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Empirical Insights from Post-Event Coastal Flood Damage Surveys after Hurricanes Helene and Milton in Florida

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ABSTRACT

Post-event damage surveys provide critical empirical evidence for understanding how buildings perform after a natural catastrophe. This paper presents findings from a post-event damage survey conducted after Hurricanes Helene and Milton, which impacted Florida's Gulf Coast in October 2024. The survey focused on six coastal counties: Lee, Charlotte, Sarasota, Manatee, Hillsborough, and Pinellas. It documents flood damage in buildings exposed to storm surge.

Field observations were collected through rapid, street-level assessments conducted within days of landfall, capturing perishable indicators such as flood depths, sediment deposition, debris accumulation, and damage to structural and non-structural components. The surveyed building stock included single-family homes, multi-family residential buildings, low-rise commercial structures, and mobile or manufactured housing spanning multiple construction eras and flood mitigation regimes. Observed damage patterns highlight strong spatial variability in flood impacts, particularly within the first few blocks from the shoreline, where several buildings experienced extensive interior damage accompanied by deep silt and mud deposition.

Survey findings demonstrate the significant influence of building elevation and mitigation measures on damage outcomes. Elevated structures generally limit damage to sacrificial lower levels, while non-elevated buildings exposed to similar surge depths sustained substantial interior and exterior damage. These observations provide clear, field-based evidence of the effectiveness of elevation and modern coastal construction practices in reducing flood impacts.

By centering on empirical survey data, this study underscores the essential role of post-event damage surveys in advancing coastal flood risk understanding. The findings offer practical insights for flood vulnerability assessment, mitigation planning, and the interpretation of hurricane flood impacts in coastal communities.

KEYWORDS: Damage Surveys; Coastal Flooding; Flood Risk; Catastrophe Modelling

1 INTRODUCTION

Coastal flooding from hurricanes remains one of the most damaging natural hazards affecting the built environment, particularly along low-lying coastlines where storm surge, wave action, and coastal rainfall interact to produce complex damage patterns. In the United States, hurricane-driven flooding accounts for a substantial portion of disaster-related economic losses, with damage mechanisms varying significantly over short spatial scales due to elevation, building characteristics, and mitigation practices (Merz et al., 2010; Wing et al., 2020). These complexities pose persistent challenges for flood risk assessment and loss modelling in coastal environments.

Advances in flood catastrophe modelling have improved the representation of coastal storm surge hazard. However, the reliability of modelled loss estimates remains strongly dependent on exposure data and assumptions used to represent building vulnerability (Merz et al., 2010). Vulnerability functions embedded in catastrophe models are often developed using limited empirical datasets, increasing epistemic uncertainty, particularly for extreme events where observational data are scarce. As a result,

post-event validation is essential to ensure that modelled losses reflect real-world building performance under flood conditions.

Post-event damage surveys play a critical role in addressing this gap by providing direct empirical observations of how buildings perform during extreme flooding. Unlike modelled outputs or insurance claims alone, damage surveys capture physical evidence of flood depths, damage mechanisms, construction details, and mitigation features that help explain why damage occurred (Do et al., 2025; Webb et al., 2024). These surveys are especially valuable in coastal settings, where surge-driven flooding can vary sharply within neighbourhoods due to small changes in elevation and local site conditions. From both academic and industry perspectives, systematic post-event surveys are a foundational component of catastrophe model development, enabling the identification of model biases and supporting iterative refinement of vulnerability assumptions (Johnson et al., 2019).

Hurricanes Helene and Milton, which impacted Florida's Gulf Coast in 2024, provide an opportunity to examine coastal flood damage through post-event reconnaissance. Both events produced significant storm surge along the coast, with additional contributions from rainfall and local drainage effects within coastal communities. Rapid reconnaissance efforts following Hurricane Milton documented widespread coastal flooding and building damage across southwest Florida, highlighting the importance of timely post-event surveys for capturing perishable damage evidence (Do et al., 2025; Webb et al., 2024). Building on these efforts, targeted damage surveys were conducted in six heavily impacted coastal counties: Lee, Charlotte, Sarasota, Manatee, Hillsborough, and Pinellas. These counties encompass a diverse coastal building stock, including single-family homes, condominiums, low-rise commercial buildings, and mobile or manufactured housing, constructed across multiple code eras and mitigation regimes.

