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International Association for Wind Engineering

Accounting for Exogenous Wind-borne Debris in Building Envelope Failure Assessment Models

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The development of resilient residential coastal communities will rely heavily on the ability of hurricane damage assessment models to identify cost effective mitigation practices that reduce the socioeconomic losses experienced by coastal communities subjected to extreme hurricane events. This can only be accomplished by continually addressing the limitations of current hurricane damage assessment models and updating them to include the most current research available. One such limitation that needs to be addressed within current hurricane damage assessment models is the influence of exogenous wind-borne debris. Exogenous wind-borne debris is debris that originates outside of the study region that is being investigated, enters the study region and potentially interacts with the building stock within that region. Typically, current hurricane damage assessment models isolate the region of interest from outside influences. While a necessary step in the evolution of such complicated models, it does raise several questions that must be answered to ensure these models remain efficacious and relevant. The two questions that present the next logical steps in hurricane damage assessment modeling are (1) does the exogenous wind-borne debris that enters a study region significantly influence the results of the hurricane damage assessment?, and (2) if exogenous wind-borne debris is statistically significant, how can it be accounted for within hurricane damage assessment models?

This research presents what is believed to be the first such study that addresses the statistical significance of exogenous wind-borne debris within current hurricane damage assessment models. The time evolution data illustrated in Figure 1 was obtained from a building envelope failure assessment model developed by the authors that

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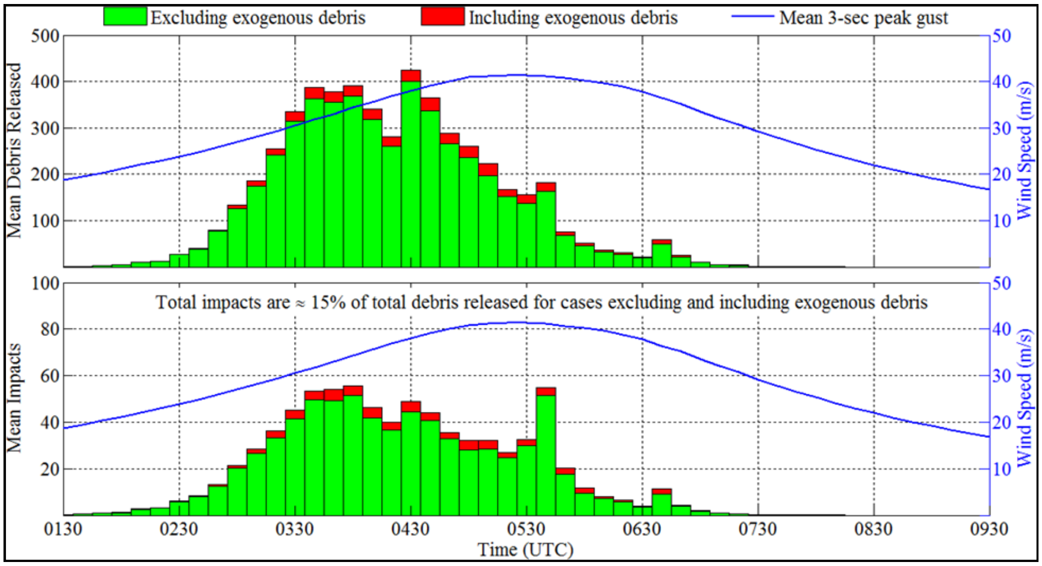

Figure 1: Time evolution of the mean debris released and the mean impacts to the building envelope that occurred during the passage of Hurricane Hugo with and without considering the influence of exogenous wind-borne debris

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subjects a typical coastal South Carolina community to the historical Hurricane Hugo. A rigorous statistical analysis is performed on this data with the results confirming that exogenous wind-borne debris can indeed have an influence on the results of a hurricane damage assessment that focuses on smaller, more detailed study regions. Based on these findings, a general methodology is presented to include the influence of exogenous wind-borne debris in a typical hurricane damage assessment model. This methodology identifies two scenarios that must be considered to appropriately account for the influence of exogenous wind-borne debris: (1) a study region (e.g., subdivision) that is surrounded by similar building stock and layouts in each of the eight principal directions (i.e., N-NW-W-SW-S-SE-E-NE), and (2) a study region that is surrounded by building stock and layout, or topography (e.g., wooded area versus populated area) that are deemed to contain enough significant differences as to influence the amount and type of exogenous debris entering the study region. The first scenario is addressed through a one-step process that captures the wind-borne debris exiting the area of interest using pre-defined exterior impact surfaces and essentially “re-injects” the exiting wind-borne debris back into the area of interest. The second scenario (2) requires a two-step process that requires the generation of exogenous wind-borne debris within the damage assessment simulations to account for identified differences in building stock, layouts, and/or topography in one or more of the eight principal directions. To facilitate the implementation of the second scenario of the methodology, a rigorous statistical analysis is presented that identifies the negative binomial distribution as the best-fit statistical distribution for use as an exogenous wind-borne debris generator. Future research will determine the size of the region of interest at which point exogenous wind-borne debris no longer has an influence on the results of a hurricane damage assessment model, and the determination of parameters that are important for determining which scenario of the methodology is applicable for a particular study region.

