Beyond the Envelope: *How a Home's Structural System Shapes Hurricane Damage*

MIT CSHub Research Brief
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How a home's structure influences its hurricane risk

States face increasing exposure to extreme weather. Florida alone carries roughly $1.8 trillion of residential property exposure to hurricanes [1]. The past three decades have taught a clear lesson: how a home is built matters as much as where it sits.

After Hurricane Andrew exposed weaknesses in 1980s construction, Florida adopted the **2001 Florida Building Code, Residential**, one of the strictest residential codes in the country. The results have been significant: homes built under the code suffer up to 72% lower wind losses than older homes. That reduction is large enough that the added construction cost pays for itself in about eight years [1].

Much of that protection (and related insurance discounts) focuses on the elements of buildings that shield the inside from wind and water, such as windows, doors, wall covering, and roof covering. These elements are collectively known as the **building envelope** [2]. Extensive post-hurricane evidence shows that when these elements fail, damage increases quickly—if a window breaks, rain pours in, and losses multiply [3]. Emphasizing the envelope has led to substantial improvements in performance, especially when the hurricane is of low-to-moderate intensity. However, the envelope is not the only part of a home that determines its resilience.

The core elements of homes that resist forces from wind and water—wall framing, roof and floor diaphragms, columns, beams, foundations, and their connections—have a critical role in influencing how damage spreads. These elements are collectively called the primary **structural system**, which is often overlooked by current mitigation and incentive frameworks in favor of the envelope. This is in part because features of the envelope are easier to standardize, inspect, and verify. This brief presents evidence from three recent hurricanes to show how different structural systems influence damage across different building components.

How a building's structure and envelope work together to survive extreme weather

Forensic studies of Hurricanes Hugo and Andrew find that most wind damage to houses is concentrated on the envelope. When rain enters a breached envelope, the insurance loss is magnified by a factor of two (at lower wind speeds) to nine (at the highest speeds observed in Andrew) [3]. The structural system, while often thought of as unrelated, is in reality the frame the envelope depends on. It is a distinct, complementary line of defense.

This research brief finds that the same roof or wall cover fares better during hurricanes when the structural system beneath is rigid rather than flexible.

Key takeaways:

- Across three hurricanes — Irma (2017), Harvey (2017), and Michael (2018) — and every major building component, homes with concrete-based structures (reinforced concrete masonry or reinforced concrete) sustained less wind damage than wood frame homes. In Hurricane Irma, overall wind damage ratios for wood frame homes were roughly twice those of reinforced concrete masonry homes.
- The structural system, not only the envelope, shaped performance. Notably, the same roof or wall cover fared better when anchored to a rigid reinforced concrete masonry or reinforced concrete frame than to a flexible wood one.
- The advantage is hazard-specific. Under Hurricane Irma's flood and surge loading, the gap narrowed to a few percentage points (overall damage ratios of 16% for reinforced concrete masonry versus 19% for wood frame), indicating that structural-system choice is chiefly a wind-resilience lever.
- This information can be used by legislators and municipal officials in hurricane-prone regions when evaluating structural-system choice alongside envelope-focused codes and mitigation credits.



House with roof-structure loss and collapse of the second-floor exterior wall following Hurricane Irma (estimated wind speed 113 mph), Ramrod Key, FL in 2017. Wind-induced structural failures observed after Irma were almost exclusively confined to older, pre-FBC construction.

Source and Image Credit: FEMA P-2023 4-6, [4].

How different structural systems shape wind damage

To study how different structural systems influence building damage during hurricane winds, the CSHub team analyzed post-storm field data from single-family homes after three major hurricanes [5-7]:

- **Irma** (2017, Category 4 at landfall in Florida)
- **Harvey** (2017, Category 4 at landfall in Texas)
- **Michael** (2018, Category 5 at landfall in the Florida Panhandle)

The datasets included field assessments of damage to the whole building and four components – roof cover, roof structure, wall cover, and wall structure – for homes with three structural systems: **wood frame**, **reinforced concrete masonry**, and **reinforced concrete**. In the dataset, damage was assigned using a five-point scale ranging from no damage to total loss (see "Modeling methodology" on the next page). The CSHub team converted these classifications into damage ratios ranging from 0 to 1 to simplify comparisons across events.

