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Transient loads on buildings in microburst and tornado winds

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Abstract

This paper presents both quasi-steady and transient wind load effects on a cubic building in a microburst and a tornado. Large eddy simulation (LES) was used to simulate the loading effects of a translating microburst with a 0.20-m-diameter jet at four different translating velocities on a 25 mm cube. The results of the numerical simulation were compared with data from a laboratory microburst simulator. The numerical simulation predicted an increase in drag forces with increase in microburst translation speed. The transient loading effects on a 229 mm cubic building from a translating tornado were also simulated in a laboratory for two different vortex core diameters and two translating speeds and the peak loads were studied. Results for the cubic building were compared with that of a tall building under the same loading conditions. Finally, peak loads and peak moments measured in this study were compared to the corresponding values specified in ASCE 7-05 [2006. Minimum Design Loads for Buildings and Other Structures, 2006. ASCE Standard, SEI/ASCE 7-05, American Society of Civil Engineers] and found to exceed them by a factor of 1.5 or more for buildings located in tornado alley of the United States subjected to tornadoes of F2 or higher intensity.

Keywords: Microburst; Tornado; LES; Peak loads; Transient effects; Cubic building

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1. Introduction

Low-speed boundary-layer wind tunnels generating straight-line winds have been used for a long time to develop design wind loads for buildings and other structures. Velocity fields resulting from some extreme wind events such as thunderstorms, microbursts, and tornados, however, are far from conventional atmospheric boundary-layer-type events. This paper reports measurements made on a cubic building model in simulated microburst (both numerical and experimental) and tornado (experimental) flow fields. These measurements are compared with forces predicted with the wind loading provisions of ASCE 7-05 (2006) as well as with a tall building under the same tornado flow fields. This section presents a brief introduction to these types of simulations.

1.1. Review of microburst

Microbursts occur in thunderstorms where the weight of the precipitation and the cooling due to microphysical processes act to accelerate the air downwards. They are characterized by a strong localized down-flow and an outburst of strong winds near the surface as the downdraft air is forced to spread horizontally near the ground level. Selvam and Holmes (1992) undertook numerical modeling of the thunderstorm downdraft phenomenon and were able to demonstrate reasonable agreement between a numerical model and limited full-scale data. Later, Holmes (1999), Letchford and Illidge (1999) and Sengupta and Sarkar (2006) undertook physical model studies of a jet impinging on a wall and again found reasonable agreement between the numerical model, physical model and full-scale observations of a jet outflow velocity profile. The following equation gives the normalized profile of horizontal velocity as measured by them in the form suggested by Wood et al. (2001)

$$\frac{U}{U_m} = C_1\left(\frac{z}{b}\right)^n\left[1 - \mathrm{erf}\left(C_2\frac{z}{b}\right)\right]. \tag{1}$$

where $C_1 = 1.52$, $C_2 = 0.68$ and $n = 1/6.5$; z is the elevation from the ground; D the diameter of the jet at the nozzle exit region; U the horizontal velocity at z; U_m the maximum horizontal velocity at a specific r/D; b the elevation from the ground at which $U = U_m/2$. The range of r/D for which the proposed empirical profile is valid is $0.75 \leqslant r/D \leqslant 3.00$. Microburst outflow characteristics have been studied by Lin and Savory (2006) and Kim and Hangan (2007). Physical and numerical simulations of microbursts to study their effects on scaled models of buildings have been conducted by Letchford and Chay (2002), Nicholls et al. (1993), Sengupta et al. (2006) and Sengupta and Sarkar (2007).

1.2. Review of tornado

Tornadoes are vortices with significant rotational velocity along with vertical and radial velocity components in the core region. Therefore, tornado flow fields are also much different from the straight-line boundary-layer wind. Many laboratory simulator designs have been based on the pioneering work of Ward (1972). Subsequent efforts—based on the Ward model—at the Purdue University (Church et al., 1979), the University of Oklahoma (Jischke and Light, 1983) and that of Davies-Jones (1976) employed various means to improve the similarity between laboratory simulations and full-scale tornado events. These