The results of the survey presented below focused exclusively on coastal areas, with emphasis on surge-dominated flooding and compound coastal flood effects. Inland regions outside the coastal zone were not surveyed; therefore, this study does not attempt to characterize inland riverine flooding or rainfall driven flooding away from the coast. Inland flooding is considered only where it manifested within coastal communities, such as back-bay flooding, canal overflow, and drainage related failures occurring behind surge affected shorelines. This explicit focus allows for clearer interpretation of observed damage mechanisms and avoids overgeneralization beyond the surveyed regions.

The objective of this paper is to demonstrate the value of post-event coastal damage surveys in improving flood risk understanding and catastrophe model performance. Specifically, the paper (1) describes the design and execution of coastal damage surveys conducted after Hurricanes Helene and Milton in Florida coastal counties; (2) provides observed damage patterns and mitigation features across different coastal buildings; and (3) discusses how these observations serve to inform and validate flood catastrophe modelling. By centring empirical survey evidence, this work highlights the essential role of field reconnaissance in advancing coastal flood risk assessment and supporting the development of more resilient coastal communities.

2 POST-EVENT DAMAGE RECONNAISSANCE SURVEYS

2.1 Survey Scope and Study Area

Hurricane Helene made landfall on September 26th, 2024, as a Category four hurricane near the mouth of the Aucilla River in the Big Bend area, Florida. Followed by Hurricane Milton, which made landfall near Siesta Key, Florida, on the evening of October 9, 2024, as a Category three hurricane. Both producing widespread coastal flooding across west Florida. In response to these events, the survey team mobilized rapidly to capture perishable damage evidence before cleanup and repair activities significantly altered site conditions.

The survey team arrived in Tampa, Florida, early on Wednesday, 23 October 2024, and conducted field surveys over three consecutive days. This deployment window allowed for systematic coverage of multiple coastal communities across six counties: Lee, Charlotte, Sarasota, Manatee, Hillsborough, and

Pinellas as shown in fig. 1. Surveys were conducted while visible flood indicators, such as waterlines, debris accumulation, and sediment deposition, were still present, enabling more reliable interpretation of flood intensity and associated damage mechanisms.

Survey teams conducted street-level assessments using a rapid reconnaissance approach, documenting damage at the individual building level. Observations were collected across a range of building occupancies and construction types, including single-family residences, multi-family residential buildings, low-rise commercial structures, and mobile or manufactured housing.

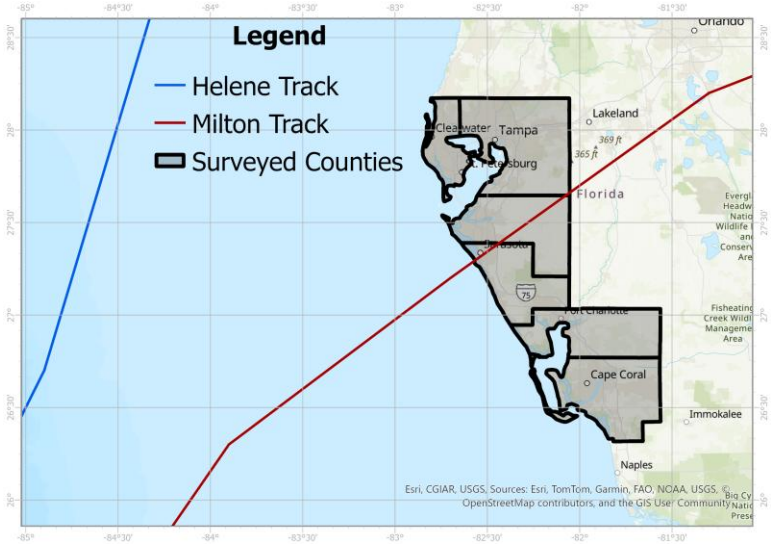

Figure 1: Damage survey study area

2.2 Data Collection and Damage Classification

The surveys relied primarily on exterior visual assessments, supplemented by limited interior observations where access was available. For each surveyed structure, the following information was documented: Building occupancy and general construction type; Apparent construction era and elevation characteristics; Presence of mitigation features, such as elevated foundations, breakaway walls, or impact-resistant openings; Observable flood damage to structural and non-structural components.

