Downburst aerodynamic loading effects on low-rise building

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SUMMARY:
Downbursts winds are extreme wind hazards characterized by non-stationary, transient, and localized nature. They constitute significant damage to structures. A downburst event represents a downdraft of cold air that impinges on the ground, causing a main rolling vortex and outflows of high velocities and turbulence intensities near the ground that greatly affect low-rise buildings. To assess the complexity of the non-stationary downburst aerodynamics, a 1:20 scale model of the Texas Tech University Wind Engineering Field Research Laboratory (TTU WERFL) building was tested against downburst wind loads produced by the large-scale downburst simulator at the National Science Foundation (NSF)-designated facility, the Wall of Wind (WOW). The downbursts simulations were carried out for different static (not rotating during the lifetime of each event) wind directions similar to the real downburst recorded in Lubbock, Texas, on June 19th, 2003, with wind directions ranging from 239.75° to 332° NW. Each of these wind directions is analyzed independently. The present study presents the instantaneous 3-sec filtered pressure coefficients. The aim is to reveal important information on downburst loading, wind direction effect, positioning of the peak height compared to the building mean roof height, and the non-Gaussian characteristics in the velocity and pressure time histories.

Keywords: Downburst, Buildings, Aerodynamics.

1. INTRODUCTION

The structural behavior of low-rise buildings subjected to high-intensity wind events (HIW), such as downbursts, is not yet well understood. Only a few wind researchers (Asano et al., 2019; Jubayer et al., 2019; Lombardo et al., 2018; Mason et al., 2009; Zhang et al., 2014) have experimentally investigated downburst aerodynamics on low-rise buildings. These studies also indicate that critical wind loads for downbursts surpass the Atmospheric Boundary Layer (ABL) wind loads. They also found that the non-stationary nature, high wind velocity near the ground, the presence of a main rolling vortex, and nonstationarity existing in the varying wind direction of the outflow constitute a great danger to low-rise buildings. The spatial and temporal localization of downbursts makes predicting critical peak loads on low-rise buildings very difficult. For this reason, it is important to investigate the peak pressure coefficients of downbursts on low-rise buildings by taking into consideration the different downburst parameters such as the local maximum velocity, the evolution of the wind velocity profile, the size of the rolling vortex outflow, and the location of the building structure relative to the wall jet initiation location. In the case of thunderstorms, wind loads from downbursts and tornadoes, as opposed to ABL synoptic straight-line winds, not only the magnitude of the wind velocity is vital, but also the outflow structure of the downburst, as this rolling pattern impacts the structure greatly. Previous downburst experiments at the Wall of Wind (WOW) have shown that the peak factors in the roof and wall flow separation and wake regions are usually very large. The influence of downbursts is not yet accounted for in most of the current design standards including the ASCE 7-22 standard. For this reason, this paper aims to further investigate the effect of varying wind angles of attack, on the resulting peak downburst pressure coefficients measured on a scaled model representing a low-rise building.

