AIRCURRENTS

THE ROLE OF WIND DURATION IN DAMAGE ESTIMATION

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EDITOR'S NOTE: AIR principal engineer dr. Vineet jain looks at the evidence of the effects of windduration on property damage, and explains how it is accounted for in all of air's tropical cyclone models.

by Dr. Vineet Jain

INTRODUCTION

Property damage caused by hurricanes is often estimated using a single parameter: peak wind speed. However, as claims data and post-disaster survey findings repeatedly and consistently show, the amount of damage a structure experiences is also a result of wind duration—how long a hurricane's winds batter a structure.

Examples abound. Hurricane Emily struck the island of Cozumel just off Mexico's Yucatan Peninsula in mid-July of 2005. Winds at landfall were 135 mph—a Category 4 hurricane on the Saffir-Simpson Hurricane Wind Scale. Emily passed over the northern tip of the Yucatan, weakened, and entered the Gulf of Mexico. Three months later Hurricane Wilma followed in Emily's path. Wilma struck Cozumel with sustained winds of about 140 mph—also a Category 4 hurricane. Like Emily, Wilma passed over the northern tip of the Yucatan, weakened, and entered the Gulf of Mexico.

Both hurricanes caused extensive damage in the Yucatan Peninsula. But the damage from Wilma was at least four times greater than the damage caused by Emily, amounting to about USD 2.75 billion compared to Emily's less than USD 630 million. (The figure for Emily, it should be noted, includes losses from a second landfall in northern Mexico.)

While a number of factors contributed to this dramatic difference (including Wilma's slightly larger size and Emily's slightly more southerly track), of particular significance was the fact that Hurricane Emily moved across Yucatan quickly—in less than six hours—while Wilma stalled, battering the peninsula for the better part of two days.

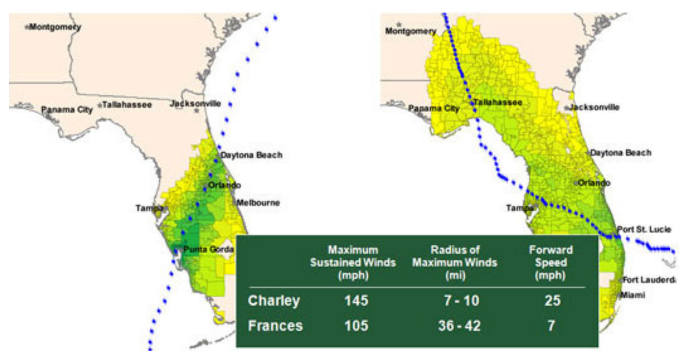

Figure 1. Summary statistics for 2004's Hurricanes Charley (left) and Frances (right). While Charley was smaller and more intense, it moved across Florida much more quickly.(Source: AIR)

Before making landfall on the east coast of Florida in 2004, Hurricane Frances—a Category 2 hurricane—virtually stalled just offshore, battering coastal structures with hurricane-force winds for nearly a day. After landfall, Frances moved very slowly (5-10 mph) across the state.

In contrast, Category 4 Hurricane Charley, which impacted Florida a month earlier, was a very fast-moving storm. Although Charley was a much more intense hurricane than Frances, the damage observed near their respective landfall locations was similar in its severity (Figure 2).

Figure 2. Despite their vastly different wind speeds, damage patterns near the landfall locations of fast-moving Hurricane Charley (left column) and slow-moving Hurricane Frances (right column) were remarkably similar. (Source: AIR and Various)

WHY HURRICANE WIND DURATION MATTERS

The physical mechanisms that cause damage in a hurricane—fluctuating wind pressures, flying debris, tree failures, wind-driven rain that enters a breached building-envelope—are all exacerbated when properties are exposed to hurricane force winds for an extended period of time. And indeed engineers have long taken the duration of wind loads into account when they design structures.