Flood intensity was inferred using physical indicators including visible waterlines, debris accumulation, sediment deposition, and damage to lower-level components such as doors, wall finishes, and mechanical or electrical equipment. Damage was classified qualitatively based on the extent and severity of observed impacts, with particular emphasis on distinguishing flood-related damage from wind-driven effects where possible.

2.3 Survey Limitations and Sources of Uncertainty

The following limitations inherent to post-event damage surveys should be noted. Access to building interiors was often restricted, limiting the ability to fully assess interior damage and contents losses. In some locations, debris removal and early repairs may have obscured flood indicators prior to survey arrival. Additionally, distinguishing flood damage from wind-related damage was challenging in areas where both hazards were present.

Despite these constraints, the survey provide a robust empirical dataset capturing spatial patterns of coastal flood damage across multiple building types and mitigation measures. The consistency of observed damage mechanisms across surveyed counties supports the use of these findings to inform coastal flood vulnerability assessment and interpretation of hurricane flood impacts.

3 OBSERVED COASTAL FLOOD DAMAGE AND BUILDING PERFORMANCE

Post-event damage surveys conducted across the six coastal counties revealed consistent spatial patterns of flood damage driven primarily by storm surge. Damage severity was strongly correlated with proximity to the shoreline, local elevation, construction material, and building age. In many surveyed communities, the most severe impacts were observed within the first two to three blocks inland from the coastline, where surge depths and sediment transport were greatest.

3.1 Residential Building Damage

Single-family residential buildings constituted a significant portion, around 65%, of the surveyed structures. As shown in fig. 2-4, for non-elevated homes, floodwaters frequently entered living spaces, resulting in extensive damage to interior finishes, wall assemblies, flooring, and household contents. Exterior damage was typically limited to lower wall finishes, doors, and garage components, though prolonged exposure led to staining, material deterioration, and contamination.

In contrast, fig. 5 and 6, elevated residential buildings often exhibited minimal damage to primary living spaces, even when evidence of surge inundation was present at ground level. For these structures, observed damage was largely confined to garages, storage areas, or unoccupied lower levels. These contrasting performance outcomes were frequently observed between neighbouring homes subjected to similar flood depths, underscoring the influence of building elevation and configuration on damage severity.

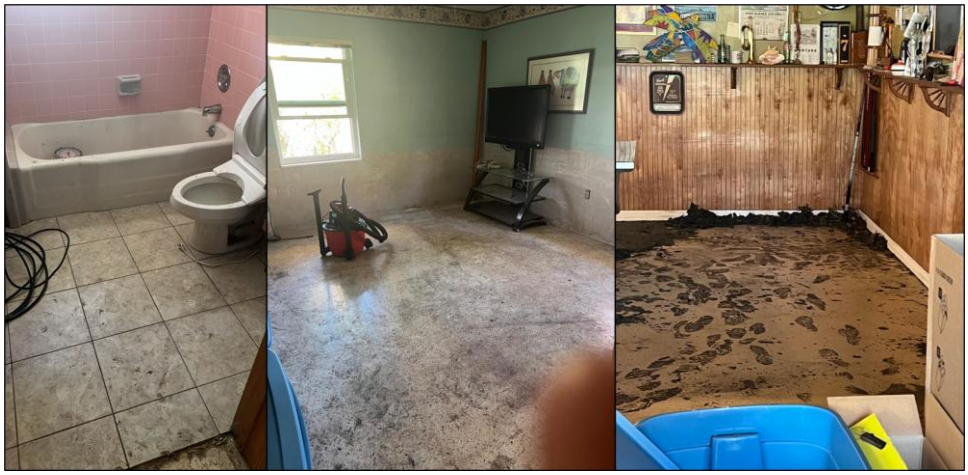

Figure 2: Interior damage of residential buildings in Punta Gorda.

