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Wind and Rain Vulnerability of Mid/High-Rise Buildings during Hurricane Events

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BACKGROUND AND SIGNIFICANCE

Mid/high-rise residential buildings (MHR) (4 stories or higher) are engineered buildings which rarely suffer significant structural damage during hurricane events. By contrast, recent hurricanes in Florida and elsewhere have shown the vulnerability of MHR to wind-driven rain ingress. Wind-driven rain is proved to be the predominant source of interior related insured losses in MHR.

The magnitude of such losses is significant enough to render accurate predictive modeling a useful tool. The authors developed a new probabilistic vulnerability model (PVM) which takes into account the physics of wind-driven rainwater ingress, distribution and propagation to produce realistic estimation of hurricane damage to buildings and contents in MHR.

METHODOLOGY

The model has two main modules: a Preprocessing Module and an Execution Module. The Preprocessing Module maps rain admittance factor (RAF), surface runoff coefficient (SRC), excess water distribution among interior components and contents, and breach area of the openings to each apartment unit for the predefined building class. The heart of the Execution Module is a Monte Carlo (MC) simulation engine, where each of 1000 simulations loops over combinations of 41 maximum wind speed (WS) intervals and 8 wind directions for a total of 328,000 simulations. For each WS, the model selects an accumulated wind-driven rain (WDR). Each simulation produces a damage ratio (DR) associated with a WS and WDR, resulting in a dataset including 328,000 datapoints (DR, WS, WDR).

For each building class, the PVM produces several outputs. They include: 1) a joint WS and WDR vulnerability tensor, whose cells are the probability of damage ($V_{WS,WDR}$) conditional on both WS and WDR; 2) WS and WDR vulnerability matrices, whose cells are the probability of damage conditional respectively on WS (V_{WS}) and WDR (V_{WDR}).

FINDINGS

There are two ways to implement the methodology. One is to treat both hazards in the vulnerability model as deterministic variables selected from preset constant intervals, e.g., WS from 50 to 250 mph in 5 mph intervals and WDR from 0 to 98 inch in 2.45 inch intervals. Generate the $V_{WS,WDR}$ tensors, and then V_{WS} and V_{WDR} result from the integration of $V_{WS,WDR}$ over the hazard probability mass functions (pmf) of each hazard conditional on the other, P(WDR|WS) and P(WS|WDR), from the hazard model.

The other way is, for each MC simulation to select one or both hazards based on their pmf's from the hazard model. E.g., for each simulation, the model can randomly select WDR from the pmf of WDR conditional on WS from the rain hazard model.

The first method guarantees the independence of the vulnerability and hazard models. Hazard pmf's from different hazard models could be easily used to derive the V_{WS} and V_{WDR}. The number of MC simulations in the vulnerability model will also be affected. Fewer simulations might be needed because the final product will actually depend on the quality of the hazard pmf's.

The paper will present the mathematical and conceptual development of the vulnerability model with results from both implementation methods, and discuss their pros and cons. It will also present sensitivity studies to identify key variables with the most impact, and will discuss numerical evaluations of uncertainty contributions from each group of variables and processes.

IMPLICATIONS

Insured losses from wind-driven rainwater ingress in engineered residential infrastructure is significant, and accurate models that can predict the loss magnitudes and the influence of mitigation measures are much needed. The authors developed such a model for the insurance industry within the framework of the Center for Wind Hazard and Infrastructure Performance (WHIP-C). This methodology applies to both building and contents vulnerabilities, and could be adapted to other combination of hazards (e.g. earthquake and fire).

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