



Hurricane Harvey Wind Damage Investigation

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Introduction

Hurricane Harvey was the first major¹ hurricane to make landfall in the U.S. since Hurricane Wilma in 2005. Harvey made landfall near Rockport, Texas, on August 26, 2017 with maximum estimated sustained (1-minute mean) winds of 130 mph. Based on HWind analysis from Risk Management Solutions (RMS), Hurricane Harvey had a relatively small, approximately 12-mile radius of maximum winds. However, Harvey's slow forward speed at landfall (7 mph) resulted in the area where the radius of maximum winds came ashore being subjected to mean winds above hurricane-force for 6–7 hours. The small size of Harvey and its short duration as an intense hurricane helped limit the storm surge. Peak water levels of 6–10 feet were observed or determined from high water marks from Port Aransas to Matagorda Bay.

Hurricane Harvey is the second-most costly hurricane in U.S. history (after adjusting for inflation), behind Hurricane Katrina (2005). At least 68 people were killed by the storm and NOAA estimates Hurricane Harvey caused \$125 billion in damage. NOAA also estimates that in the initial landfall zone (Aransas, Nueces, Refugio, and San Patricio Counties):

- 15,000 homes were destroyed
- 25,000 homes were damaged
- 220,000 customers lost power (Blake and Zelinsky, 2017).

The Texas Department of Insurance estimated a total of 391,000 residential and commercial claims for Harvey in all of Texas (TDI 2018).

Meteorological History

Hurricane Harvey began as a classic African easterly wave that exited the African coast on August 12, 2017. By August 16, a low-pressure center became more defined. The National Hurricane Center (NHC) upgraded the tropical wave to a depression on August 17. The system became Tropical Storm Harvey twelve hours later and moved quickly westward, passing over Barbados and Saint Vincent during the day on August 18.

As Harvey entered the Caribbean, wind shear increased and it weakened to an open tropical wave on August 19. The remnants of Harvey moved rapidly westward through the Caribbean, crossed the Yucatan Peninsula on August 22, and moved into the Bay of Campeche early on August 23 where it re-intensified into a tropical depression. Harvey then entered a rapid intensification phase late in the day on the 23 that would continue up to landfall. Harvey became a hurricane on August 24, a major hurricane 24 hours later. By 00

¹ Category 3 or higher using the Saffir-Simpson Hurricane Wind Scale

UTC (7 p.m. CDT) on August 26, Harvey became a Category 4 hurricane as it approached the Central Texas coast. During Harvey's rapid intensification phase, it strengthened from a tropical depression to a Category 4 hurricane in only 57 hours. Harvey made landfall at peak intensity approximately four miles east of Rockport, Texas, on San Jose Island at 03 UTC (10 p.m. CDT). Figure 1 shows the Hurricane Harvey best track.

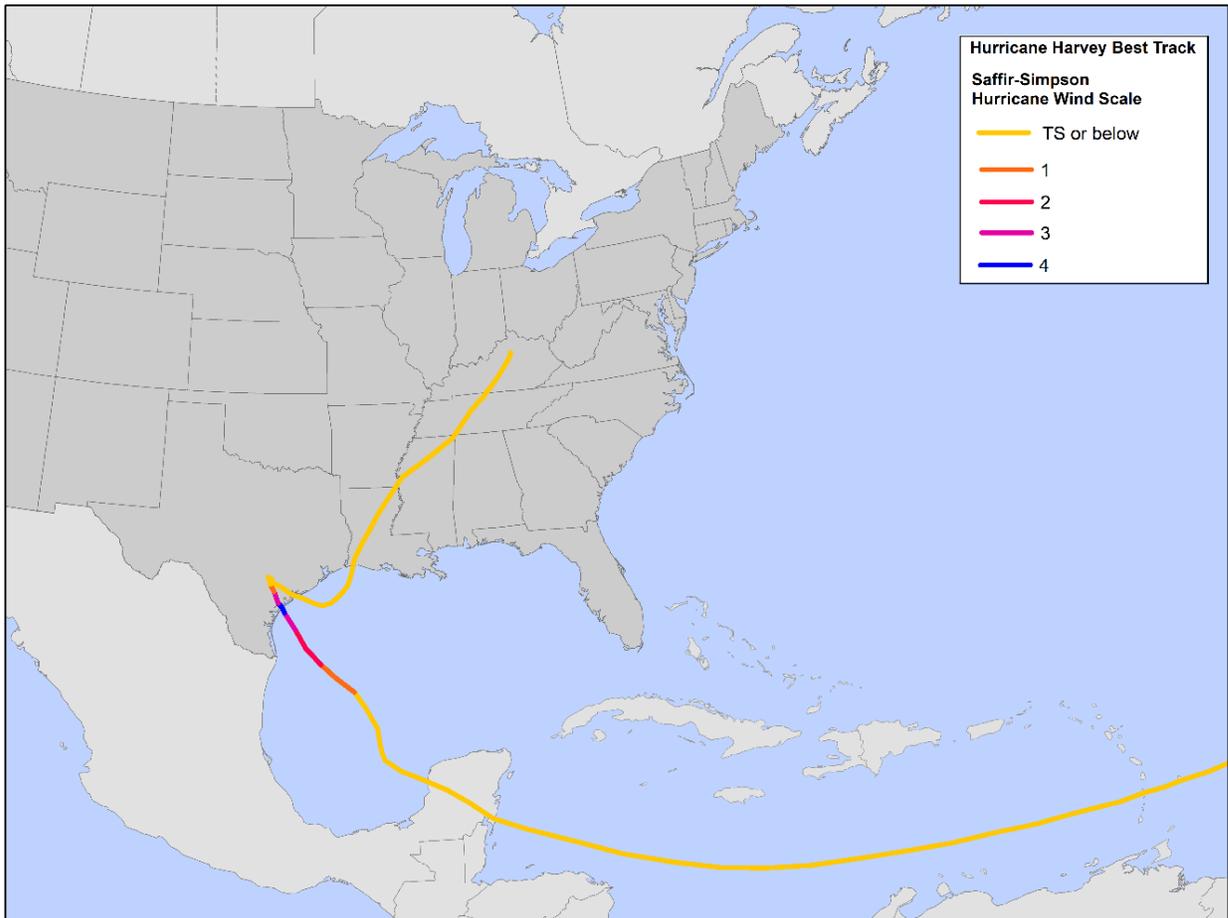


Figure 1. Hurricane Harvey best track data.

At landfall, Hurricane Harvey had a minimum central pressure of 937 mb and maximum estimated sustained (1-minute mean) winds of 130 mph. After landfall, Harvey encountered weak steering currents and stalled for several days just inland, leading to record rainfall and catastrophic flooding across southeast Texas (Blake and Zelinsky 2018).

This report focuses on IBHS damage assessments of direct hurricane wind effects associated with the first landfall of Hurricane Harvey on the Central Texas coast. The flooded areas further north and near Houston were not visited by IBHS teams, and are not discussed in this report.

Post-Disaster Investigation Tool

IBHS used a software application to collect data on damage resulting from Hurricane Harvey. The post-disaster investigation (PDI) software application was developed by IBHS in 2006–2007 as a tool to systematically collect data on a large number of damaged or undamaged residential structures subjected to high winds following a hurricane. The tool is not designed to collect data regarding storm surge or flood damage. The tool was subsequently expanded for data collection on commercial structures. The residential data collection version was recently converted for use on any Apple or Android device to allow for broader team participation.

All data are georeferenced and focus on details such as terrain exposure, elevation and roof structures, finishes, openings and opening protection, attached structures, and damage to these building systems. Pictures can be included with each logged structure. The software uses a decision-tree method where certain questions are only triggered by specific and relevant responses to previous questions. For example, the tool does not ask about window damage on a specific elevation unless the user previously responded that there were windows present on that elevation. This decision-making logic reduces the time required for data collection by eliminating the need to navigate irrelevant data entry fields.

Deployment Strategy

The IBHS damage assessment focused on the initial landfall location near Rockport, Texas, to investigate structural performance of residential buildings where the highest winds occurred. Because damage data are perishable as recovery efforts begin, it was imperative to arrive in the affected area as soon as safely possible. Hurricane Harvey made landfall on the evening of August 26, and the first member of the IBHS team arrived in Corpus Christi, Texas, on the evening of August 28 to begin preparations.

Logistics

Corpus Christi was selected as the operational hub for the mission because it was close to the landfall location, it had a functioning airport with rental cars available, and it did not suffer large-scale power outages. Hotel reservations were made for all team members by August 27, and sell-outs happened shortly thereafter. All team members arrived in Corpus Christi by mid-day on August 29. The survey team traveled from five separate locations to Corpus Christi and comprised four IBHS engineers, two staff from SwissRe, and two staff from State Farm’s Technology Research and Innovation Lab.

Damage was concentrated in small spatial zones, and the investigation team was small, so all teams usually remained in the same neighborhood while collecting data. In a few instances,

a small team split off from the larger group to evaluate commercial structures or known code-plus structures. For safety reasons, investigators generally “hop-scotched” house-to-house along a street, so that there was always another team member one or two houses away. Observations were made from the street or sidewalk, unless a team member was invited to come closer by the building owner.

Site Selections

One key goal of the damage investigation was to assess building performance across wind speed zones, exposures, and for different construction eras. The following datasets were used to help determine survey locations:

- Wind speed or radar measurements made by field research teams (University of Florida, Texas Tech University, and the Center for Severe Weather Research)
- RMS HWind wind field analysis
- Intelligence received from other colleagues conducting damage surveys
- NOAA post-event aerial photographs (access became available on August 29, with more data uploaded daily)
- Google Earth base maps (to assess pre-event condition, and determine era, type of construction, and exposure) Texas Department of Transportation maps (to ensure that selected zones were physically accessible)

The locations and individual houses selected and included in the database are not randomly distributed. Therefore, the results presented here offer a snapshot of the trends seen, but selection of a different set of houses would have yielded slightly different results.

Figure 2 provides an overlay of RMS HWind peak 3-second gust wind speeds with locations of University of Florida and Texas Tech University instruments, and the IBHS damage investigation sites that were primarily located on the left side of the track. Areas near the coast on the right side of the track experienced higher wind speeds according to the HWind analyses, but these areas are isolated and unpopulated.

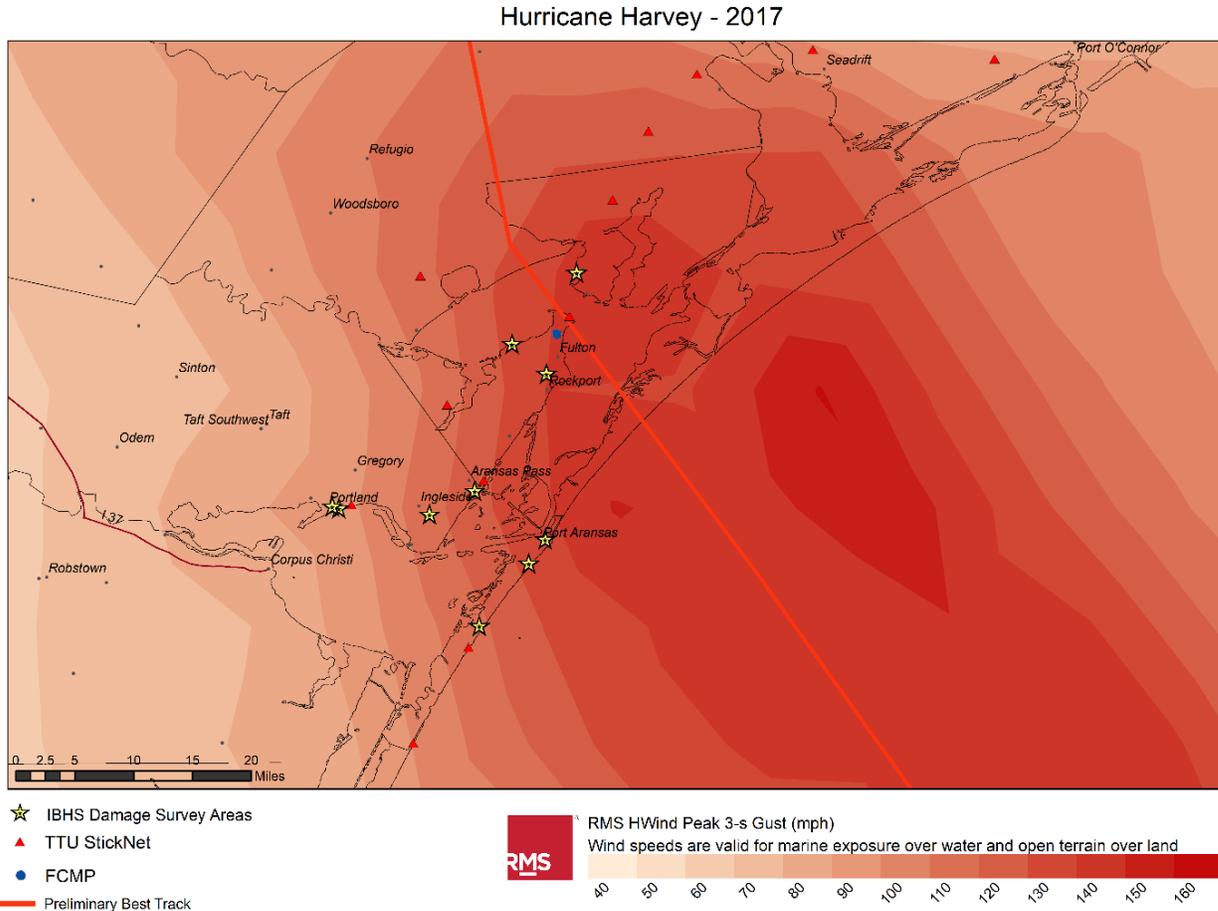


Figure 2. RMS HWind peak 3-second gust wind speed swath overlaid with university instrument and IBHS damage survey locations. The wind data represent open terrain exposure over land and marine exposure over water.