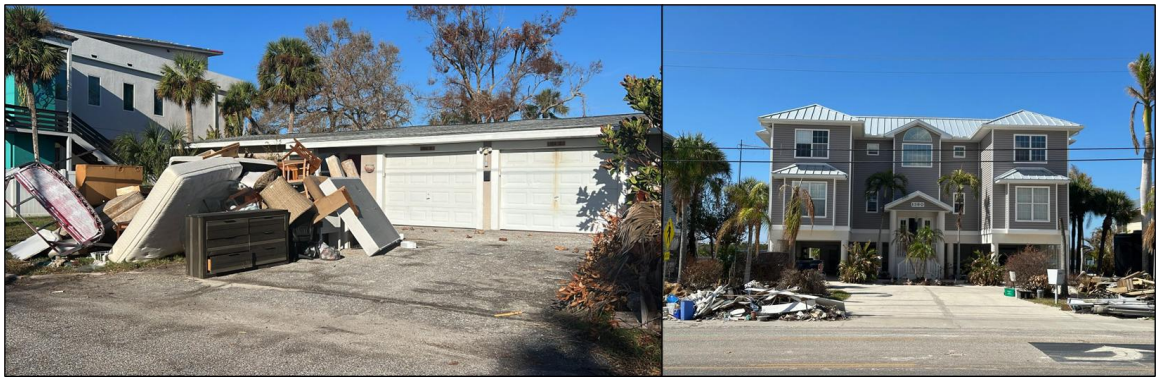

Figure 3: Widespread damage to interiors and content was found in most of the surveyed residential neighbourhoods

3.2 Commercial Building Damage

Low-rise commercial buildings in coastal areas experienced damage patterns similar to residential structures but often at larger scales. Ground-floor commercial spaces showed widespread interior damage, including failure of drywall systems, damage to electrical and mechanical equipment, and loss of inventory as shown in figure 7. In several cases, thick sediment deposits covered entire ground-floor areas, complicating cleanup efforts and extending business interruption periods.

Commercial buildings located within the immediate coastal zone were particularly susceptible to flood damage due to slab-on-grade construction and limited elevation above surrounding grade. As shown in figure 8, exterior walls, exterior signage, storefront glazing, and service equipment were commonly damaged or displaced, although structural frame damage was generally limited.

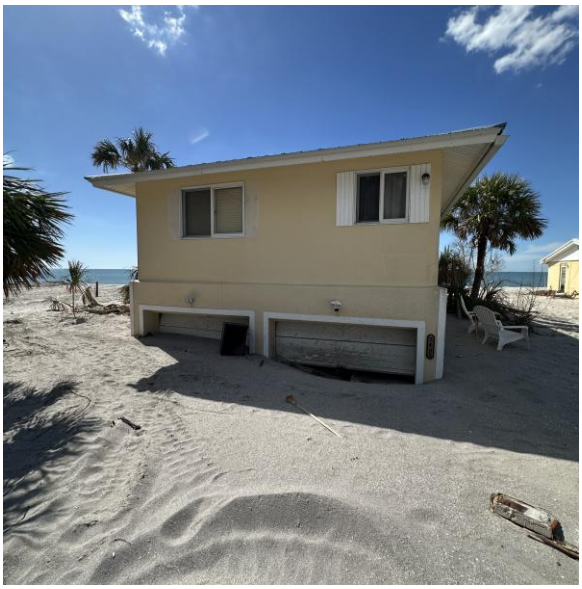

Figure 4: A coastal house that is covered in 3-4 ft of silt and mud in Manasota Key.

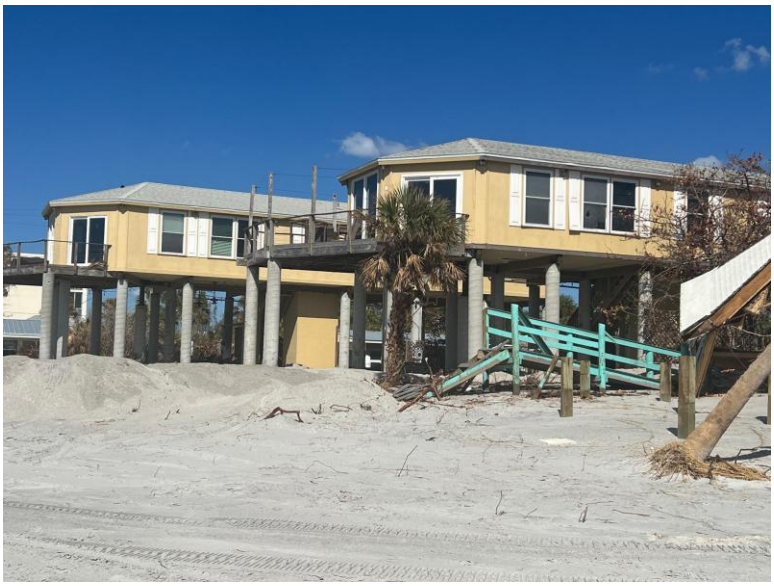

Figure 5: Elevated buildings, on the coast in Manasota Key, suffered minimal damage.