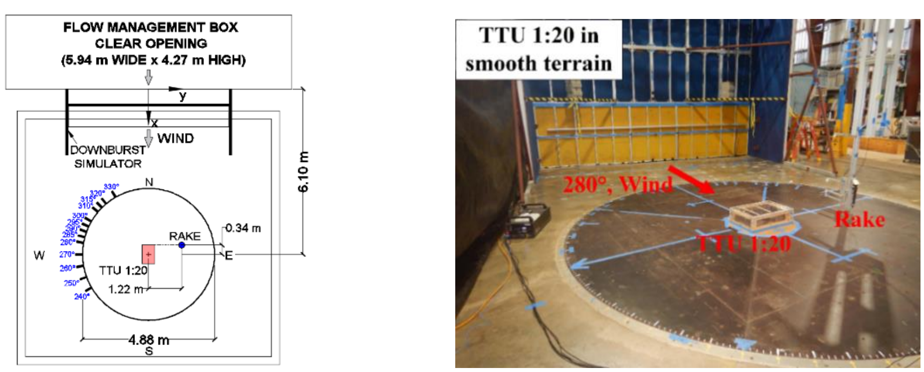
2. EXPERIMENTAL SETUP

2.1 Wall of Wind Experimental Facility

The NSF-Natural Hazards Engineering Research Infrastructure (NHERI)-WOW Experimental Facility at Florida International University in Miami, USA, is a large-scale, open jet wind testing facility capable of replicating hurricane winds up to Category 5 on a Saffir-Simpson scale (Chowdhury et al., 2017). The WOW consists of a 12-propeller fan matrix configuration arranged in 2 rows by 6 columns blowing large volumes of wind into a contraction section followed by a rectangular section with a cross-sectional area of 5.94 m wide by 4.3 m high. The longitudinal fetch of the flow management box is 9.75 m. The distance from the exit of the flow management box to the turntable center (TTC) is 6.1 m.

2.2 Downburst simulator at the Wall of Wind

A large-scale downburst simulator is placed directly in front of the existing WOW flow management box outlet, as shown in Figure 1. The downburst simulator can produce large-scale downburst-like outflows traveling through the test section of the WOW. The downburst-like outflow enables structural testing under non-stationary winds. The downburst simulator at the WOW adopts the 2-D wall jet method. Simulator specifics and design techniques can be found in (Mejia et al., 2022).



(a) (b)

Figure 1. (a) Plan view (b) Aerodynamic testing of TTU 1:20 model at WOW

2.3 Scale Building model

A 1:20 scaled model of the Texas Tech University Wind Engineering Field Research Laboratory (TTU WERFL) building was subjected to downburst outflows with wind directions varying from

240° to 330° in 10° intervals, considering the same wind directions that occurred to the full-scale building on June 19th, 2003, in Lubbock, Texas. The TTU WERFL building model was placed on the turntable center (TTC) of the WOW testing section, and several outflow tests were conducted. 204 pressure taps were connected to a Scanivalve ZOC33 pressure scanner. Velocity measurements were obtained with a Cobra probe placed at the 0.198 m eave height, the reference height, of the building model and positioned 1.22 m east and 0.34 m north from the center of the turntable. The sampling frequency for the pressure and velocity measurements was 625 Hz, and the estimated duration of the slats opening was 3 sec.

3. RESULTS

The instantaneous 3-sec pressure coefficients for each of the 204 pressure taps were determined at the time step when the northwest corner roof tap had the most suction. In Figure 2(a,b), it is shown the instantaneous 3-sec pressure coefficients $\bar{C}_{p,3\text{sec},inst.}$ at 280° wind direction for the TTU 1:20 scaled building model tested at the WOW and the full scale TTU building.

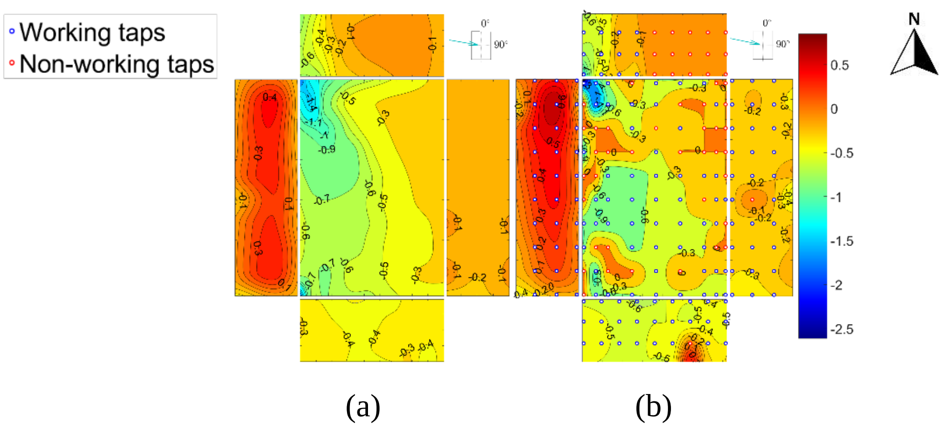


Figure 2. Instantaneous filtered 3-sec pressure coefficients, $\bar{C}_{p,3\text{sec},inst.}$ at 280° wind direction for the TTU building: (a) TTU 1:20 scaled building model and (b) Full-scale TTU.