Duration and Fatigue

Wood, for example, has been found to have greater strength when loads are applied for a moment than when they are applied over an extended period. Hurricane wind loads on a structure's frame and various components exacerbate the stresses imposed because they fluctuate significantly due to turbulence. Recurring loads over an extended period of time, as happen when hurricanes stall, will cause a material to fail at a much lower load level than the material's inherent strength would suggest.

This property of a material is represented by its "S-N curve"—Stress (load) related to some Number of cycles of application—which indicates the number of times (cycles) a material can be stressed before it fails. The load required for a structure to fail becomes less as the number of load cycles increases (left-hand panel in Figure 3). The implication is that even moderate wind speeds will cause damage if they persist for long periods.

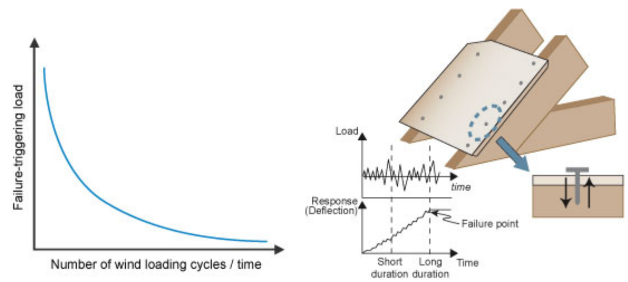

Figure 3. S-N curve (left) and schematic of fatigue failure mechanism for a fastener (right). As the number of load cycles increases, the load required to trigger failure decreases. (Source: AIR)

The vulnerability of buildings is tied to the strength of the connections between different building components, such as roof-to-wall connections and roof sheathing connections (as illustrated above). Continuous, fluctuating wind loading over a long duration can cause fatigue in these connections, thus increasing the likelihood of their failure (right-hand panel in Figure 3).

Duration and Debris

A stalled or slowly moving hurricane can increase damage in another way: damage caused by debris will increase as wind duration increases. Assume, for example, that the probability of a window being hit by debris in a one-hour period is 1% when winds are 80 mph, and that the probability is 5% when the winds are 120 mph. Now consider periods of longer duration—5 and 15 hours—with no change in the per-hour probability of the window being hit—i.e., the amount of debris is constant. For the window subjected to 80 mph winds, the probability of being hit by debris increases to 5% over a five-hour period, and to 14% for a 15-hour period. For the window subjected to 120 mph winds, the probabilities increase to 23% and 54%, respectively. These probabilities are illustrated in Figure 4.

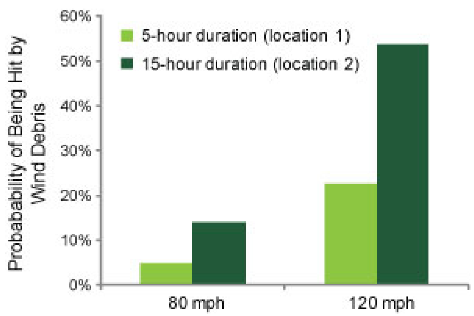

Figure 4. Effect of duration on probability of impact by wind-borne debris (Source: AIR)

This idealized example demonstrates the increasing probability of a window being hit by debris as time goes by, assuming that the amount of debris available to cause damage is constant. In fact, however, as the duration of high winds increases, new flying debris is created—which will increase the probabilities shown in Figure 4. Similarly, a hurricane's extended duration over a location also exposes structures to longer periods of wind-driven rain—thereby increasing the probability that water will penetrate roofs and windows, and cause damage to interiors and contents.

QUANTIFYING THE EFFECT OF DURATION USING CLAIMS DATA

While damage survey data bear visual witness to the effects of wind duration, detailed location-level claims data make it possible to quantify its effects. Figure 5 shows observed mean damage ratios derived from claims data for different counties in Florida for a number of recent storms. The blue data-points represent damage ratios corresponding to damaging winds that lasted for less than ten hours, while the green points indicate the damage ratios for when the duration was longer than ten hours. The damage covered by the claims was caused by wind speeds of 40-60 mph. Figure 5 clearly shows that the observed mean damage ratios are significantly greater in those counties that were impacted by wind for more than ten hours.