The team also separated damage caused by wind from damage caused by water (floods and storm surges). Buildings react to each hazard differently, so this allows for a better comparison of structural systems.

The analysis revealed a strong relationship between the choice of structural system and how much wind damage was experienced. Under hurricane conditions, **homes made with reinforced concrete masonry or reinforced concrete frames sustained lower damage ratios – and therefore less loss of value due to damage – than wood frame homes in every storm for every component**. This is largely because these structural systems better protected wall and roof structures, and likely the connections between those structures and the envelope components attached to them, since envelope damage followed a similar pattern. In contrast, wood-framed elements steadily lost strength under wind pressure (Figure 1). Damage to the roof cover and wall cover occurred across every structural system, but was consistently higher for wood-frame homes, reinforcing that both structural connections and the envelope itself contribute to a home's resilience.

Why the structural advantage narrows with water damage

The choice of structural system had less of an influence on the severity of water damage. When faced with Hurricane Irma's flooding and storm surges, reinforced concrete masonry homes fared only slightly better than wood frame homes, with overall damage ratios of 16 percent compared to 19 percent (Figure 2). This gap was driven almost entirely by how the wall cover withstood water. Wood-based finishes degraded more than moisture-resistant masonry surfaces, but core structural elements in both systems sustained minimal damage.

One important note here is that this comparison rests upon a single event and should be read as illustrative rather than definitive. However, the contrast with the wind damage results is instructive. The choice of structural system strongly influences vulnerability to wind but has a much more limited impact on flood losses. Therefore, the primary tools in defending against water damage remain elevation and floodplain management.

Overall, these case studies demonstrate that while structural systems are often overlooked by current incentives and frameworks in favor of the envelope, it has a distinct impact on a building's resilience – especially its vulnerability to wind.