3.3 Wind–Flood Damage Interaction

Although the focus of this study is flood damage, evidence of wind-related impacts was observed in several surveyed communities, figure 9. This included roof covering damage, loss of exterior attachments, and damage to carports and screened enclosures, particularly in mobile and manufactured housing. In some cases, wind damage may have increased flood vulnerability by creating additional pathways for water entry. Distinguishing between wind and flood damage was not always possible using exterior observations alone and represents a source of uncertainty in damage interpretation.

Figure 6: Two single-family houses across the street from each other, affected by around 4 feet of storm surge, in Punta Gorda.

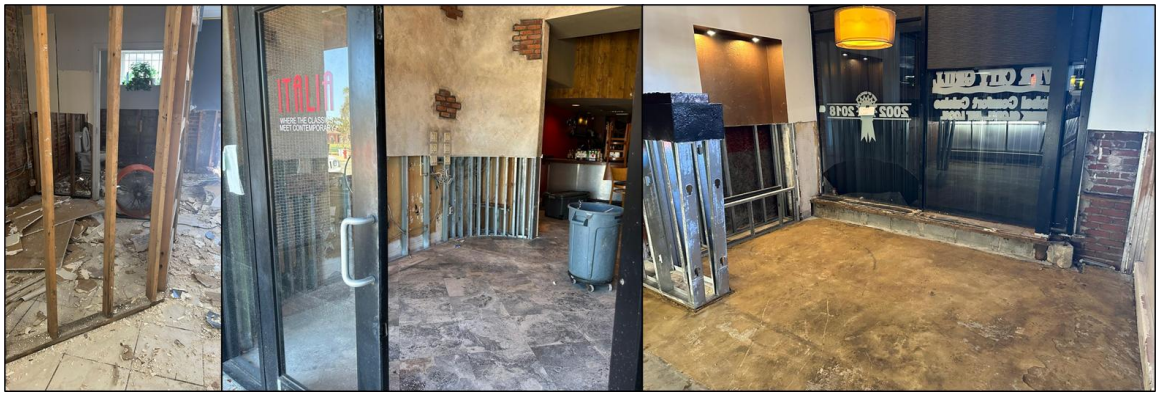

Figure 7: Interior and content damage of commercial buildings in Punta Gorda.

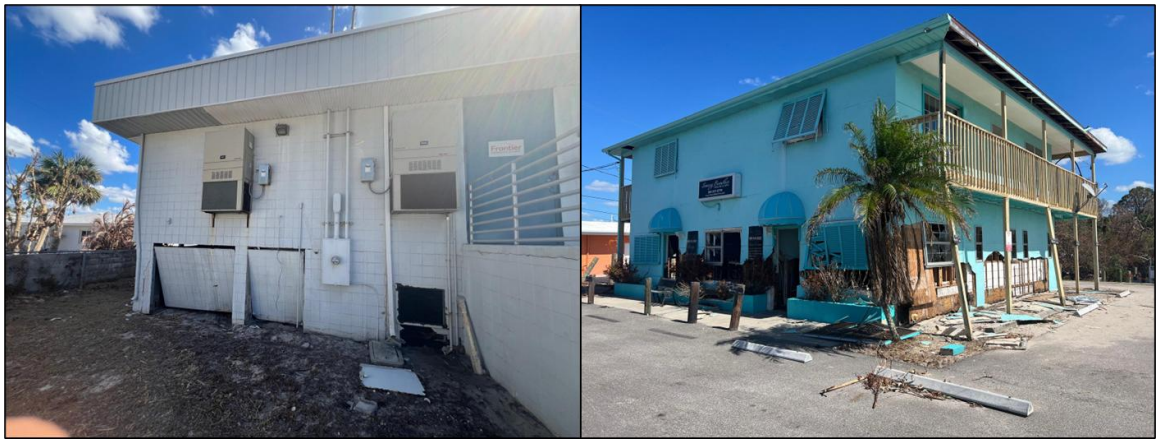

Figure 8: Low-rise commercial buildings, near the coastline, suffered damage to exterior walls and windows due to storm surge in Manasota Key.

