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Effects of Various Opening Configurations on Tornado-Like Loading on a Low-Rise Building Model

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ABSTRACT

This study investigates tornado-like loading on a low-rise building with various opening configurations in its envelope. Based on the testing of a building model in a two-celled tornado-like vortex, the effects of the openings on the internal pressure in the building and resultant forces are revealed. The differences in the effects of different opening configurations are also quantified.

BACKGROUND

Because openings in the envelope of low-rise buildings can significantly affect the internal pressure in buildings, numerous studies have been conducted to investigate the dependence of the internal pressure on opening characteristics. These investigations have led to discoveries such as the phenomenon of internal pressure resonance in buildings with a large opening. However, most research on internal pressure has focused on buildings in boundary-layer type winds, and the study of internal pressure in buildings under tornadic loading has been limited. This paper presents an investigation of internal pressure in a low-rise building model with various opening configurations and the characteristics of the overall loading when it is subjected to a tornado-like vortex.

METHODOLOGY

The study is based on testing of a low-rise building model in a two-celled tornado-like vortex generated by a tornado simulator. The tests were conducted with three configurations of the model envelope: fully enclosed (“FE”), with background leakage (“BL”) only, and with a dominant opening (“DO”) only. For each envelope configuration, the model translated at a speed of 1.25 m/s along a path that passes through the center of the vortex. The dominant opening with an opening ratio of 0.63% is located in a wall of the model, and the background leakage is represented by holes of 1 mm in diameter that are distributed over the roof and walls. The porosity ratio of the background leakage is 0.065%. The results presented in the following are based measurements of pressures on the external and internal surfaces of the model.

REPRESENTATIVE RESULTS

Figure 1 shows the evolutionary power spectral density (EPSD) function of internal pressure when the model with the two different opening configurations translates along a line through the center of the vortex. Here x is the radial position and r_c is core radius of the vortex. Significant internal pressure fluctuation at frequencies close to 50 Hz can be observed for the model with a dominant opening only but not for the model with background leakage only, indicating internal pressure resonance occurring for the model with a dominant opening. In addition, the low-frequency fluctuation of the internal pressure is much more pronounced for the model with a dominant opening than for the model with background leakage only. This reflects the fact that the small openings representing background leakage attenuates the effect of the external pressure fluctuation on the internal pressure. A frequency component at about 2.73 Hz is present in the internal pressure of the model with both types of opening. This is caused by a narrowband component of the same characteristic frequency in the tornado-like flow.

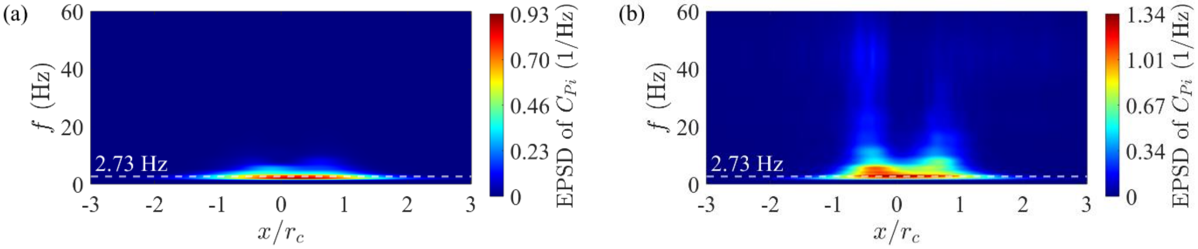

Figure 1 EPSD of internal pressure in the model with (a) BL and (b) DO

Figure 2 shows the mean and variance of internal pressure for the two opening configurations. It is seen that when the model is at positions where x/r_c<-0.23, the magnitude of the mean internal pressure in the model with background leakage is larger than that of the model with a dominant opening. This is due to the positive dynamic pressure at the location of the dominant opening when the model is at these positions. Figure 2 also shows that the internal pressure fluctuation in the model with a dominant opening is much more intense than that in the model with background leakage only, which is consistent with what is observed in Figure 1. Figure 3 shows the histograms of the peak uplift forces based on data from all test runs. It is seen that most of the peaks occurred inside the core area. For the model with a dominant opening, the peaks occurred only when x/r_c<0. However, peaks occurred on both sides of the center of the vortex for the fully enclosed model and the model with background leakage only. The mean peak uplift force is the largest when the model is fully enclosed and smallest when the model has background leakage only.

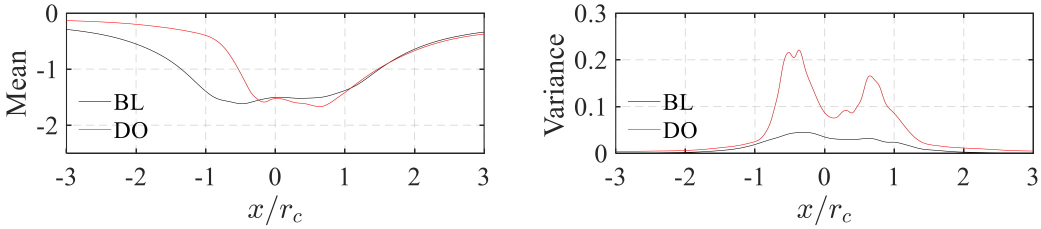

Figure 2 Mean and variance of internal pressure in the model with different opening configurations

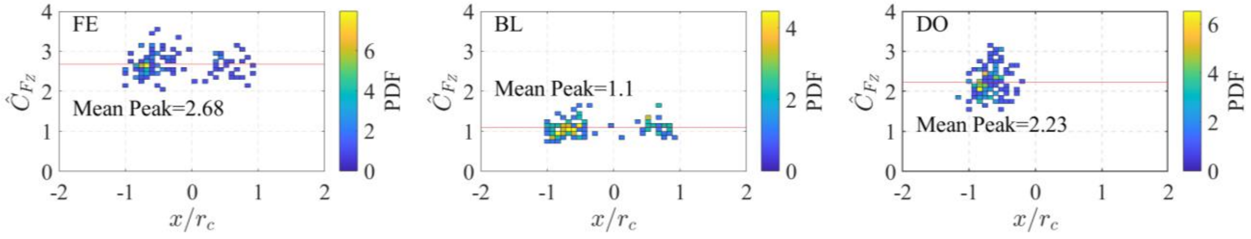

Figure 3 Histogram of peak uplift forces on the model with different envelop opening configurations