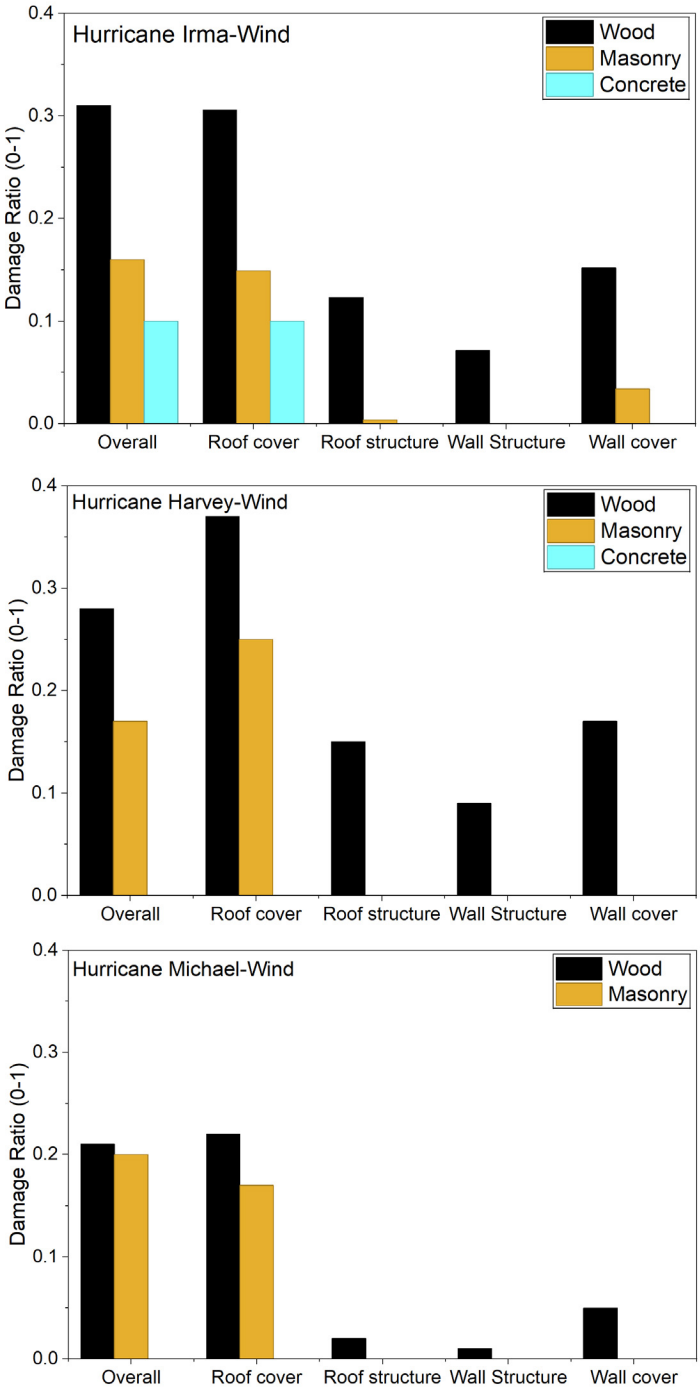


Figure 1: *Comparison of wood frame, reinforced concrete masonry, and reinforced concrete home component damage under wind-induced conditions during Hurricanes Irma, Harvey, and Michael. Damage ratios (0–1) shown for the overall building and by component. Across every component and storm, more rigid structural systems sustained less damage. The gap in performance across structural systems is small in Michael overall, but the observation is robust when the full set of results is considered. No reinforced concrete observations were present in the Hurricane Michael dataset. [a, b]*

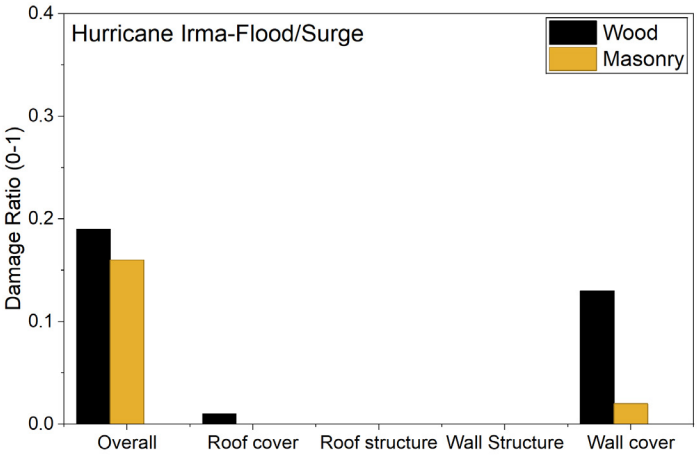


Figure 2: *Comparison of wood frame vs. reinforced concrete masonry home component damage under Hurricane Irma flood and storm surge conditions. [a, b]*

How large is the upfront premium?

Building beyond the established code carries an added first cost. Two documented reference points bound its scale: retrospective analysis indicates the Florida Building Code itself added roughly $3,000 to the average Florida home and paid that back through lower losses in about eight years [1], and industry analysis puts the IBHS FORTIFIED upgrade at roughly 0.5–3 percent of construction cost [8]. The incremental cost of choosing a reinforced concrete masonry or reinforced concrete structural system varies with market and design and is not estimated in this brief; these figures indicate the frame in which such a choice can be evaluated — an upfront cost weighed against avoided damage over the life of the home.

What legislators and municipal officials can do

Florida's experience after Hurricane Andrew already demonstrates the core lesson: stronger residential construction sharply reduces hurricane losses, and it does so cost-effectively [1]. The results in this brief extend that lesson to an influential factor behind resilience that current policy frameworks largely overlook: the primary structural system.

For legislators, the data show that resilience strategies which focus only on the building envelope leave potential risk reduction benefits on the table. If the performance of structures is to be better reflected in policy, two pathways warrant further investigation:

1. Extending existing incentives and insurance credits to recognize the importance of the structural system
2. Disclosing a home's structure at the point-of-sale. This would make the structural system visible to buyers in the way envelope features are through wind mitigation inspection forms.