4 MITIGATION PERFORMANCE AND KEY LESSONS FROM FIELD OBSERVATIONS

Post-event damage surveys conducted after Hurricanes Helene and Milton provided clear empirical evidence of the influence of mitigation measures on coastal flood damage outcomes. Across the surveyed coastal communities, mitigation performance varied substantially depending on building elevation, construction era, and the treatment of lower building levels. Field observations consistently demonstrated that relatively simple mitigation measures, particularly elevation above anticipated surge levels, were highly effective in reducing damage severity.

Figure 6 shows a representative example observed during the surveys involved two single-family homes located directly across the street from one another, both exposed to approximately 3–4 ft of storm surge inundation. The non-elevated home experienced substantial interior damage, including impacts to wall finishes, flooring, and building services, along with minor exterior damage. In contrast, the adjacent elevated home showed almost no observable damage, with floodwaters restricted to the lower, non-habitable level. This side-by-side comparison highlights the effectiveness of elevation in mitigating flood damage under similar hazard intensity and exposure conditions.

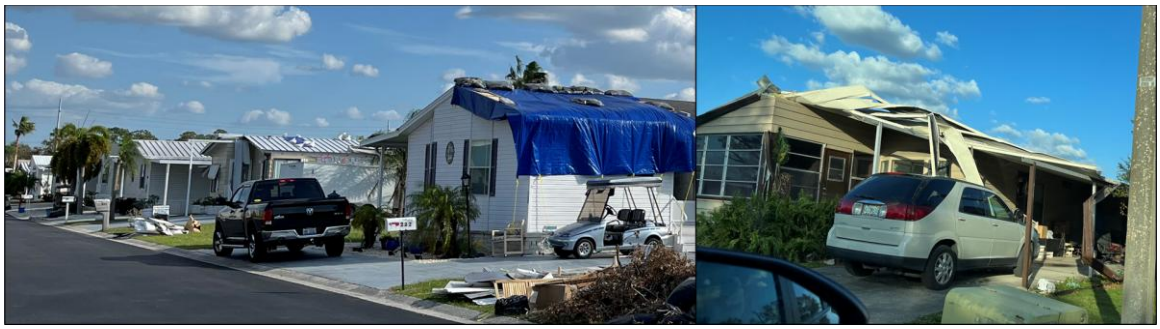

Figure 9: Widespread roof damages for mobile/manufactured homes in Hillsborough County.

5 CONCLUSION

This study demonstrates the critical value of post-event damage surveys in advancing the understanding of coastal flood impacts and building performance during hurricane events. Through targeted field surveys conducted after Hurricanes Helene and Milton in six coastal counties along Florida's Gulf Coast, empirical observations were collected that document flood damage mechanisms, mitigation effectiveness, and spatial variability in surge-driven impacts.

Survey findings highlight the dominant role of storm surge in driving damage within the first several blocks from the shoreline, where inundation depths and sediment deposition were often severe. Extensive interior damage, accumulation of silt and mud, and impacts to mechanical and electrical systems were commonly observed in non-elevated residential and commercial buildings. In contrast, elevated structures generally performed significantly better, with floodwaters confined to lower levels and limited or no damage to primary living spaces. These observations provide clear, field-based evidence of the effectiveness of elevation as a flood mitigation measure in coastal environments.

By centring on direct field observations, this work reinforces the essential role of post-event damage surveys in capturing perishable evidence that cannot be fully inferred from hazard models or remote data alone. The findings from Hurricanes Helene and Milton contribute to a growing body of empirical knowledge that supports improved coastal flood vulnerability assessment, more informed mitigation strategies, and enhanced interpretation of hurricane flood impacts. Continued investment in systematic post-event damage surveys will remain vital for strengthening flood risk understanding and promoting resilience in coastal communities.

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