Preliminary Findings and Observations

IBHS released a [preliminary findings report](#) to members in October 2017. It described overall observations regarding residential and commercial structure damage; vulnerable components; effects of exposure and age of building; and factors that led to challenges in recovery that could have been mitigated through use of IBHS’ FORTIFIED programs.

Data Summary

Assessment teams collected data for 213 structures in nine neighborhoods over two and a half days. Table 1 summarizes the age of the buildings, wind speed and damage by location. Buildings were generally site-built, wood-frame, single-family, one- or two-story residential structures with roof pitches greater than 2/12. Foundations were typically slab-on-grade, or built on piers, with a limited number of crawlspace foundations. Because data were

generally collected from the legal right-of-way (street or sidewalk), access to all four elevations of a given house was typically not available.

Table 1. Damage survey locations and characteristics.

Location	Construction Era	Estimated Wind Speed	General Damage State
Portland	1960s–1970s	80–90 mph	Minor: finishes, attached structures, roof cover
Ingleside	1960s–1990s	80–90 mph	Minor: finishes, garage, rooftop items, roof cover
Mustang Island	1990s–2010s	90–100 mph	Minor: finishes, garage, door, attached structures
Aransas Pass	1990s–2000s	110–120 mph	Minor: finishes, garage, rooftop items, roof cover
Port Aransas North	1960s–2010s	110–120 mph	Minor (newer homes), Major (older homes): finishes, wall structure, garage, windows, doors, attached structures, roof cover, roof structure
Rockport Southeast	2000s	120–130 mph	Minor: finishes, roof cover
Holiday Beach	1960s–1990s	120–130 mph	Major: finishes, wall structure, garage, windows, doors, attached structures, roof cover, roof structure
Port Aransas South	2000s–2010s	120–130 mph	Minor: finishes, wall structure, garage, windows, doors, attached structures, roof cover, roof structure
Rockport Northwest	1960s–2010s	130–140 mph	Major: finishes, wall structure, garage, windows, doors, attached structures, roof cover, roof structure

Overview of Building System Performance

IBHS evaluated the full data set to determine the performance of roof cover, roof slope, roof shape, roof components, and attached structures, and to investigate the effect of exposure to wind.

Roof Cover: Asphalt Shingle Roofs

- More than 85% of the roof covers investigated were asphalt shingle roofs, with no quantities greater than 5% for other roof cover types.
- For the shingle roofs, Figure 3 shows:
 - More than half of the shingle roofs surveyed had some roof damage and cover loss.
 - 3-tab shingle roofs had higher damage frequencies than architectural shingle roofs.
- This could be due to the age of the buildings, as architectural asphalt shingles have become more popular in recent years (Roofing Contractor 2018). However, 3-tab shingles have also been found to have higher damage rates compared to architectural shingles of the same age (Dixon et al., 2014).

- The roof cover damage rate for each shingle type is nearly identical to the overall roof damage rate, which means that if a roof displayed damage, it nearly always had roof cover damage.
- The frequency of underlayment and roof decking damage did not seem to be influenced by shingle type, and was much lower than the rate of shingle damage.

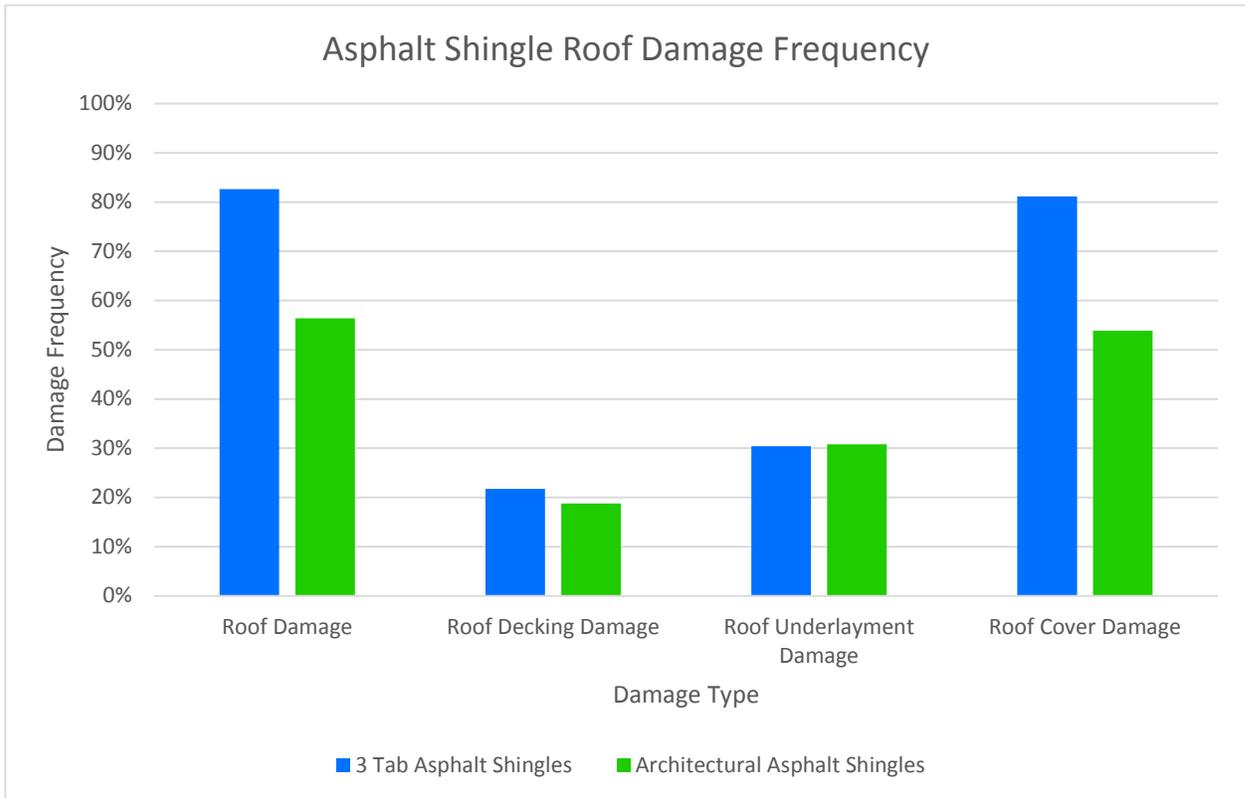


Figure 3. Distribution of damage frequency to roof system components by asphalt shingle type.

Roof Slope: All Roofs

Most of the roofs assessed had a moderate slope (11–30 degrees, or between 2/12 and 7/12). However, there were representative amounts of shallow (less than 10 degrees, or less than 2/12) and steep (greater than 30 degrees, or greater than 7/12) roofs, which allowed for performance comparisons to be made.

- For all roofs evaluated (all roof cover types), Figure 4 shows:
 - Roof cover damage was generally consistent among the roof slope categories, ranging from 63%–72%.
 - Roof decking and underlayment damage were influenced by roof slope. Steep-slope roofs had the lowest percentage of roof underlayment or decking damage observed. Low-slope roofs had the highest percentage of roof underlayment or decking damage.

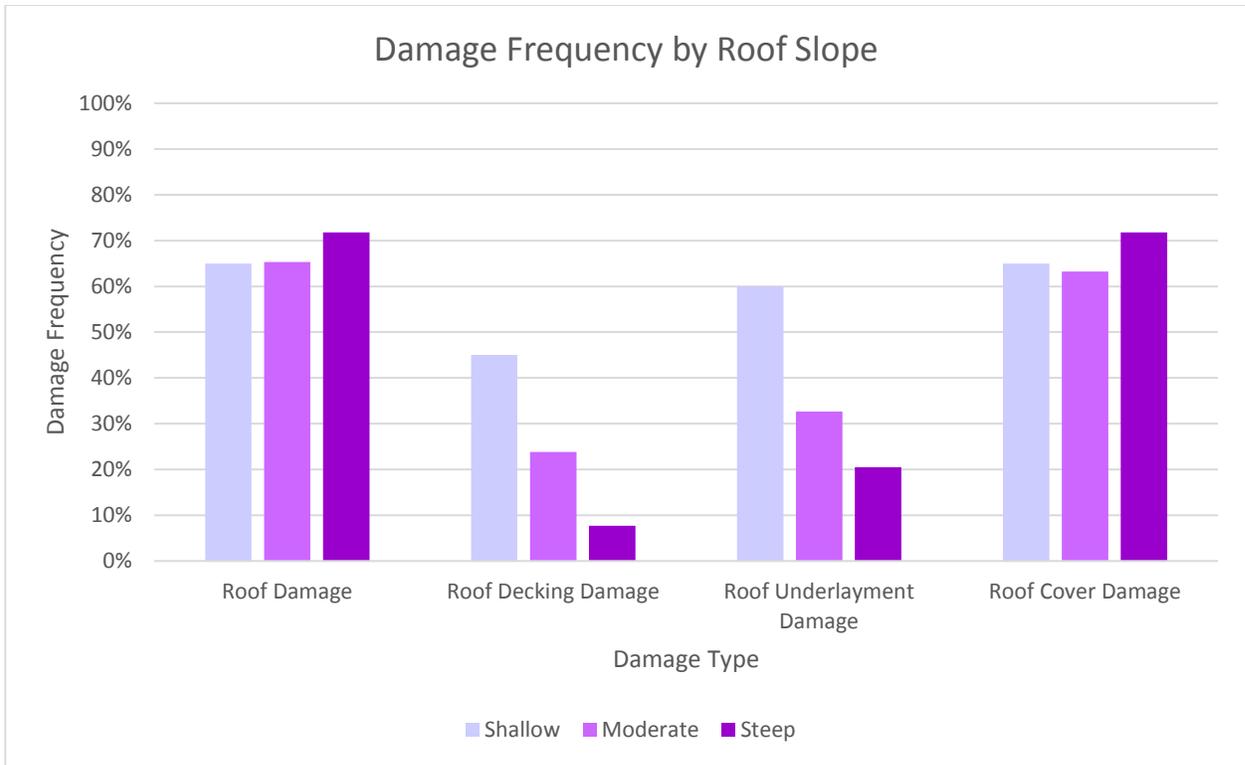


Figure 4. Distribution of damage frequency to roof system components by roof slope.

Roof Shape: All Roofs

- Most of the roofs assessed were gable, hip, or gable/hip combination roofs. Other shapes did not constitute a large enough sample size to do adequate performance comparisons.
- Other studies have found that hip roofs are typically more resistant to wind damage than gable roofs (Meecham et al., 1991; Meecham, 1992; Kopp et al., 2016; Gavanski and Kopp, 2017; Stevenson et al., 2018).
- For all roof cover types evaluated, Figure 5 shows:
 - Roof shape did not cause much variation in roof cover damage, with damage ranging between 60%–71%.
 - Gable roofs had higher rates of roof underlayment and decking damage compared to hip and combination roof shapes.

