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An experimental study on wind loads acting on a high-rise building model induced by microburst-like winds

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ABSTRACT

In the present study, an experimental investigation is conducted to quantify the characteristics of the microburst-induced wind loads (i.e., both static and dynamic wind loads) acting on a high-rise building model, compared to those with the test model placed in conventional atmospheric boundary layer (ABL) winds. The experimental study is performed by using an impinging-jet-based microburst simulator available at Iowa State University. In additional to conducting flow field measurements to quantify the flow characteristics of the microburst-like wind, both mean and dynamic wind loads acting on the test model induced by the microburst-like wind are assessed in detail based on the quantitative measurements of the surface pressure distributions around the test model and the resultant aerodynamic forces. It is found that the microburst-induced wind loads acting on high-rise buildings would be significantly different from their counterparts in conventional ABL winds. Both the static and dynamic wind loads acting on the high-rise building model were found to change significantly depending on the radial locations and the orientation angles of the test model in respect to the oncoming microburst-like wind. The dynamic wind loads acting on the test model were found to be mainly influenced by the periodical shedding of the primary vortices and the high turbulence levels in the microburst-like wind. The findings derived from the present study are believed to be useful to gain further insight into the underlying physics of the flow–structure interactions of high-rise buildings in violent microburst winds for a better understanding of the damage potential of microburst winds to high-rise buildings.

1. Introduction

High-rise buildings are commonly designed to resist extreme wind conditions with long lifespans. Although catastrophic structural failures induced by strong winds are almost unlikely to occur, researches about wind loading effects on high-rise buildings are still more than necessary from serviceability and economic points of view. Local wind damages, such as broken glass and local component failures for high-rise buildings, could be induced by extreme winds due to the effects of either the external pressure fluctuations or wind-borne debris. To better understand the mechanisms of wind-induced static and dynamic loads and reduce the risk of damage, wind tunnel testing has been carried out by many researchers and proven to

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be an effective tool to investigate wind loads acting on high-rise buildings. For example, Melbourne (1980) compared the measurement results of pressure distributions and force responses on the CAARC (i.e., Commonwealth Advisory Aeronautical Research Council Coordinators) standard rectangular tall building model (Wardlaw and Moss, 1970) from six establishments and obtained a good consistency among different research groups. Tanaka and Lawen (1986) studied the same building model with a different scale (1:1000) and concluded that almost no deficit could be found due to the exaggerated small length scale of the test model. Lin et al. (2005) conducted extensive experiments to study the local wind loads on nine high-rise building models with different rectangular cross-sections and revealed different parametric effects on wind loadings. Fruitful research accomplishments have also been achieved over the past years covering a wide variety of interesting topics related to wind loadings effects on high-rise buildings, such as across-wind responses of tall buildings (Kwok, 1982; Kawai, 1992; Marukawa et al., 1992; Kareem, 1992), mitigation of cross-wind response by aerodynamic modifications (Kwok, 1988; Kim et al., 2008; Kim and Kanda, 2010), and interference effects on wind loads among multiple high-rise buildings (Sykes, 1983; Kareem, 1987; Taniike, 1992; Lam et al., 2011). While most of those previous studies were performed with atmospheric boundary layer (ABL) winds, a great amount of wind hazards, however, could be contributed by other non-conventional ABL winds. Chen and Letchford (2004) compared the maximum dynamic magnification factor (MDMF) of the CAARC building model induced by standard wind profile and conceptual generic downburst wind profiles. Sengupta et al. (2008) performed a laboratory test to study the transient loads of a cubic building in a translating tornado and microburst winds. Both tornado and microburst loads were found to exceed the design standard of ASCE 7-05. Yang et al. (2011) studied the flow–structure interactions and the resultant wind loads acting on a high-rise building model in a tornado-like wind. Nevertheless, the investigations on the wind loading effects on high-rise buildings induced by extreme non-conventional ABL winds are still very scarce and “the impact of these ‘non-standard’ wind profiles on tall buildings needs further research” as suggested by Irwin (2009).

Extreme winds can be produced either by tropical cyclonic systems, such as typhoons or hurricanes, or by localized severe weather conditions, such as thunderstorms. Compared with the tropical storms, local wind storms are usually more devastating to the affected area and much more difficult to predict due to the small length scale and short lifespan. Downburst is one kind of such local storms usually hidden within a thunderstorm, whose flow regime is analogous to a “reversed tornado”. As a tornado causes a low-pressure core and sucks air inwards and upwards (Yang et al., 2011), a downburst, originated from an intense downdraft of air, usually produces radial outburst winds due to the high pressure in the core (Chay and Letchford, 2002; Zhang et al., 2013a, 2013b). More specifically, Fujita (1985) defined that a microburst is a MISO-scale downburst which extends less than 4 km radially. It could cause a damaging outburst wind speed up to 270 km/h (168 mph) based on the information available at NOAA website of http://www.erh.noaa.gov/cae/svrwx/downburst.htm. Fig. 1 shows schematically the flow features of a microburst along with the relative scales of a low-rise building and a high-rise building compared with the outburst profile of the microburst. Basically, the flow field of a microburst can be divided into four regions according to different flow characteristics, i.e., downdraft region, stagnation region ($r/D \leq 0.5$), transition region ($r/D \approx 0.5$–1.0), and outburst region ($r/D \geq 1.0$), where r denotes the radial distance from the microburst center and D denotes the diameter of the downburst jet flow as shown in Fig. 1. A microburst wind usually has the following characteristics: (1) high static pressure in the stagnation region. This is often referred to as the “pressure nose”, which is opposite to the pressure drop in a tornado core. (2) Impinging-jet-like flow characteristics in the outburst region. A microburst can produce an impinging-jet-like outflow profile diverging from its center with the maximum velocity occurring at an altitude of less than 50 m above the ground (Hjelmfelt, 1988). The velocity profile of a microburst wind no longer follows the log-law function of conventional ABL winds. (3) High turbulence levels and strong wind shear near the ground in the outburst region. Due to the strong shear at the jet–ambient interface, turbulence levels in the outburst region of a microburst could be much higher than those in ABL winds. As shown in Fig. 1, since the height of high-rise buildings is

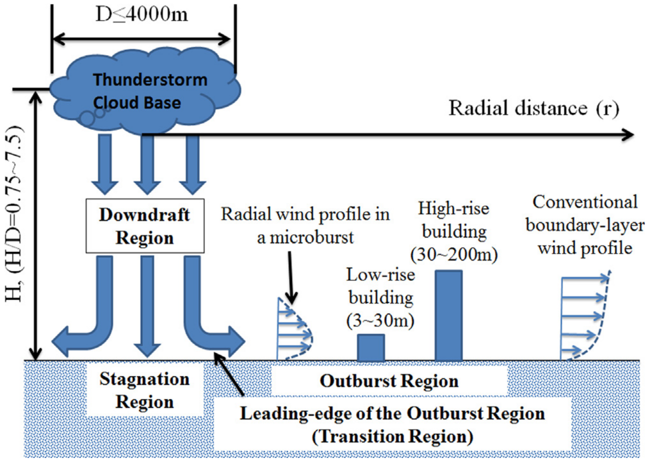

Fig. 1. Schematic of a microburst.