The 2024 World Congress on
The 2024 Structures Congress (Structures24)
19-22, August, 2024, The K hotel, Seoul, Korea

Fragility Modeling of Tall Buildings subjected to Windborne Debris during Hurricanes

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ABSTRACT

Windborne debris is a primary cause of damage to tall buildings envelopes under hurricanes. Under strong winds, windborne debris can become a high speed missile breaking cladding systems and building façades, including glass window panes and doors. The localized high impact energy of these windborne missiles may also injure building occupants. Furthermore, broken glass and damaged wall panels can become a secondary source of debris and result in cascading effects thereby inducing even more damage to a building. The existing debris damage assessment models for tall buildings often neglect the geometries of building clusters for simplification purposes. However, these simplified methods may introduce significant uncertainty for urban tall buildings with complex geometries and distributions. To address the shortcomings of the existing models, this paper proposes a new fragility model to assess non-structural damage to tall building envelopes caused by windborne debris from hurricane wind. This new model explicitly considers both the individual building geometries and the complex surrounding environment. To develop this fragility model, a physical model of windborne debris damage, which models the wind field around buildings, debris generation, trajectory and impact, is first established. The gravel on the rooftop is specifically considered in this study for modeling. The wind field on the building rooftop, which is the region of debris generation, is complicated by the separated turbulence flow and formation of intense vortices. Therefore, the wind field in the main flow region and that on the rooftop are investigated separately in this study. In the main flow region, the turbulence in wind speed and wake effect, are considered. The local wind field on the rooftop is described by a parametric vortex model based on numerical simulations

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[1)] Postdoc fellowship

and experimental measurements. Using the simulated wind field as the input, the model of debris generation is developed based on the existing experimental studies of critical wind speed that causes blow-off of debris. The trajectory of debris flight can be numerically simulated using Newton's second law. Then, a fragility model is developed to estimate the probability of failure of building envelopes based on the new physics model of the windborne debris damage process. The performance of the proposed fragility model is evaluated by comparing the simulated debris damage for specific building complexes under hurricanes with field observation data.