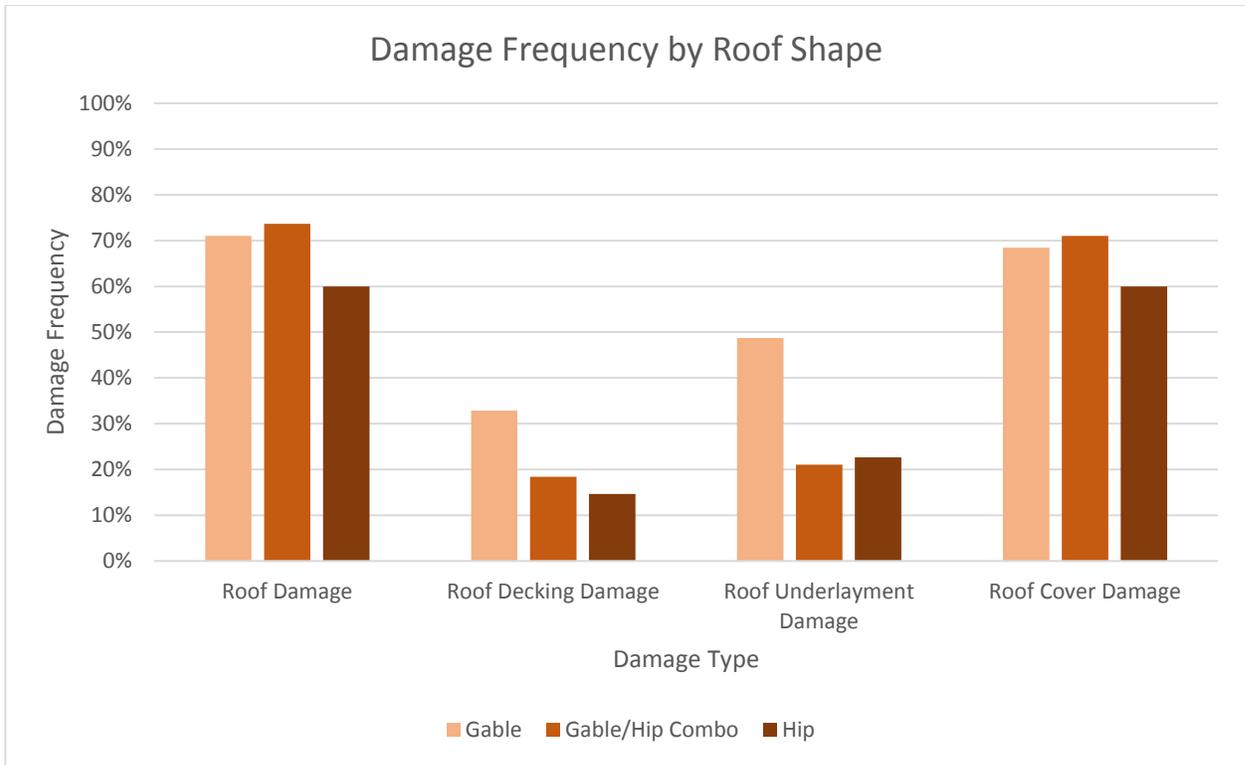


Figure 5. Distribution of damage frequency to roof system components by roof shape.

Roof Components: All Roofs

For all roof cover types evaluated, Figure 6 shows:

- The majority of visible damage was associated with damage to the roof covering in the field, eave, or rake edge.
- Damage rates were also higher for ridge and hip ridges.
- Total roof collapse occurred for less than 10% of the buildings surveyed.

From a life-safety perspective, the building code generally did its job, but significant insured losses associated with this hurricane still occurred.

- Damage rates for roof accessories such as vents and skylights were low.

Because not all elevations were accessible, this report might not account for additional roof components or damage to them.

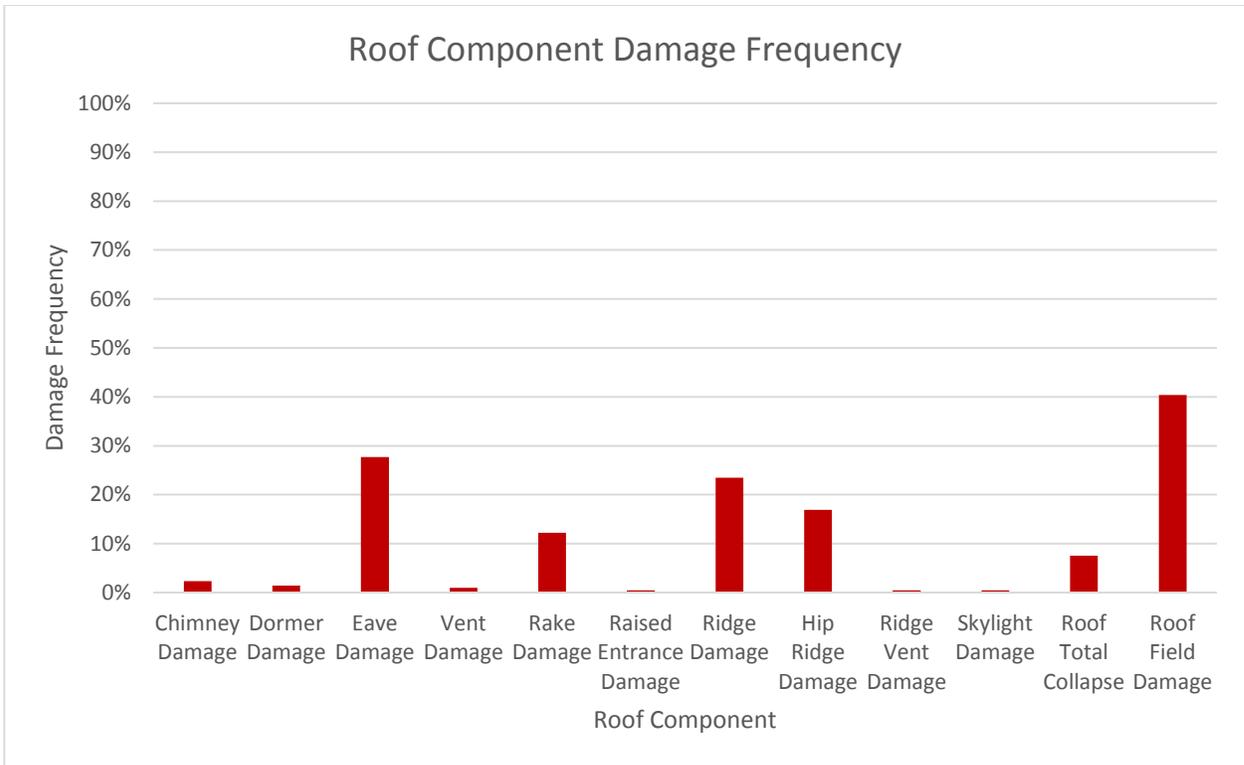


Figure 6. Distribution of damage frequency to roof system components.

Doors

The doors on all elevations were evaluated to determine type of door, whether the door was protected, and whether the door was damaged. Figure 7 shows:

- Unprotected doors were damaged two to six times more often than protected doors
- Slider doors had the highest incidence of damage for both protected and unprotected doors

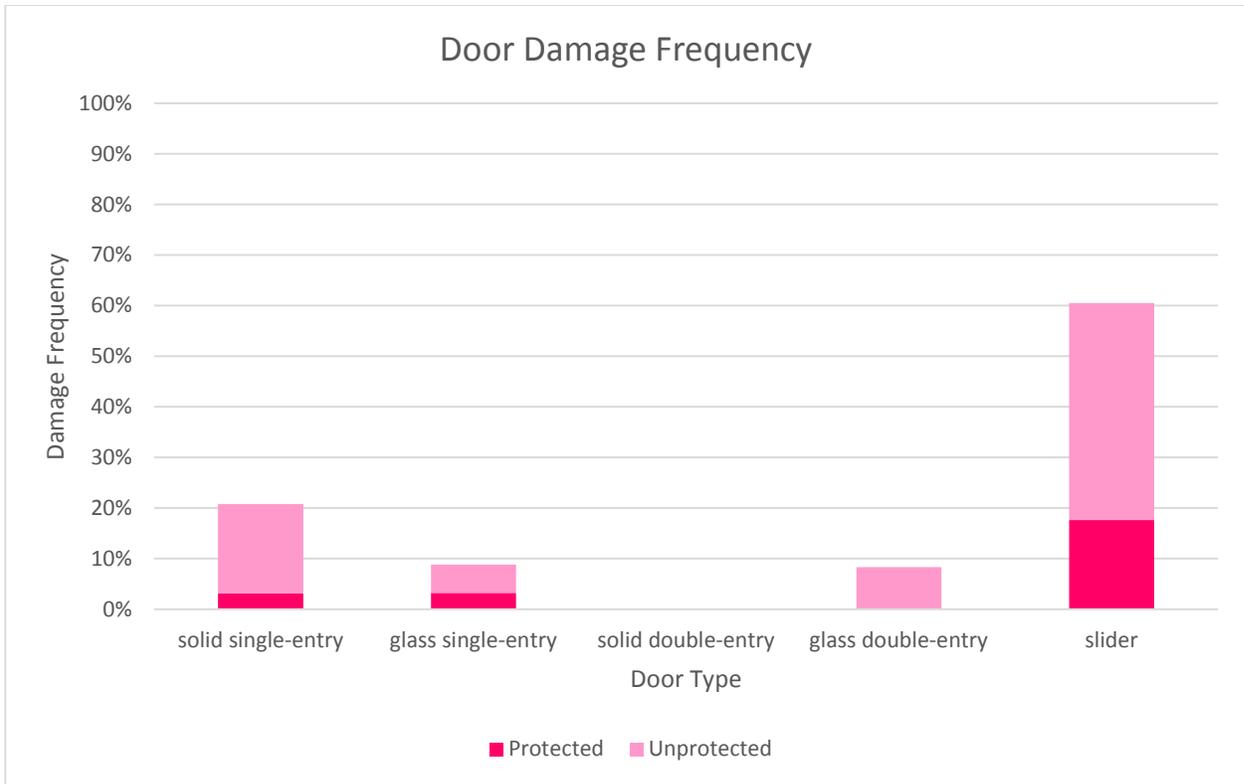


Figure 7. Distribution of damage frequency by door type and whether it was a protected opening, or unprotected.

Attached Structures

Structures such as porches, sunrooms, pool cages, and others are frequently attached to the primary residential building. The connections between the primary and attached structures are often weak or inadequate. Consequently, damage to attached structures is common in wind events and in many cases, causes additional damage to the primary building, such as the example in Figure 8 from Holiday Beach.

- 23% of the attached structures evaluated in Hurricane Harvey were damaged.
- The back elevations, and some other elevations in many situations, were not accessible. It is likely that additional attached structures existed on the surveyed houses that could not be assessed from the public right-of-way. An aerial investigation could help fill this data gap.
- By contrast, a study conducted by IBHS following Hurricane Charley in 2004 found that pool cages and screened porches were damaged for about 80% of residential properties with claims.



Figure 8. Example of an attached porch that was damaged and may have caused additional damage to the roof of the main building.

Exposure

The surrounding terrain exposure and fetch proved to be a key characteristic that affected the damage rate of the buildings surveyed.

- The strongest winds on the storm-relative right side of Harvey’s track came ashore in an unpopulated area. On the left side of the track where IBHS damage investigations were conducted, the winds generally had an overland fetch back toward the Gulf of Mexico.
- The topography of the area resulted in the strongest winds flowing over the relatively smooth Copano Bay into two neighborhoods (Rockport Northwest and Holiday Beach). This allowed the mean flow to speed up relative to overland exposures upstream and these two neighborhoods had the most severe total damage of the areas investigated by IBHS teams.
- Although the assessment areas in Portland, Aransas Pass, Mustang Island and Port Aransas were within one half mile of the shore, the fetch in these areas was over land, which reduced the mean wind speeds, thus causing less damage.

Each elevation that was accessible and investigated by IBHS was treated individually to characterize the exposure and resulting damage. It should be noted that minor differences in the hurricane track would have altered the wind direction and therefore the upstream terrain features may have been different, which could have slowed or accelerated the winds

that impacted a specific structure, causing a different damage state. The total count of elevations with different exposures was calculated and a damage rate determined as shown in Figure 9 .

- Elevations with the least amount of roughness or obstructions to slow the wind, such as open water and open land, had the highest rate of observable damage.
- Elevations with higher roughness, such as dense suburban with dense trees, had the lowest observable damage rates.