Dynamic Simulation of Long-span Cable-stayed Bridges Subjected to Multiple Service and Hazardous Loads

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Cable loss is a critical extreme event for cable-supported bridges, which sometimes governs the bridge design. Regardless of causes, most cable-loss events occur suddenly without much warning when service loads like traffic and wind often still apply on slender long-span bridges simultaneously. These service loads, although not causing safety problem most of the time during normal situations, can significantly increase the risk of triggering cascading or progressive failure of long-span bridges after one or multiple cables fail. A three-dimensional analytical platform is established in this study with the developed finite element program in order to perform the dynamic simulation of a cable-stayed bridge with combined service and extreme loads. In this study, the combined loads include stochastic traffic, wind loads and/or abrupt cable breakage load. The cellular automaton (CA) traffic simulation model, a type of agent-based microscopic traffic model, is adopted in the present study to simulate the stochastic traffic with different traffic densities and vehicle occupation types [2]. The equivalent moving traffic loads, obtained from the fully-coupled dynamic interaction analysis of the bridge-traffic system, are applied on the corresponding nodes of the finite element bridge model to represent the stochastic dynamic traffic loads including bridge-traffic coupling effects [1]. The spectral representation method is adopted to simulate the fully correlated turbulent wind speed histories at different locations along the bridge span. The unsteady aerodynamic forces, including self-excited forces and buffeting forces, are expressed by convolution integrals and incorporated in the time domain analysis. The Newmark-β step-by-step integration algorithm with a time step of 0.01 second is used to calculate the dynamic responses of the bridge in the dynamic simulation scenarios. For most cable-breakage studies, the dynamic impact from the ruptured cable is typically characterized by adding the counteracting forces at the two ends of the ruptured cable [3]. Different from the cable breakage simulation method described above, the cable breakage in this study is simulated by updating the equilibrium position and structural matrix of the bridge system in the dynamic process. With the proposed finite element-based simulation platform in the present study, the cable breakage event will occur at a selected non-zero dynamic initial state during a dynamic simulation process considering both turbulent wind and stochastic traffic.

The prototype cable-stayed bridge in the numerical study has a total length of 836.7 m, with a main span of 372.5 m, two side spans of about 155.0 m and two approaching spans of 79.25 m.

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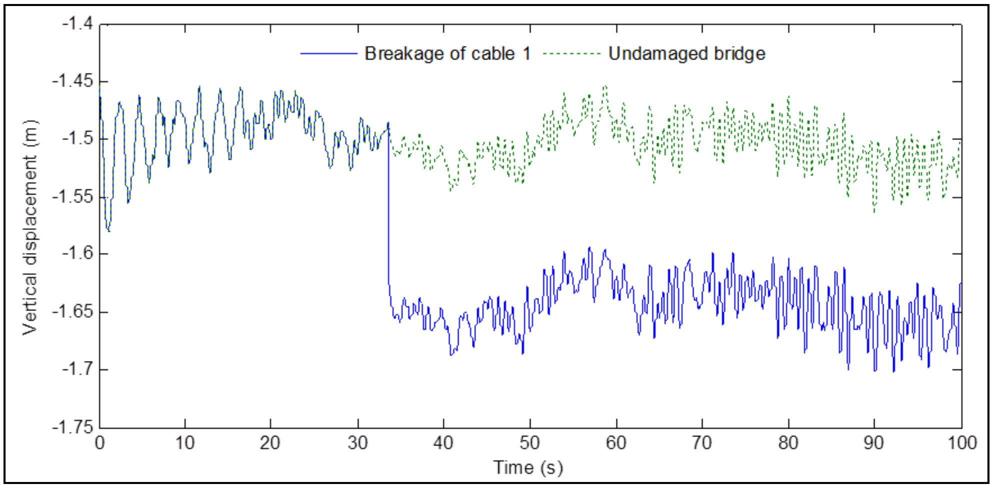

Figure 1: Vertical displacement histories at the connecting joint of cable 1 under both busy traffic and wind

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The developed finite element program is validated by comparing the results with those from the SAP2000 program. As a representative case study, the breakage of the cable connecting the joint closest to the mid span, referred to as cable 1, starts at a local maximum position between 30 second and 40 second in a dynamic simulation process under both wind and stochastic traffic. In the numerical study, wind speed is assumed to be 20 m/s when the busy traffic with a density of 50 veh/mile/lane on the bridge can be reasonably assumed unaffected. The vertical displacement histories at the connecting joint of the breaking cable for the case of breakage and undamaged bridge are demonstrated in Figure 1. It is shown that an abrupt vertical displacement increase will occur therefore the total responses and stresses will increase accordingly.

