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Effects of Openings and Translation Speed on Tornado-Like Loading of a Low-Rise Building Model

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ABSTRACT
Experiments were conducted in a large-scale tornado simulator to study tornado-like loading on low-rise buildings. A building model with various configurations of openings in its envelope was tested in a two-celled tornado-like vortex to examine the effects of building openings on the loading. For each opening configuration, the pressure acting on the model was measured while it translated across the vortex. The speed at which the model translated was varied to evaluate its effect on the loading. The model was also tested at various fixed locations in the vortex to provide a context for the interpretation of the loading on the translating model. The outcome of the research reveals that the presence of openings in the building envelope significantly changes the uplift force. It also suggests that the translation speed of the model affects both the external pressures and the internal pressures, resulting in changes to the characteristics of the loading on the model.

BACKGROUND
The presence of large openings in the envelope of a low-rise building, such as those created by debris impacts during windstorms, can significantly affect the pressure inside the building. Many studies have been conducted to investigate the internal pressure of a building with dominant openings in boundary layer type winds and its effect on the overall wind loading. Those have led to findings such as the existence of internal pressure resonance when the building envelope has a large opening. However, Studies of internal pressure of buildings during the passage of tornadoes have been limited. This paper presents an investigation of internal pressure of a building model and the characteristics of the loading on the model when it is subjected to a tornado-like vortex.

METHODOLOGY
The study is based on experiments in a large-scale tornado simulator. In the experiments, a model of a low-rise building was tested in a two-celled vortex. The tests were conducted with three configurations of the model envelope: fully enclosed, with background leakage, and with both background leakage and a dominant opening. For each envelope configuration, the model was translated at two speeds (0.25 m/s and 1.25 m/s) each along two lines that traverses different regions in the vortex. The characteristics of the internal pressure and the overall tornado-like loading on the translating model are interpreted and compared to those on a model that was fixed at various locations in the vortex.

REPRESENTATIVE RESULTS
The experiments revealed different characteristics of the internal pressure when the model was stationary on the simulator floor and when it translates through the vortex. For example, Fig. 1 (a) shows the power spectral density (PSD) function of the internal pressure and that of the external pressure around the dominant opening when the model with a dominant opening was fixed at a

location that is a core radius from the axis of the vortex, and Fig. 1 (b) and (c) show the evolutionary power spectral density (EPSD) function of the internal pressure when the same model traversed along a line through the center of the vortex. The EPSD is shown over the specific ranges to highlight the particular frequency contents. While the pressure inside the stationary model shows a clear sign of resonance with a characteristic frequency close to 55 Hz, no sign of internal pressure resonance can be observed for the translating model. However, A frequency component at about 2.7 Hz is present in the internal pressure both when the model was stationary and when it translated across the vortex. This component in the loading was caused by a narrowband component of the same characteristic frequency in the tornado-like flow.

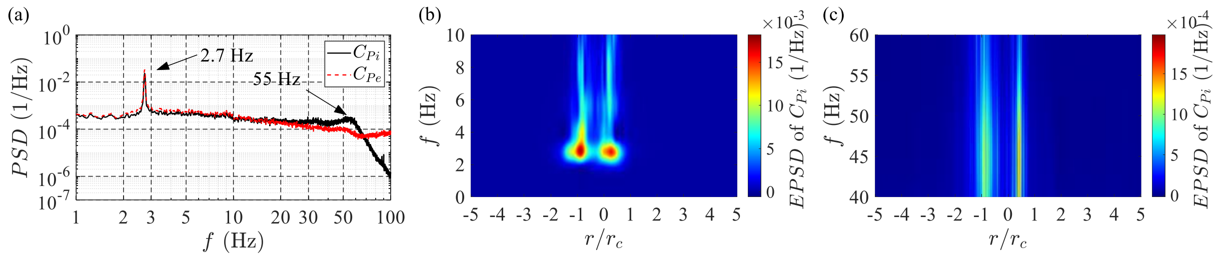

Fig. 1 (a) *PSDs* of internal (C_{pi}) and external (C_{pe}) pressure coefficients of the stationary model and *EPSD* of the pressure inside the translating model over the frequency ranges of (b) 0~10 Hz and (c) *EPSD*, 40~60 Hz

Fig. 2 (a) shows the position-varying mean values of the uplift force coefficeints (C_L) of the translating model with the three envelope configurations. The translation speed was 0.25 m/s. It is apparent that the mean lift force reached the maximum value when the model is fully enclosed. This is because the varying negative (relative to the reference pressure outside the simulator) mean static external pressures over the roof of the model is partially offest by the the negative internal pressure when the model has openings on its envelope but not by the mean internal pressure in the fully enclosed model. The fact that uplift force of the model with a dominant opening reached higher values than did that of the model with background leakage is because the mean dynamic pressure in the model with a dominant opening is larger than the mean dynamic pressure in the model with background leakage only. Fig. 2 (b) shows the position varying standard deviations of the uplift force coefficients of the translating model. It is seen again that the standard deviation was the largest when the model was fully enclosed.

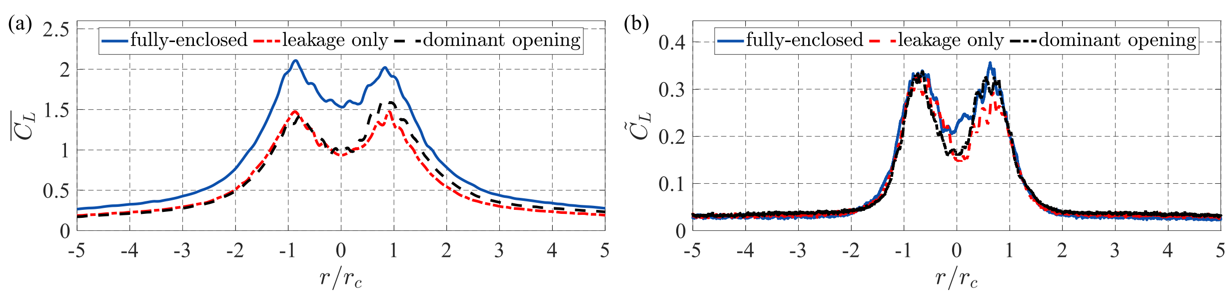

Fig. 2 position-varying (a) mean values and (b) standard deviations of the uplife force coefficeints of the model with three envelope configurations translating at 0.25 m/s

More detailed results from the experiemental investigation will be presented in the full paper.