For **municipal officials**, the evidence also shows the importance of code enforcement. The reach of the FBC accounts for the majority of the observed reduction in hurricane losses. However, intensive local administration and enforcement (staffing, plan review, and inspection) have been associated with a further 15-25% reduction in losses [9]. When provided by municipalities, these resources produce benefits for any home built under its jurisdiction.

As with any technical findings, these findings are necessary but not sufficient to drive change alone. Whether and how to act also depends on local risk, political context, and willingness to pay. The upfront costs for more resilient homes fall on builders and buyers, but much of the benefit accrues over decades and across the insurance and disaster-relief systems. The goal of this brief is to characterize the evidence about the significance of structural systems clearly enough that it can be weighed alongside the envelope mitigation measures that Florida already employs.

The next phase of this work is to extend this comparison to future climate conditions and to assess how reinforced concrete and reinforced concrete masonry systems retain their resilience under repeated hazard exposures during their service life.

Modeling methodology

Scope and case studies

This analysis draws on empirical, post-storm observational data for single-family homes from three major hurricanes: Irma (2017, Category 4 at Florida landfall), Harvey (2017, Category 4 at Texas landfall), and Michael (2018, Category 5 at landfall, Florida Panhandle). Field observation data characterizing single-family building damage were sourced from published NSF NHERI DesignSafe public repositories for Hurricane Irma (n = 309; PRJ-1828) [5], Hurricane Michael (n = 244; PRJ-2113) [6] and Hurricane Harvey (n = 436; PRJ-1668) [7]. The dataset evaluates wood, masonry, and concrete structures impacted by wind (Figure 1) and flood/surge (Figure 2) [b]. Building damage ratings (1–4 scale) were assigned during post-event visual field surveys by trained StEER/NHERI reconnaissance teams following standardized structural damage classification guidelines, where Ratings 1, 2, 3, and 4 represent minor, moderate, severe, and total structural destruction, respectively. Performance is compared across three structural systems – wood frame, reinforced concrete masonry, and reinforced concrete – at the whole-building level and for four sub-assemblies: roof cover, roof structure, wall cover, and wall structure. No reinforced concrete observations were present in the Hurricane Michael dataset, so that comparison is limited to wood frame and reinforced concrete masonry.

Damage quantification framework

Building condition is recorded on a discrete five-level field scale – no damage, minor, moderate, severe, and total damage – following the damage-state convention used in FEMA's Hazus hurricane model [10]. For quantitative comparison across events, the categorical observations are converted to equivalent percentage damage values of 0%, 10%, 30%, 50%, and 75%. The resulting damage ratio, bounded between 0 and 1, expresses physical degradation relative to the intact state of the component or building.

Analytical controls and uncertainty

Observations are explicitly separated into wind-induced and water-induced (flood and storm surge) damage pathways, so that each structural system's response to wind can be evaluated independently of fluid forces. Results depend on the loading characteristics of the specific events, on regional construction practices, and on the coverage of the post-storm datasets; the water-pathway comparison in particular rests on a single event. As such, these findings are best read as relative comparisons of structural-system performance under common conditions, not as absolute loss predictions for future storms.

Citation

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Endnotes

[a] The damage axis in Figures 1–2 is a normalized damage ratio (0–1).

[b] The breakdown of single-family buildings with observed damage in the NSF NHERI DesignSafe public repositories as represented in the figures are as follows (sorted by structural type):

Figure 1 (damaged by wind):

- Hurricane Irma: 106 masonry buildings, 181 wood buildings, 3 concrete buildings
- Hurricane Harvey: 14 masonry buildings, 418 wood buildings, 4 concrete buildings
- Hurricane Michael: 6 masonry buildings, 238 wood buildings, 0 concrete buildings

Figure 2 (damaged by water):

- Hurricane Irma: 10 masonry buildings, 9 wood buildings, 0 concrete buildings

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Further reading

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