To obtain the instantaneous 3-sec pressure coefficient values, the following Eq. (1) is used:

$$\bar{C}_{p,3\text{sec},inst.} = \frac{[p(t_{peak}) - p_{static}]_{3\text{sec}}}{{}^{1}/_{2} \cdot \rho_{air} \cdot \bar{U}^{2}_{3\text{sec,max}}} \qquad (1)$$

where p is the observed pressure value measured at the time of instant t_{peak} at which the roof corner tap experiences the maximum suction and p_{static} is the static pressure; the pressure differentials (p-p_{static}) are filtered with a 3-sec time average; $\bar{U}_{3\text{sec,max}}$ is the maximum 3-sec moving mean wind velocity in the downburst outflow at the building eave height. In Figure 2 it is shown that the instantaneous pressure coefficient distribution is similar between the full-scale and the scaled TTU building model. To assess the non-Gaussian characteristics in the reduced velocity and pressure fluctuations, the following Eq. (2) and Eq. (3) are used:

$$\widetilde{u'}(x, y, z, t) = \frac{u'(x,y,z,t)}{\sigma_{u'}(x,y,z,t)} \qquad (2)$$

$$\tilde{C}'_{p,3\text{sec}} = \frac{C'_{p,3\text{sec}}}{\sigma_{C'_{p,3\text{sec}}}(x,y,z,t)} \quad (3)$$

where $\widetilde{u}'(x,y,z,t)$ and $\tilde{C}'_{p,3\text{sec}}$ are the reduced velocity and 3-sec pressure coefficient fluctuations, u' and $C'_{p,3\text{sec}}$ are the residual velocity and 3-sec pressure coefficient fluctuations and $\sigma_{u'}$ and $\sigma_{C'_{p,3\text{sec}}}$ are the standard deviations of the velocity and 3-sec pressure coefficient fluctuations. In Figure 3(a,b), it is shown the Probability Density Function found in the TTU 1:20 scale building model experiment for the velocity and pressure coefficient at the North-West corner.

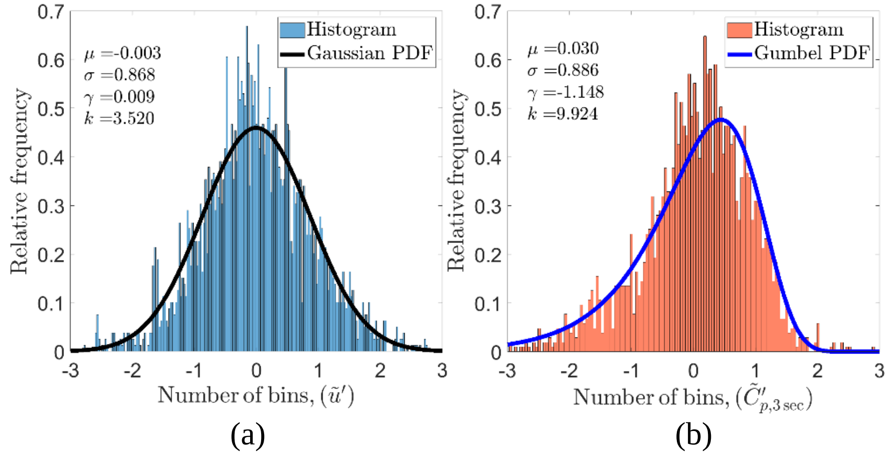


Figure 3. Probability Density Function of (a) velocity at eave height and (b) 3-sec pressure coefficient at NW tap for TTU 1:20 scale building model.

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