be significantly different form the mean peak uplift force when the dominant opening is permanently present.

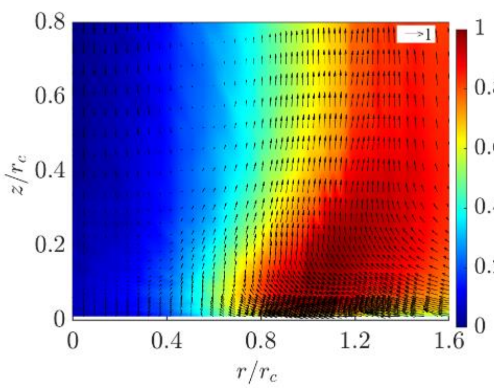
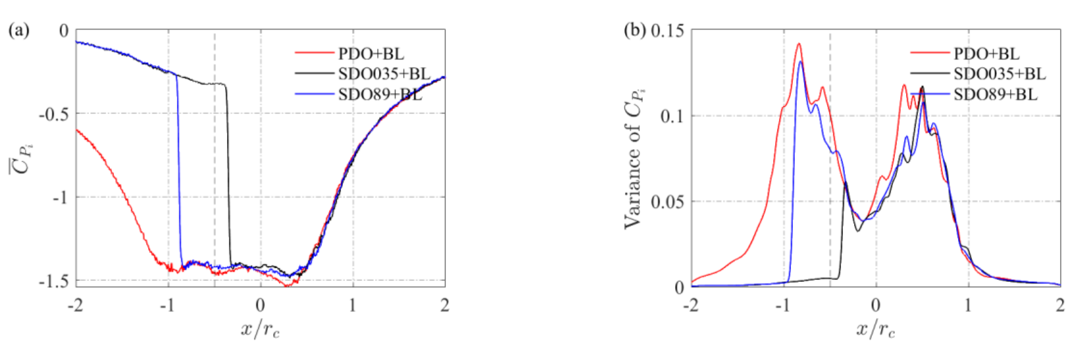


Figure 2 Mean flow velocity field of the tornado-like vortex

Table 1. Estimated peak net uplift force coefficient

	SDO035+BL	SDO089+BL	PDO+BL
C_{Fz}	3.50	3.53	3.63



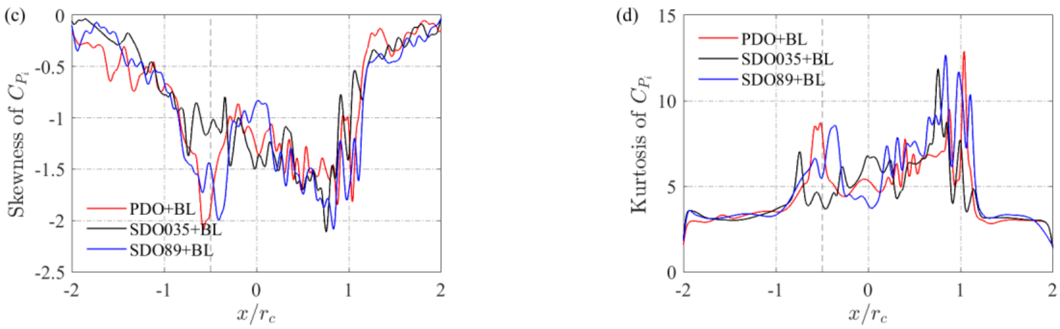


Figure 3 a) mean value, b) variance, c) skewness, and d) kurtosis of the internal pressure for various opening configurations.

4. CONCLUSION

An experiment is conducted in a tornado simulator to test a building model with a suddenly appearing dominant opening when it translates through a tornado-like vortex. The results suggest that a suddenly appearing dominant opening in the building envelope does not significantly affect the loading on the building when compared with the case when the dominant opening is permanently present.

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