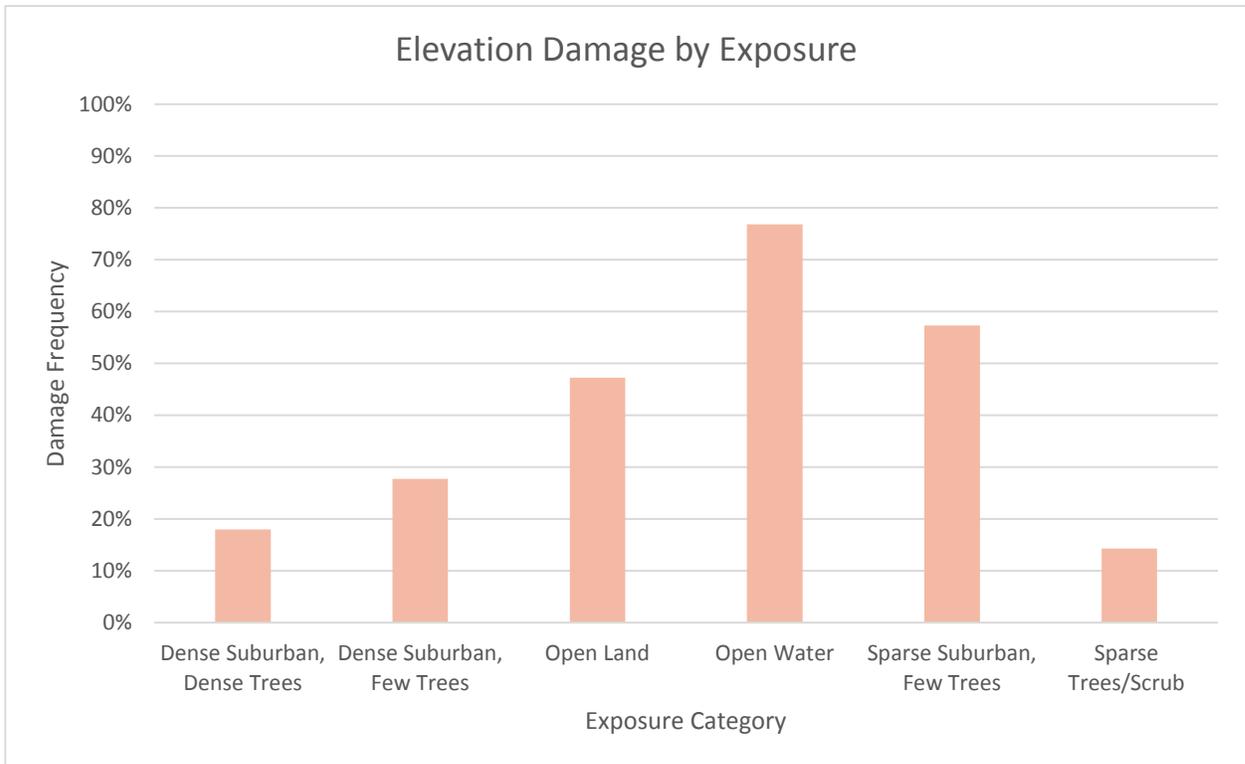


Figure 9. Distribution of damage frequency of individual elevations by exposure.

Damage Effects by Wind Speed Zone

In addition to observing general damage trends, damage was investigated by neighborhood, which allowed for an examination of the effects of wind speed and construction era. All the neighborhoods investigated by the IBHS team were located within the ASCE 7-10 design wind speed zone of 140–150 mph, as shown in Figure 10. Newer homes in these areas should have been able to resist wind pressures and loads associated with 140–150 mph winds. However, none of the areas investigated experienced peak 3-second gust wind speeds higher than 140 mph, meaning the design pressures and loads should not have been exceeded, yet damage still occurred to both newer and older homes (see Table 1).

Hurricane Harvey Wind Speeds vs. Design Level Wind Speeds

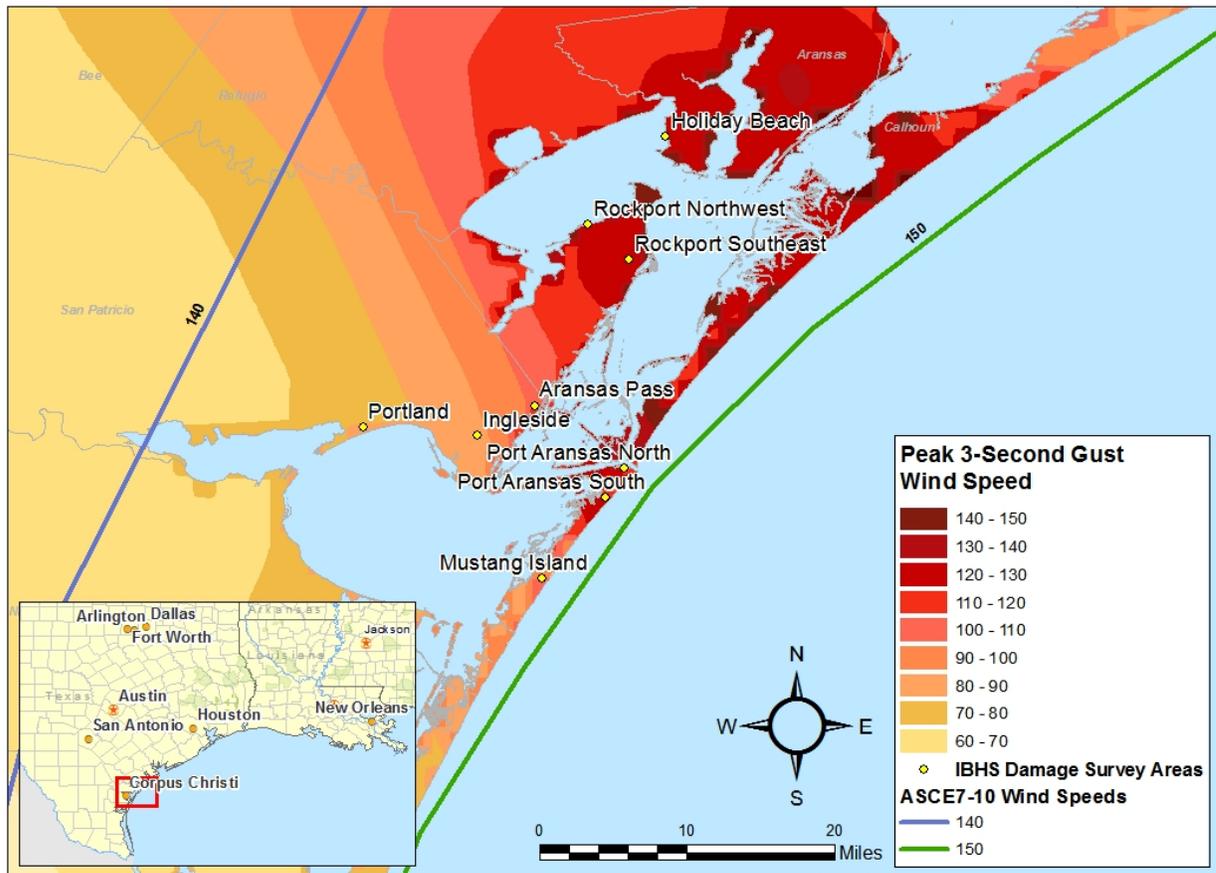


Figure 10. Peak 3-second gust wind speeds experienced in Hurricane Harvey are overlaid with design level wind speeds contours from ASCE 7-10 and neighborhoods investigated by IBHS. The peak 3-second gust data are from RMS HWind analysis and represent peak winds for an open terrain exposure over land areas.

Roof Damage of Asphalt Shingle Roofs

Shingle Damage Frequency

The roof damage frequency for asphalt shingle roofs was evaluated for each neighborhood, and grouped by the wind speed zones outlined in Table 1. Figures 11–14 show the following:

- Holiday Beach, one of the most severely damaged zones overall, had a lower roof cover damage frequency than Rockport Southeast and Port Aransas South.
- Both Rockport Southeast and Port Aransas South had little to no structural damage and were in the same wind speed region as Holiday Beach.
- Homes in Ingleside, with estimated 3-second gust wind speeds of 80–90 mph, had roof cover damage frequencies (50%–70%) similar to those in some areas that experienced 110 mph or greater wind speeds, such as Holiday Beach (61%–83%) and Port Aransas North (54%–75%).

Based on the typical size and construction, the homes in Ingleside were generally older and lower-value homes.

- Roof damage frequency generally increased with increasing wind speed and, as expected, 3-tab roofs suffered the most damage. Vulnerability curves for both shingle types (Figure 12) provide relatively strong fits to the data as shown by the high R^2 values (0.78). This means roof cover loss rates are reasonably well-behaved by wind speed, and thus can be modeled relatively well.

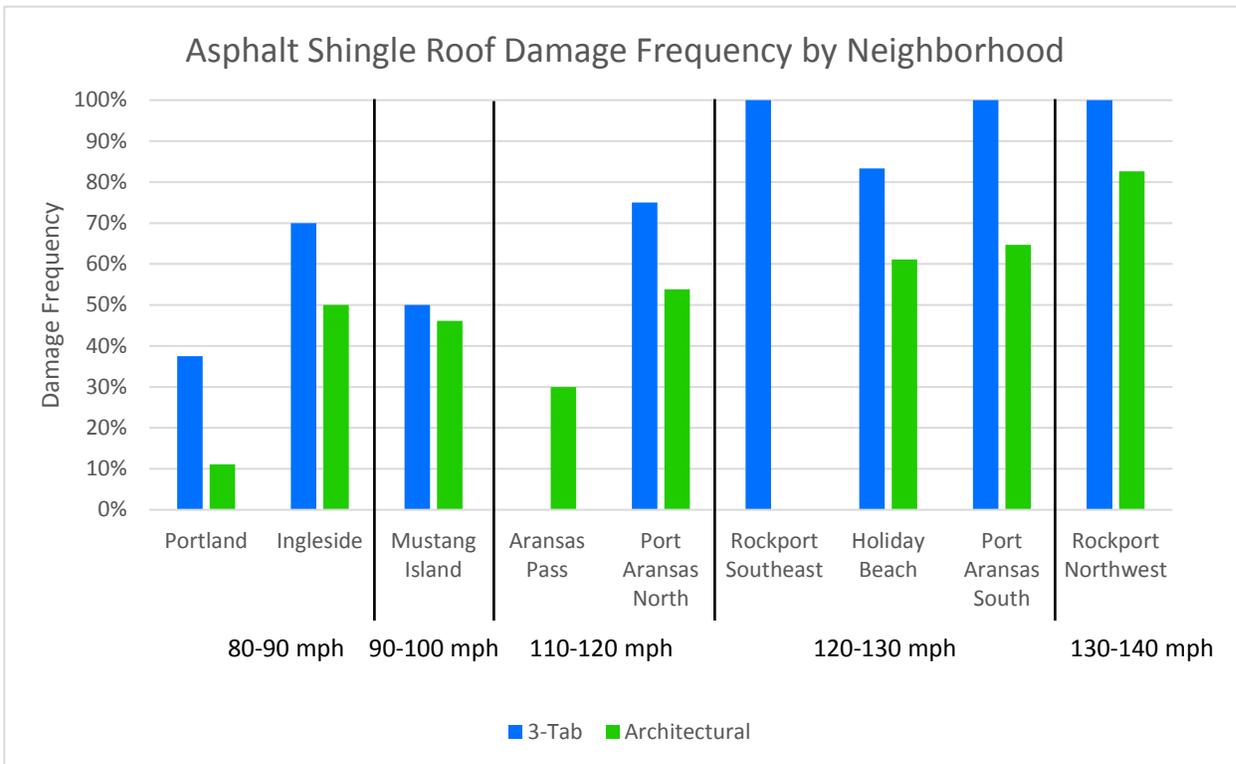


Figure 11. Distribution of roof damage frequency of asphalt shingle roofs by wind speed zone.

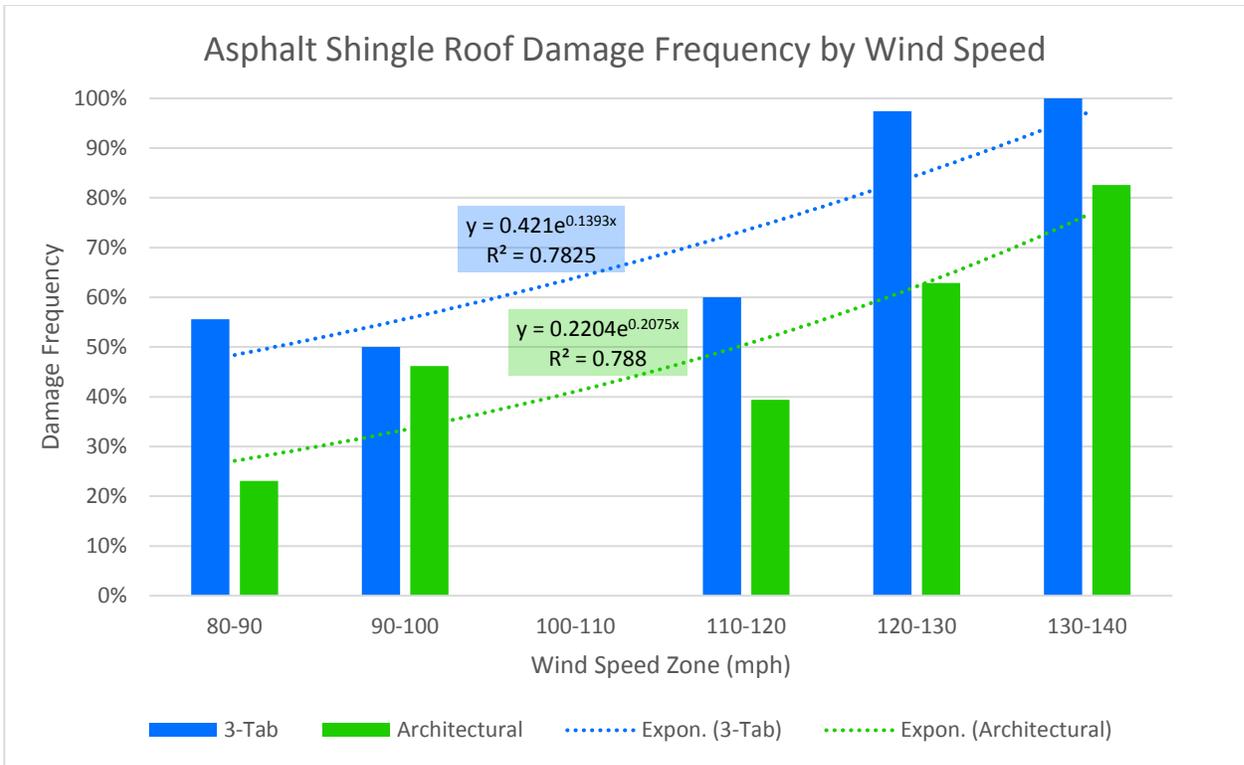


Figure 12. Roof cover damage frequencies in neighborhoods with the same wind speed were combined to generate vulnerability curves. Exponential trend lines were fitted to the data and are displayed with R^2 values. No data were collected in the 100–110 mph wind speed zone.