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Modeling Hurricane-Induced Building Downtime

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Key sectors of the United States have been increasingly involved in understanding and managing hurricane risk. Building downtime—a performance metric defined as the amount of time a building is unusable after a hurricane strikes—is contingent upon the interactions of the storm with the building inventory, and the community’s resilience. Despite the lasting consequences associated with prolonged building downtimes (i.e. population displacement, price surges, and lack of temporary housing), attempts to estimate this quantity are missing in the hurricane-risk literature. Accurate estimation of this performance metric is important to make informed decisions in emergency planning and in designing risk mitigation strategies. This paper proposes a methodology to estimate hurricane downtime of typical residential buildings and presents preliminary results for a case study in Miami-Dade County, FL.

Downtime consists of a mobilization time (i.e. delays before building repairs begin), and a repair time (i.e. to restore the building to a habitable status). Mobilization time includes activities of uncertain duration, such as building inspection, financing, and bidding; the length of mobilization time in this study as dependent on the forcible closure of buildings. To assess the probability of closure we developed a hurricane virtual inspector, after a method proposed in the earthquake engineering literature, which virtually tags buildings according to the estimated damage sustained. Building damage (exterior and interior) is simulated using results from the Florida Public Hurricane Loss Model. The virtual inspector checks the sustained component damage against guidelines for damage thresholds, and assigns safety tags accordingly. An estimated mobilization time associated to the safety tag is provided by expert opinion. Total building repair times are quantified for the simulated damage, and estimated based on the critical path in a Gantt chart of the damage repair schedule.

Preliminary downtime curves developed for buildings in the case study region are shown in Figure 1. These are consistent with building performance (e.g. strong buildings suffer less downtime than weaker buildings; timber houses have more downtime than concrete-block structures). The curves were preliminarily validated with estimates by contractors of the time necessary to build similar houses to those modeled in the study. The predicted downtimes for a complete damage state match quite well with the ranges from the survey. Further work is needed to understand how the downtimes vary spatially as a function of storm intensity. To that end another study is underway to identify the most vulnerable areas for specific scenarios (Figure 2).

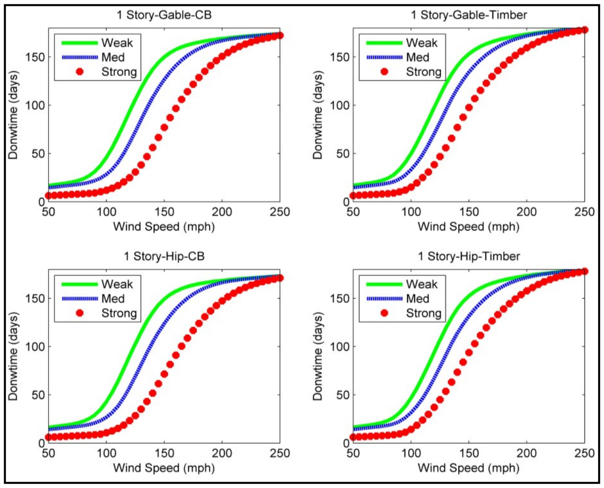

Figure 1: Sample downtime curves for typical residential buildings.

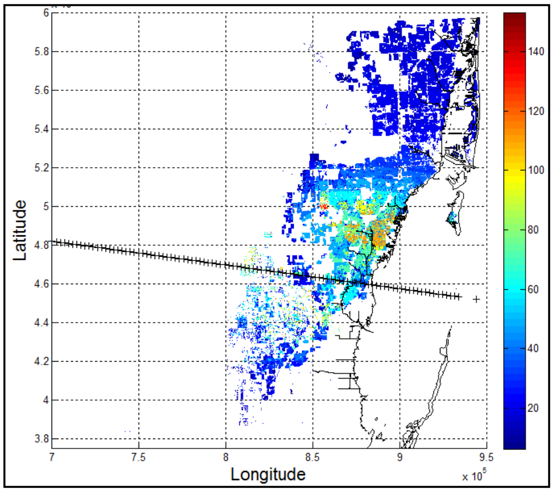

Figure 2: Average number of downtime days for a simulated hurricane making landfall at different locations along the coastline.

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