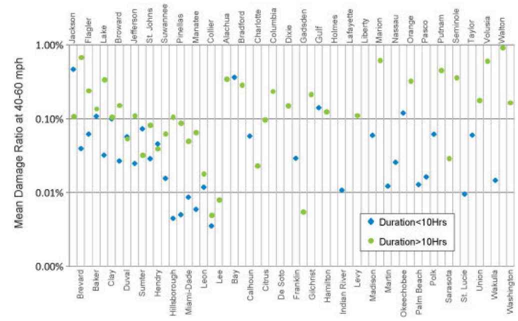

Figure 5. AIR's analysis of detailed claims data demonstrates the effect of wind speed duration on building damage ratios. (Source: AIR)

MODELING THE EFFECT OF DURATION ON DAMAGE

The scientific literature discusses various types of models designed to estimate accumulated damage caused by cyclical loading. However, to model with detailed precision each of the several direct variables that contribute to damage over time—fluctuating loads, wind-driven rain, flying debris, falling trees—is both procedurally complex and computationally intensive. Most models therefore use just one variable—peak wind speed—and a single corresponding damage ratio to estimate damage. The AIR tropical cyclone models, however, capture the combined effect of all these variables by way of a robust approach to modeling the effect of duration.

The left-hand panel of Figure 7 shows an idealized profile of hurricane wind speeds as a function of time at a specific location. Wind speeds increase as the hurricane approaches, rising to a peak wind speed at t4, and then begin to diminish as the storm recedes. Each time step is associated with a wind speed, wi. In turn, each wind speed, w, is associated with a damage ratio, d, which can be defined as the ratio of the repair cost of the property to its total replacement value. This relationship is shown in the right-hand panel of Figure 7 and represents an idealized damage function.

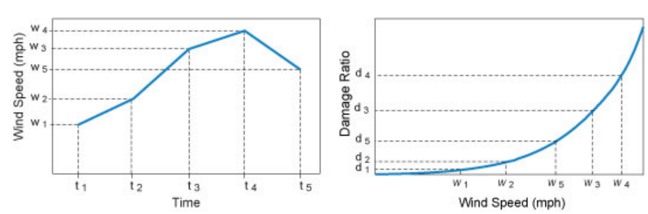

Figure 7. A sample wind speed profile (left) and corresponding damage ratios (right) (Source: AIR)

Figure 8 can be imagined as a series of snapshots of a building subjected to the passage of a hurricane. Before the storm's arrival —t0—the building has suffered no damage. By t1, wind speeds have risen to w1 and a damage ratio, d1, is applied to the property's total replacement value. At each subsequent time step, however, the damage ratio is applied only to whatever portion of the building remains undamaged from the preceding time step.

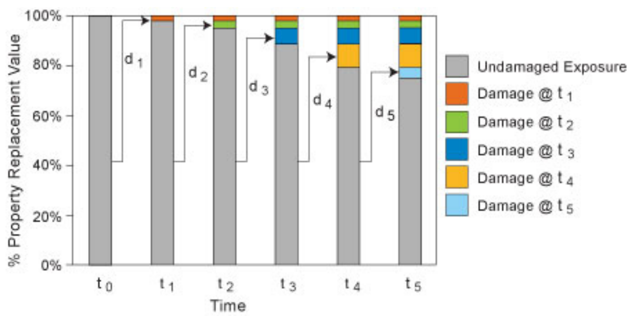

Figure 8. Accumulated damage over the duration of the storm. (Source: AIR)

CONCLUSION

Undoubtedly, the peak wind speed to which structures are subjected during the passage of a hurricane is the primary determinant of damage, particularly at high wind speeds. However, it is not the only determining variable. Engineering analysis, damage survey findings and claims data all demonstrate that the application of wind loads over time—and particularly the kind of fluctuating wind loads imparted by hurricanes—can amplify property damage, particularly at low to moderate wind speeds. Models that do not account for wind duration do not capture the cumulative effects on properties of prolonged winds.

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