Damage Frequency of 3-Tab Shingles

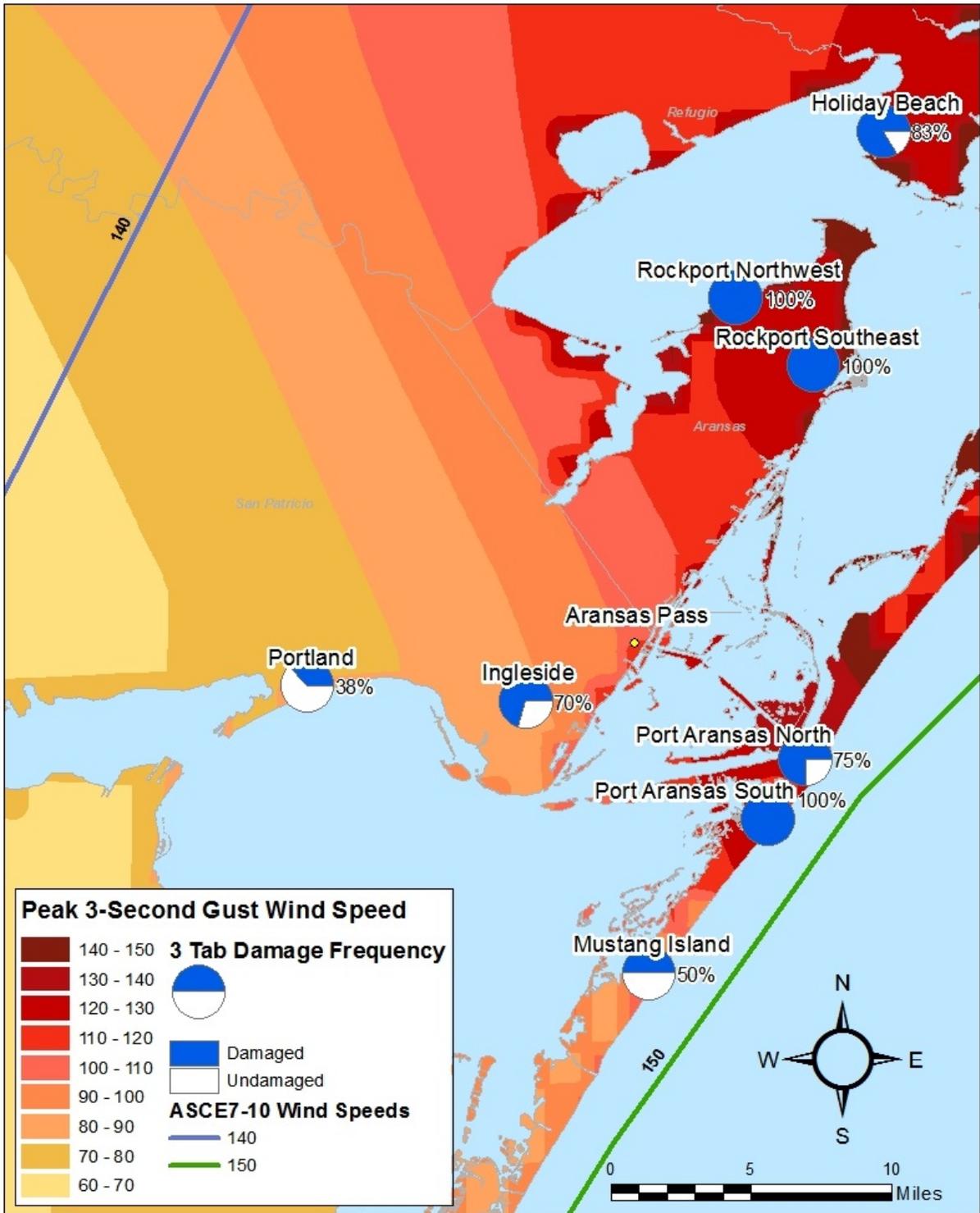


Figure 13. Damage frequency of 3-tab shingles. There was only one 3-tab shingle roof in Aransas Pass, and it was undamaged, resulting in a 0% damage frequency for that location.

Damage Frequency of Architectural Shingles

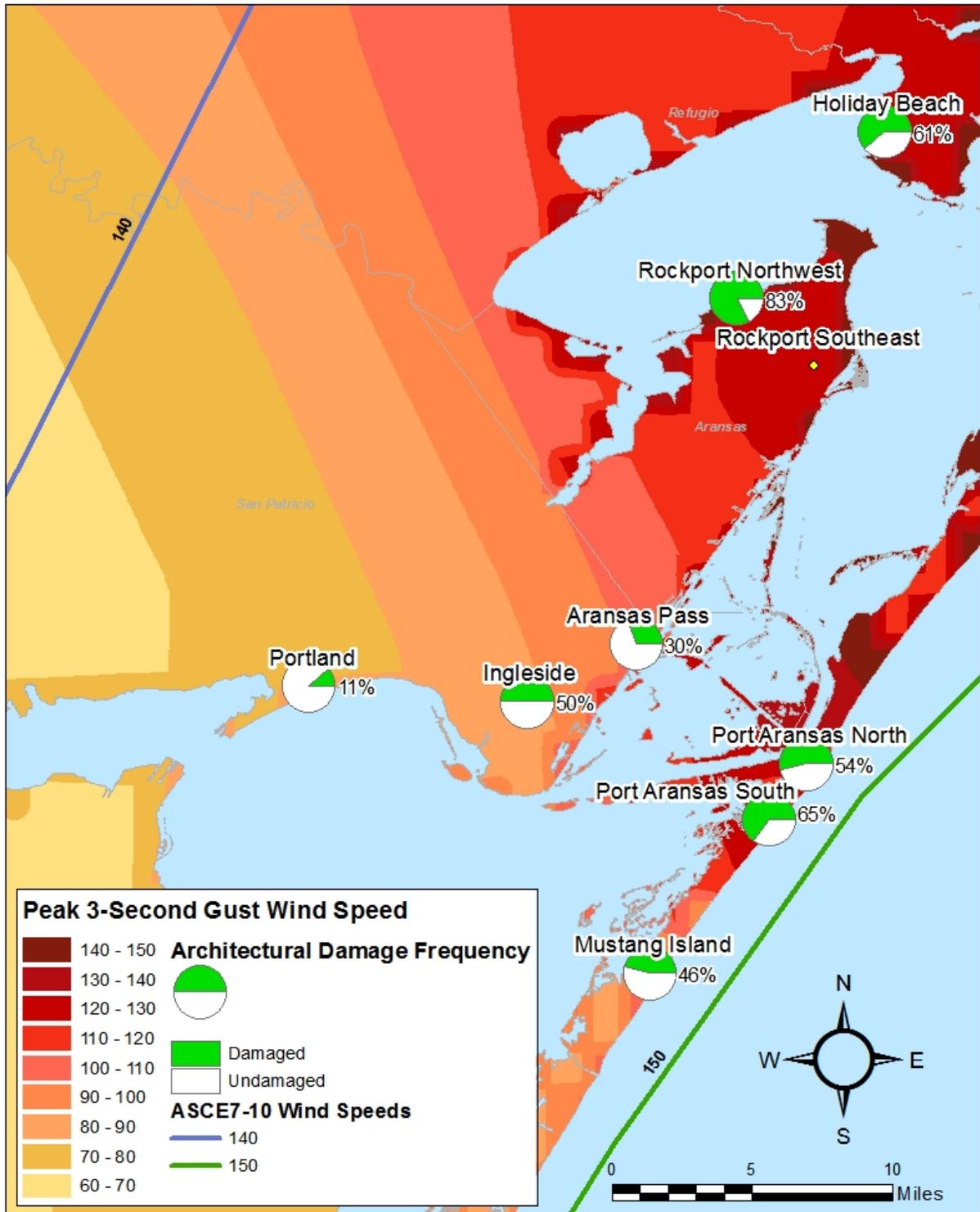


Figure 14. Damage frequency of architectural shingles. There were no architectural shingle roofs in Rockport Southeast, resulting in a 0% damage frequency for that location.

Shingle Damage Severity

The roof damage severity for asphalt shingle roofs was evaluated for each neighborhood. Figures 15–17 show that:

- The roof cover damage severity in Port Aransas South was less than Port Aransas North, especially for 3-tab shingle roofs (37% vs. 83%), despite being less than 2.5 miles apart and Port Aransas South having wind speeds 10 mph higher. The southern neighborhood was typically much newer construction with higher-value homes.
- Roof cover damage severity was approximately the same in Rockport Southeast and Northwest, even though the southeast neighborhood had a much rougher exposure, was located inland, and had wind speeds estimated to be about 10 mph lower.
 - The southeast neighborhood had only 3-tab shingle roofs, and they all displayed a classic pattern of diagonal tab loss (see Figure 16) following the pattern of unsealing noted by Dixon et al. (2014).
 - Additional research is needed to understand why shingles become unsealed at the edge of the shingle along the pattern of installation. Changes in materials and/or installation patterns are needed.
- The high roof cover damage severity for 3-tab roofs in Port Aransas North caused a spike in the damage frequency in the 110–120 mph wind speed zone, which caused a poor fit in the vulnerability curve ($R^2 = 0.41$) in Figure 17.
- The vulnerability curve (Figure 17) fit for architectural shingles is good, with an R^2 value of 0.8, which indicates the damage severity of architectural shingles by wind speed can be modeled well in this dataset.

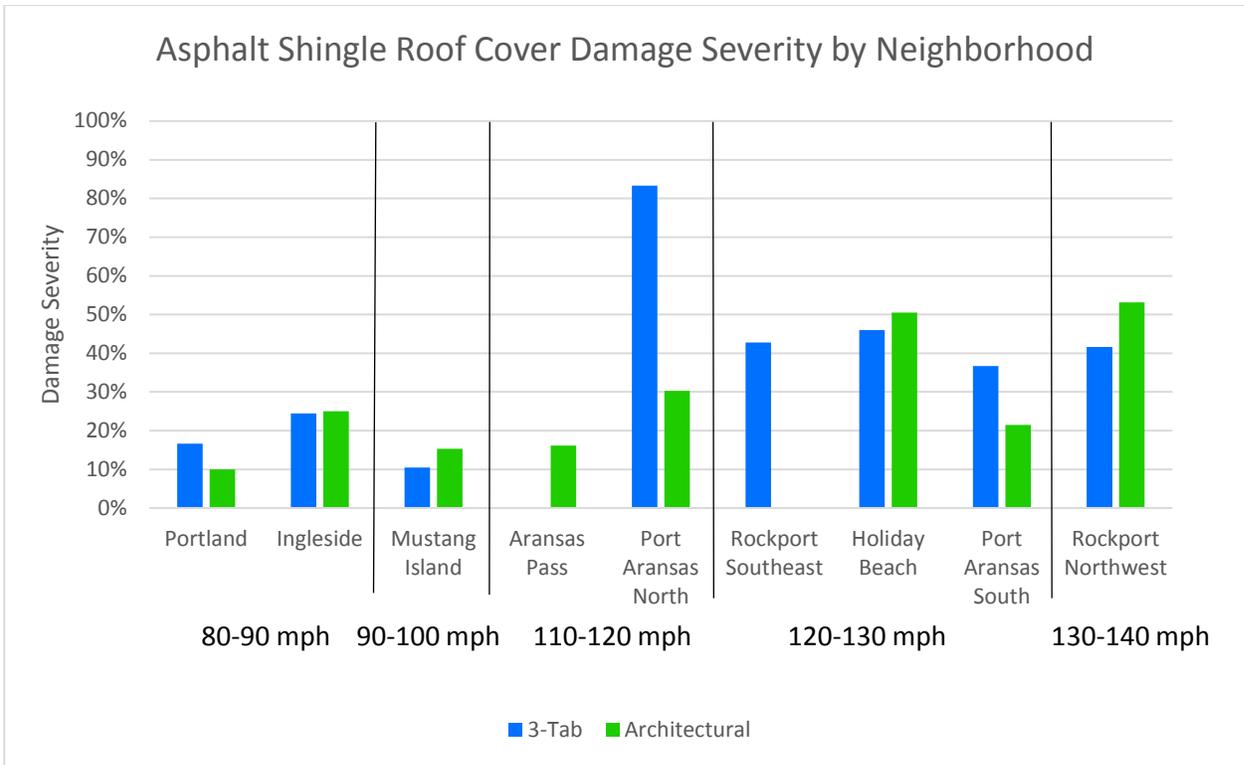


Figure 15. Distribution of roof cover damage severity of asphalt shingle roofs by wind speed zone.



Figure 16. Example of diagonal damage to 3-tab shingles, which have been shown by Dixon et al. (2014) to occur most frequently at the end of the shingle and oriented along the pattern of installation.

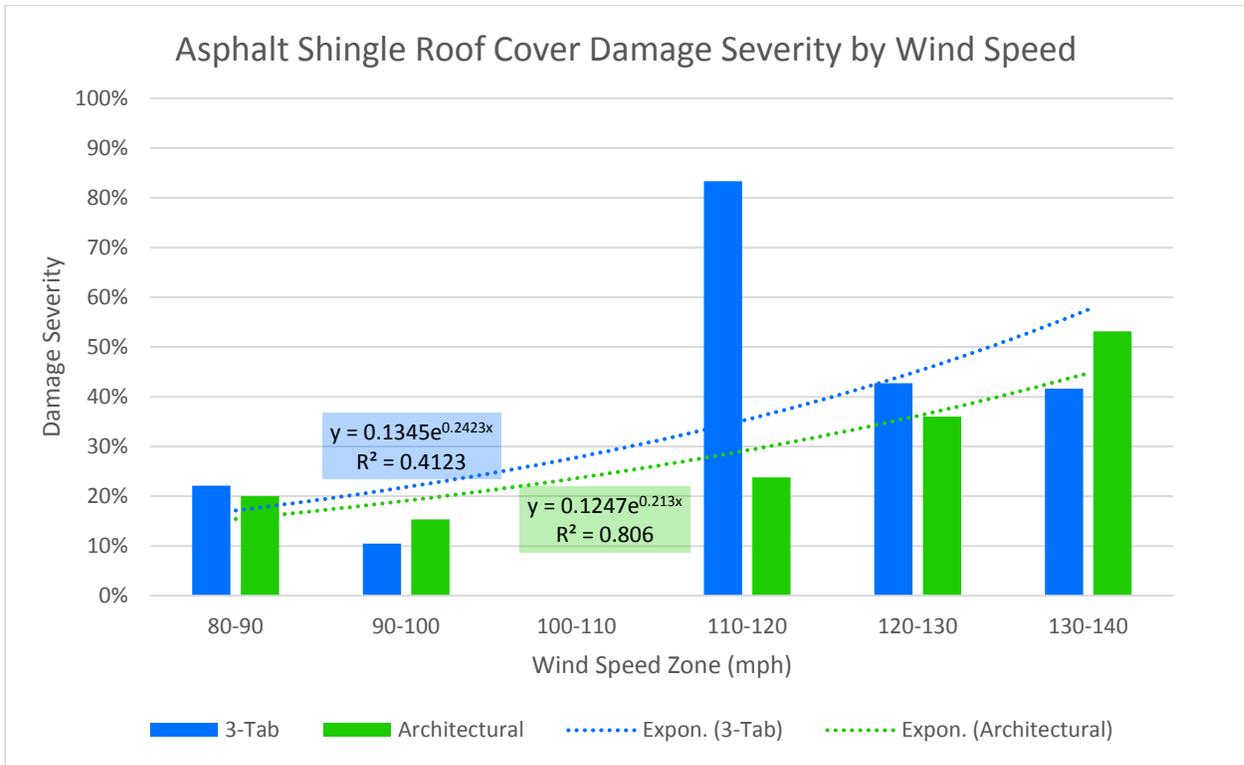


Figure 17. Asphalt shingle roof cover damage severities in neighborhoods with the same wind speed were combined to generate vulnerability curves. Exponential trend lines were fitted to the data, and are displayed with R^2 values. No data were collected in the 100–110 mph wind speed zone.

Underlayment and Roof Deck Damage Severity for Shingle Roofs

The underlayment and roof deck damage severity for asphalt shingle roofs was also evaluated for each neighborhood. Figures 18–20 show that:

- Although 3-tab shingle damage was most severe for Port Aransas North (Figure 17), Holiday Beach and Rockport Northwest had the most severe structural damage of all areas visited.
- Damage severities for underlayment and roof decking on shingle roofs were generally higher for neighborhoods in the 110 mph wind speed zone or above. However, the highest wind speed zones did not necessarily have the highest levels of damage to underlayment and decking.
- Underlayment and decking damage on shingle roofs was typically highest in Holiday Beach, Port Aransas North and Rockport Northwest, which aligns with the areas of worst overall structural damage. Additionally, these zones had wind flow off bodies of water as opposed to land and experienced winds close to that shown in the HWind analysis for open terrain exposure (or slightly higher if the upstream fetch was over a smooth bay).
- As was seen for shingle damage severity (Figure 17), the spike in underlayment and roof deck damage severities for 3-tab roofs in Port Aransas North caused a poor fit in the vulnerability curves (Figures 19–20).

- However, the vulnerability curves for underlayment and deck damage severities on architectural shingle roofs were quite good (Figures 19–20; $R^2 = 0.82$ and 0.92 , respectively).

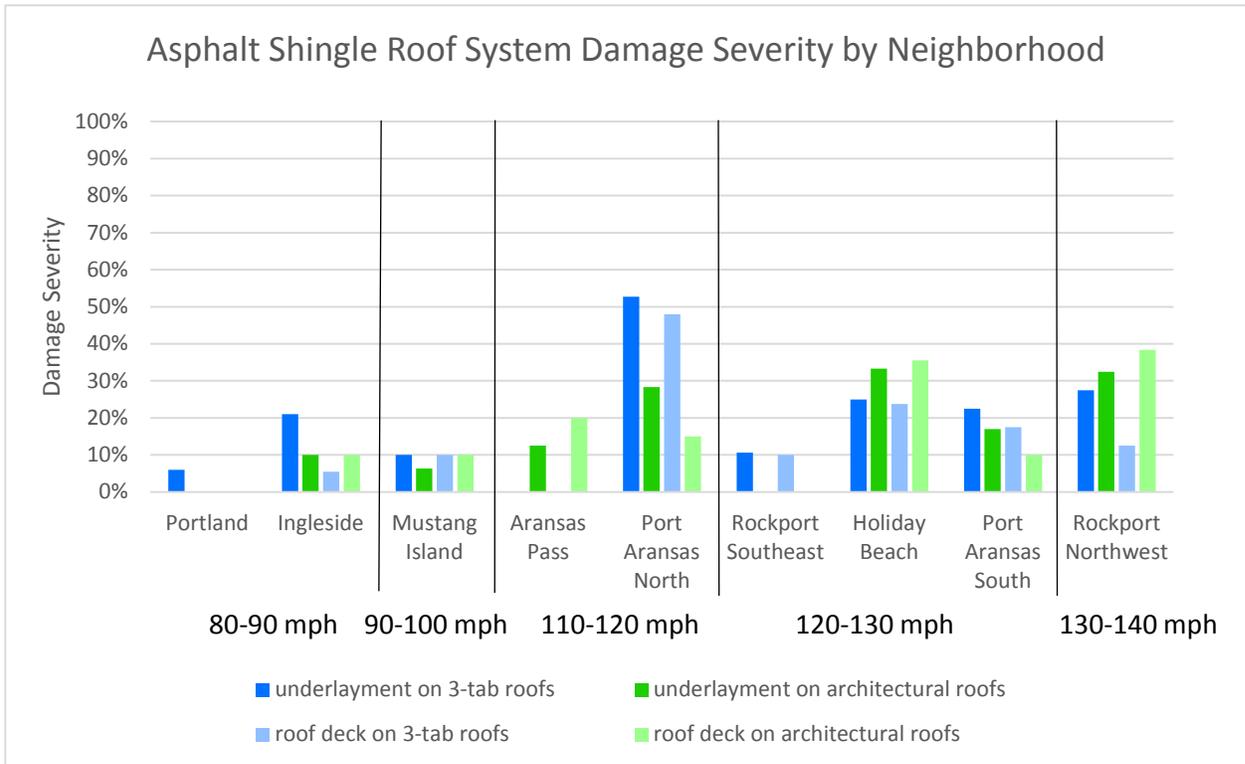


Figure 18. Distribution of roof system damage severity for asphalt shingle roofs by wind speed zone.

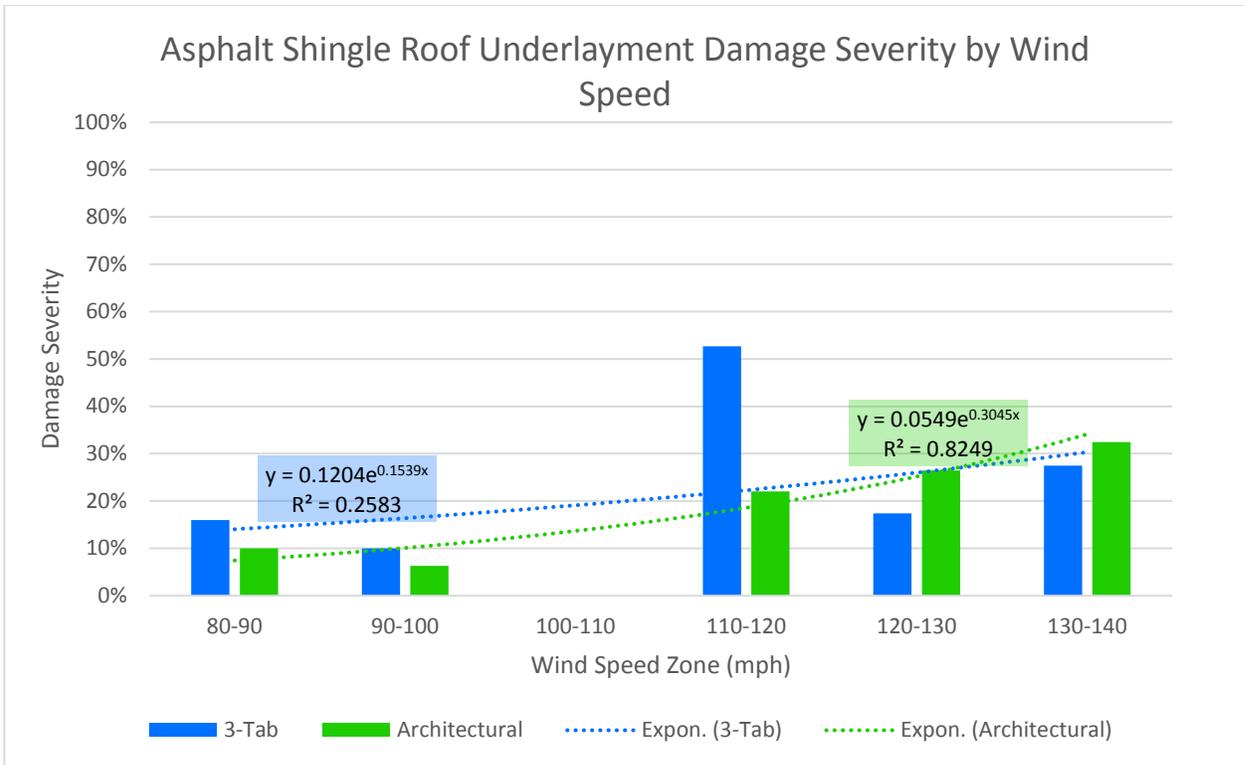


Figure 19. Underlayment damage severities on shingle roofs in neighborhoods with the same wind speed were combined to generate vulnerability curves. Exponential trend lines were fitted to the data, and are displayed with R^2 values. No data were collected in the 100–110 mph wind speed zone.

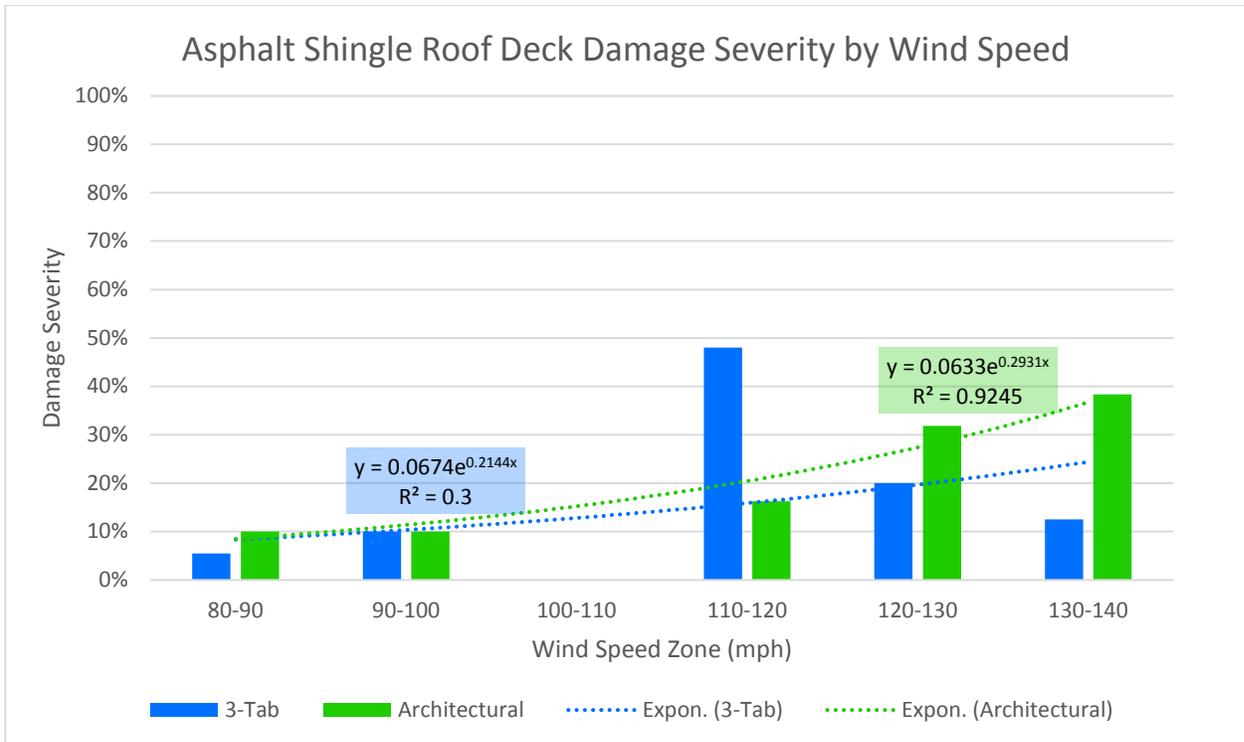


Figure 20. Roof deck damage severities on shingle roofs in neighborhoods with the same wind speed were combined to generate vulnerability curves. Exponential trend lines were fitted to the data, and are displayed with R^2 values. No data were collected in the 100–110 mph wind speed zone.

Distribution of Roof System Damage Severities

The distributions of the severity of roof covering damage, underlayment damage and roof deck damage on asphalt shingle roofs were evaluated for wind speed zones of 110 mph or higher. Figures 20–22 show that:

- For 3-tab shingles, the results were mixed. Although many roofs had a large percentage of shingles damaged or removed, other roofs had very little damage or loss.
- For architectural shingles, most exposures had 20% or fewer of their shingles damaged or removed.
- Regardless of shingle type, most roofs had little to no damage to underlayment or roof decking. More than 75% of the exposures had underlayment damage of 10% or less and 85% of the exposures had decking damage of 10% or less.

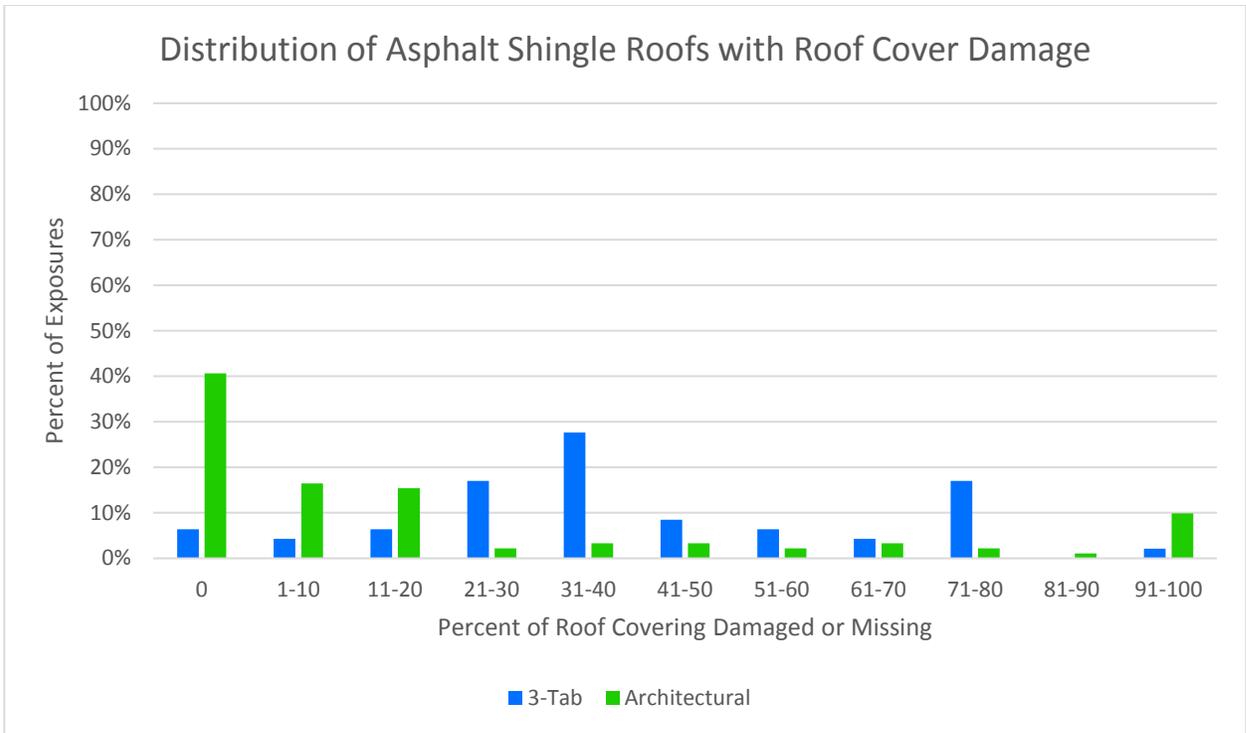


Figure 21. Distribution of asphalt shingle roofs with roof cover damage.

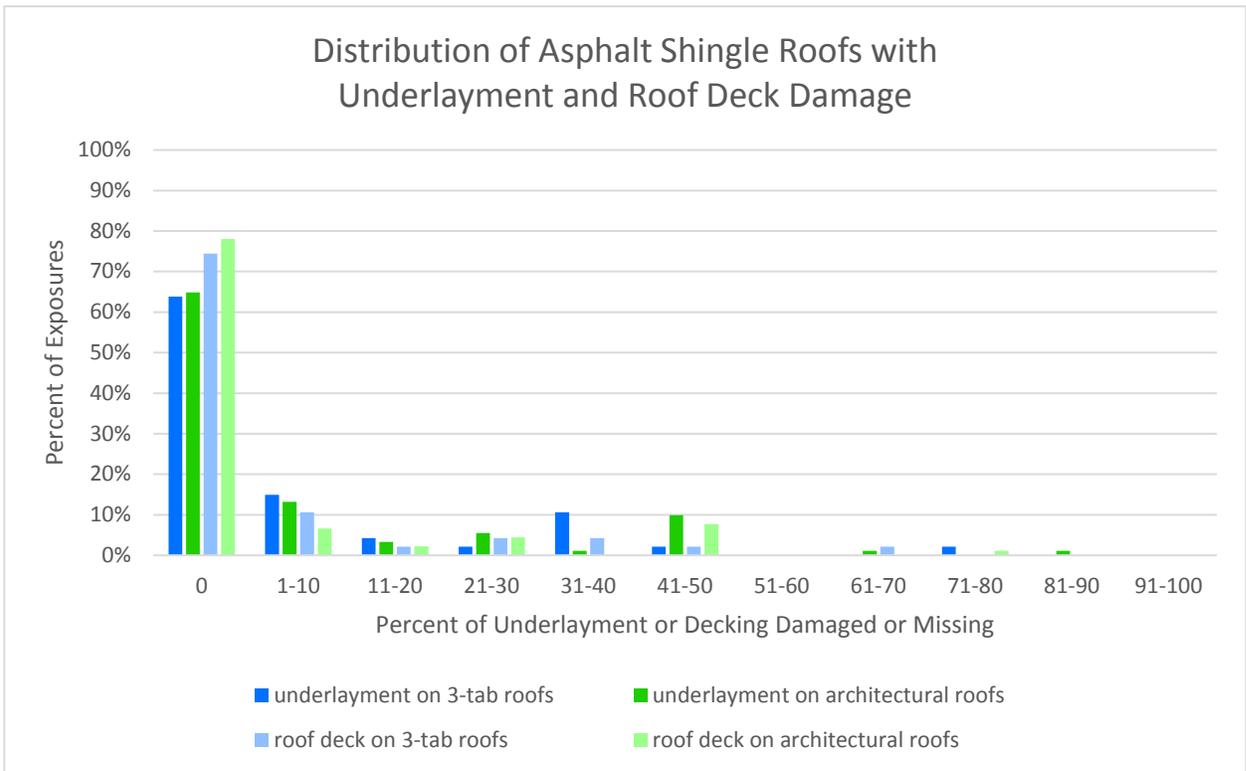


Figure 22. Distribution of asphalt shingle roofs with underlayment and roof deck damage.

Garage Door Damage

Garage doors or roll-up doors on residential and commercial structures are often damaged in hurricanes, tornadoes and high-wind events (Wadsworth 2014; Graettinger et al. 2014; Dao et al. 2014; Kovar et al. submitted 2018). Failure of these large openings often leads to additional structural damage to roofs and walls due to internal pressurization of the building. Figure 23 and Figure 24 show the damage frequency of garage doors by door size and wind speed, which show that:

- Single-car garage doors had a higher damage frequency than double-car doors. This is consistent with results found by Kovar et al. (submitted 2018).
- Only one double-car garage door located in Port Aransas North, out of 62 in the entire dataset, had a failure. Double-car garage doors were found in all neighborhoods except Mustang Island and Holiday Beach.

Most double-car garage doors were in Rockport Southeast, which was one of the most inland and protected exposure zones, and Aransas Pass, which was also sheltered from on-shore winds.

- Single-car garage door failure rates were highest in neighborhoods with wind speeds of 110 mph or higher. Single-car garage doors were present in all neighborhoods except Rockport Southeast.
- There is a general trend of increasing garage door damage frequencies with increasing wind speed (Figure 24). However, the relationship is not as strong (R^2 value of 0.57) as shingle damage frequencies.

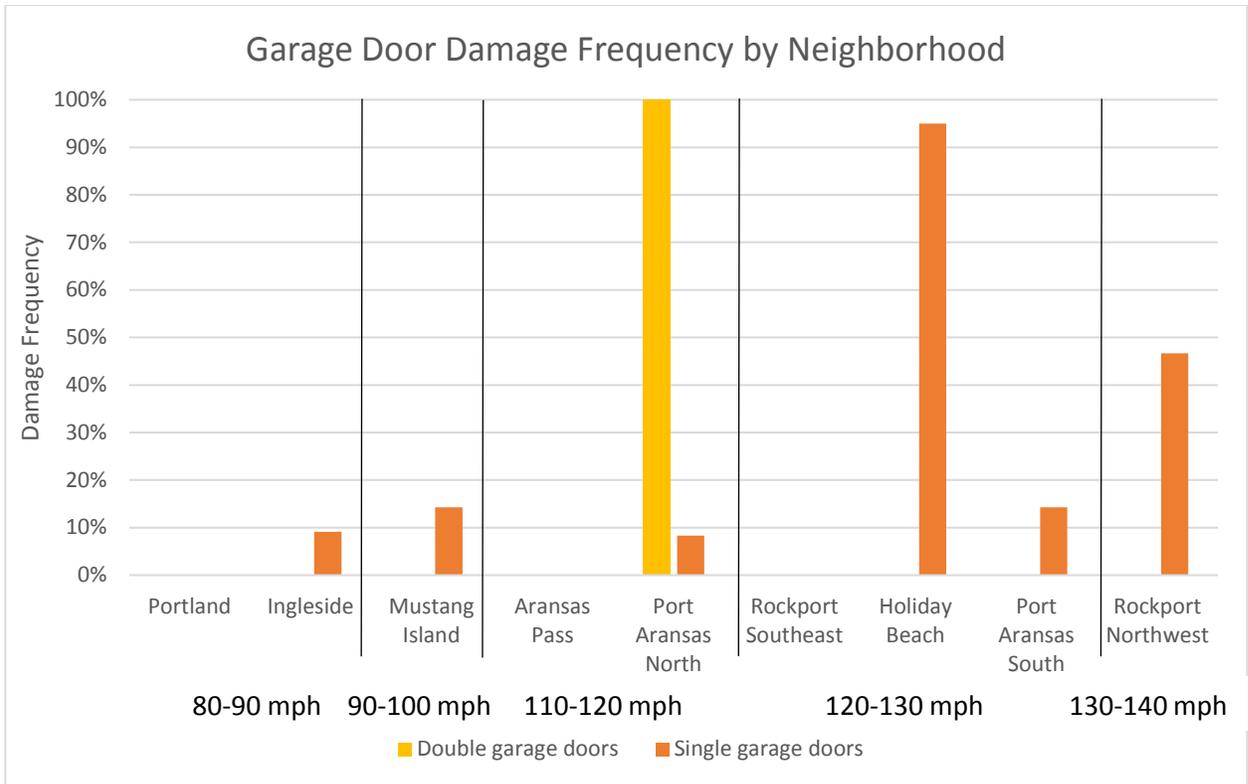


Figure 23. Distribution of garage door damage frequency by door size and neighborhood. There was only one double-car garage door in Port Aransas North, and it was damaged, leading to 100% damage frequency there.

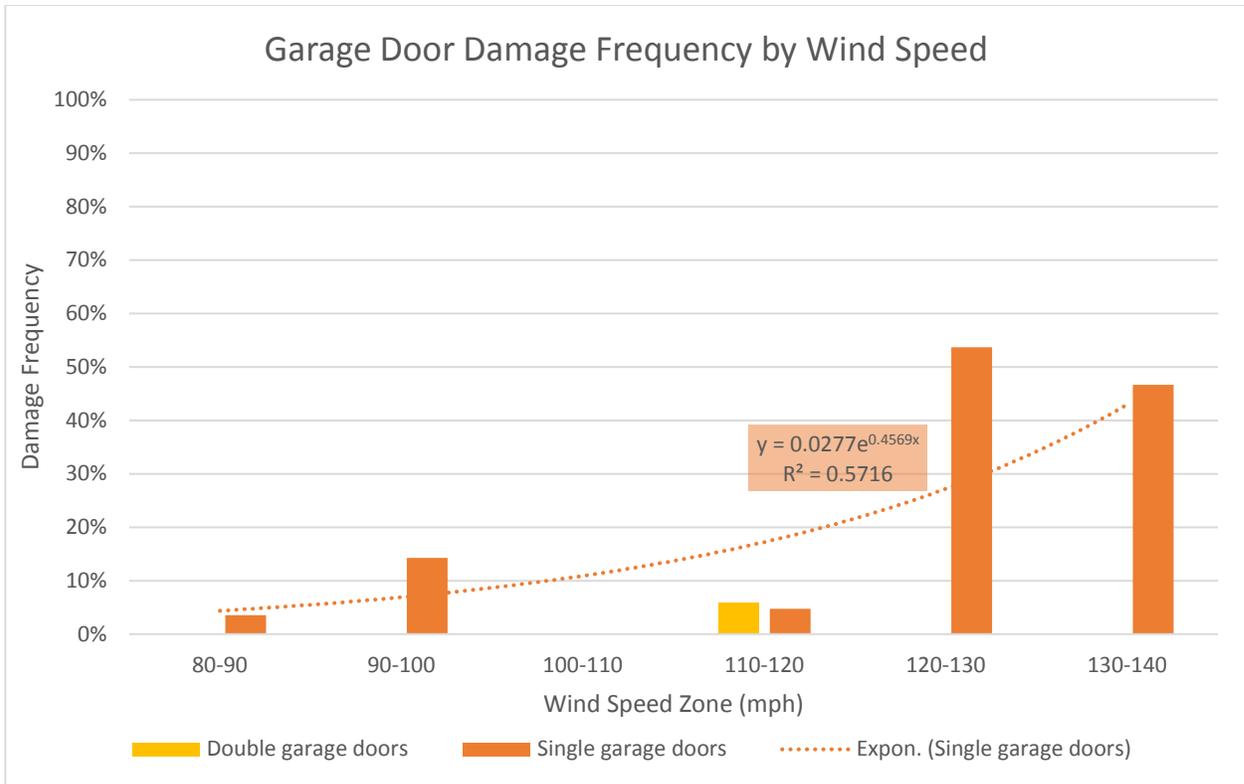


Figure 24. Garage door damage frequencies in neighborhoods with the same wind speed were combined to generate a vulnerability curve for single-car garage doors. An exponential trend line was fitted to the data, and is displayed with R^2 values. No data were collected in the 100–110 mph wind speed zone. There was only one failed double-car garage door and thus not enough data points to fit a vulnerability curve.

Effects of Building Codes

Building codes typically focus on life-safety—keeping structures intact long enough or well enough that the occupants can escape or survive major damage. Codes are typically not designed to prevent damage to finish materials such as components and cladding, doors and windows (outside of areas that require opening protection), and attached structures. Enhanced construction practices and materials are needed to help further mitigate insured and economic losses.

Texas

The state of Texas has adopted the 2006 edition of the International Residential Code® (IRC®) as the minimum standard for residential construction. Local jurisdictions may choose to adopt and enforce more recent editions of the IRC, but there is no process for enforcing the code at the state level and there is no mandate by the state for local jurisdictions to enforce the code. Code enforcement is solely within the purview of individual local jurisdictions. For this reason, Texas ranks 15th out of 18 coastal hurricane-prone states in

IBHS' *Rating the States: 2018* report. However, to obtain insurance coverage through the Texas Windstorm Insurance Association² (TWIA), homes must comply with the building code in force at the time of their construction.

The areas investigated for damage in this study were in municipalities that have adopted more recent editions of the IRC than what the state has adopted. Ingleside, Rockport (which includes Holiday Beach), and Aransas Pass have adopted the 2012 edition of the IRC. Port Aransas (which includes Mustang Island) and Portland have adopted the 2015 edition of the IRC. While adoption of these newer modern codes is a positive step, there is no information available regarding quality of enforcement.

The IBHS team noted generally better performance of both residential and commercial buildings in areas of newer construction compared to older construction. Examples are shown in Figure 25 and Figure 26.



Figure 25. Performance comparison for two homes located 250 feet apart in Port Aransas North, built in 1987 (left) and 2006 (right). These two structures likely experienced very similar wind conditions.

² TWIA is a source of wind and hail insurance for consumers unable to purchase private insurance in hurricane-prone areas.



Figure 26. Performance comparison for two commercial structures located about 1 mile apart in Port Aransas, built in 1984 (left) and 2017 (right).

Florida

Florida has adopted the 2015 IRC, and ranks first in the IBHS *Rating the States: 2018* report. In contrast to Texas, enforcement of the building code is mandated statewide and statutes provide for a robust enforcement regime that includes certification and training of code enforcement officials, and licensing and continuing education for building contractors. As a result, code enforcement in Florida tends to be more consistent than in states that do not mandate enforcement.

The zones visited by the IBHS team following Hurricane Harvey all had peak gust wind speeds of 140 mph or less, which is just below the ASCE 7-10 design wind speed of 150 mph (Figure 10). In comparison, during Hurricane Irma, the areas along the west coast of Florida experienced peak gust wind speeds of 80–110 mph (in regions with open upstream terrain exposure), with design level winds of 140–180 mph. Although areas of the Florida Keys may have experienced wind speeds at or slightly above design level, most locations experienced wind speeds well below their design level.

Outside of the Florida Keys, the damage caused by Irma was generally minor and primarily to finishes as opposed to structural damage. Therefore, given the gap between the actual wind speeds and the design wind speeds along the west coast of Florida, the observation was not surprising. It is difficult to evaluate in any detail the true effect of more stringent codes in these areas, relative to the initial landfall region of Hurricane Harvey, as a large portion of the severe damage from Irma in the Keys was to mobile homes. Table 2 provides a comparison of estimated damage and injuries for Hurricanes Harvey and Irma. It should be noted that there does not appear to be a systematic or nationwide source for these types of data, which makes assessing impacts and comparisons difficult.

Table 2. Comparison of the impact of Hurricanes Harvey and Irma.

	Hurricane Harvey (initial landfall)	Hurricane Irma (Florida)
Fatalities	88 ¹ (US total)	84 ¹
Buildings Destroyed	15,000 ²	509 ³
Buildings Damaged	25,000 ²	24,423 ³
Power Outages	220,000 ²	7.7 million ⁴
Number of Insurance Claims (Residential & Commercial Property)	391,000 ⁵ (includes all of Texas)	882,277 ⁶
Cost of Damage	\$125 billion ²	\$50 billion ⁷

1. Cangialosi et al. 2018
2. Blake and Zelinsky 2017
3. Storm Data 2018
4. Florida Division of Emergency Management 2018
5. Texas Department of Insurance 2018
6. Florida Office of Insurance Regulation 2018
7. National Hurricane Center 2018

Summary and Considerations for Property Insurers

The data collected by the IBHS damage assessment team and presented here can be used to infer vulnerabilities for some building characteristics. Some key findings that could be of interest to individual insurers in underwriting and other operations, or could affect secondary modifiers in catastrophe models include:

- Building terrain exposure played a large role in the amount of damage that occurred. Elevations surrounded by relatively open exposures (open water, open land) had high damage frequencies.
- Asphalt shingles continue to dominate the residential roofing market and this makes it difficult to assess and compare the performance of other roof coverings using damage surveys alone. Claims datasets and laboratory experiments are necessary to evaluate the vulnerability of other roof materials to fill the data gaps.
- Asphalt shingle damage continues to be problematic, with more than half of the shingle roofs investigated displaying some level of roof cover damage.
 - Roofs with architectural shingles had an average damage severity of less than 20%.

- 3-tab shingle damage occurred on every home investigated in Rockport Southeast, Port Aransas South and Rockport Northwest. Damage often included a diagonal loss pattern along the end of shingle strips, consistent with unsealing of shingles that often occurs with typical aging and weathering effects that follow along the installation pattern.
- As the most common damage mode, these roofs would benefit from a sealed roof deck to keep water out.
- Roof slope and shape did not appear to contribute to roof cover loss.
- Steep-slope roofs had lower damage frequencies of underlayment and decking damage compared to moderate- and low-slope roofs.
- Gable roofs had higher damage frequencies of underlayment and decking damage compared to hip roofs and gable/hip combination roofs.
- Roof component damage was most frequent for roof fields, eaves, rakes, ridges, and hip ridges, again highlighting difficulties with roof cover performance. Damage rates for other components and total roof collapse were low.
- Twenty-three percent of the attached structures assessed were damaged.
- Unprotected doors were damaged up to six times more frequently than protected doors. Damage frequencies were highest for slider doors.
- Single-car garage doors failed at a higher rate than double-car doors. This warrants further investigation.
- The highest wind speeds did not always correlate with the highest damage frequencies. The influence of building age, construction type, and exposure also contributed to damage frequencies and sometimes outweighed the wind speed effects.

Vulnerability curves by wind speed zone were developed from the data for:

- Asphalt shingle damage frequency and severity
- Underlayment and roof deck damage severity on shingle roofs
- Garage door damage frequency

Areas for Future Research

This study found results that would benefit from and support additional laboratory testing, and post-disaster investigations or claims studies to solidify the findings. These include:

- Higher damage frequencies for single-car garage doors
- Higher damage frequencies for slider doors
- Vulnerability by wind speed of non-shingle roof covering materials and other materials such as soffits, siding, windows, etc.

This study was conducted for a limited number of homes in each of nine impacted neighborhoods, which limited the sample sizes for some building components. Moving the PDI tool from a beta version to an operational platform would allow a larger number of team members to collect data on a larger number of buildings. This would allow a better understanding of relationships for additional building systems, such as soffits, windows, siding materials, and non-shingle roof materials.

Additionally, it would be beneficial to develop and integrate a complete PDI toolbox for commercial structures and expand the residential tool to include data fields to support FORTIFIED Home™ characteristics. Future expansions could include versions tailored for hail or wildfire events.

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