

# SURVIVING NATURE'S FURY:

## PERFORMANCE OF ASPHALT SHINGLE ROOFS IN THE REAL WORLD

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### INTRODUCTION

When Hurricanes Gustav and Ike raked the coastlines of Louisiana and Texas in 2008, researchers from the Institute for Business & Home Safety (IBHS) and the University of Florida (UF) were presented with a valuable opportunity to investigate the performance of asphalt shingle roofs in real-world storm conditions.

Roof cover damage continues to be the most frequent source of hurricane-related insurance claims not connected to storm surge. To minimize future losses, there must be a solid basis for understanding damage risks for current roofing products and for improving products and producing wind ratings that are meaningful for predicting performance in hurricanes and other severe wind events. This research addresses this need by taking a broader approach than what was attempted by prior post-hurricane disaster investigations. The analysis examined damage levels at relatively low wind speeds as a function of the age of the roof, the adoption and enforcement of modern building codes and investigated the validity of questions concerning whether the current approach to the design of shingles that reduces uplift loads is adequate.

Twelve days and about 375 miles separated the landfalls of Hurricanes Gustav and Ike, which were the two most destructive hurricanes of the 2008 season. Gustav

caused an estimated \$3.5 billion in insured property damage after making landfall September 1, 2008, in Cocodrie, LA. On Sept. 13, Hurricane Ike made landfall along the north end of Galveston Island, TX, causing \$12.5 billion in insured losses.

Asphalt shingles historically have dominated and are predicted to continue to dominate the roofing market, according to roofing industry data. It's likely that many homes located in the hurricane-prone areas from Texas to Maine, where there remains about \$9 trillion worth of vulnerable insured coastal property, have this type of roof covering. Therefore, the findings from this research have broad implications. As wind speeds increase, so do the frequency and severity of the damage.

Clearly, this study only begins to address the issues associated with shingle performance in high winds. More research is needed both in terms of field investigations for events where new wind-rated products are exposed to higher wind speeds, and in a controlled environment such as the new IBHS Research Center, where effects of aging and wind speed can be investigated on demand for a variety of products.

### Roof Cover Damage

The most frequent source of hurricane-related insurance claims not connected to storm surge continues to be roof cover damage. In fact, some 95% of residential wind-

related insurance claims resulted in a payment for roof repairs following Hurricane Charley.<sup>1</sup> Postdisaster investigations conducted following hurricanes Hugo<sup>2</sup> and Andrew and Iniki<sup>3</sup> also emphasized the importance of minimizing roof cover damage to reduce subsequent water intrusion.

As part of a continued effort to explore and improve roof cover performance, IBHS and UF researchers conducted the following study of 1,412 single-family homes affected by Hurricane Gustav in Houma, LA, and Hurricane Ike in two communities in Chambers County, TX. Researchers set out to explore the damage sustained to shingle roofs; to identify trends in damage observations with regard to wind speeds, the age of the roof, and its shape and code changes; and to create a database for use in roof performance analysis now and in the future.

This study builds upon prior posthurricane damage surveys conducted by IBHS staff and other research organizations. Researchers have continually observed large variations in the extent of damage to shingle roofs. For example, an analysis conducted after Hurricane Charley in 2004 examined reroofing permits issued for homes that were less than 15 years old in Charlotte County, FL. The analysis assumed that the home age could be used as a proxy for the age of the roof. The analysis revealed older roofs were more likely to be damaged at lower wind speeds.<sup>4</sup> In areas

Classification	Three-Second Gust-Design Wind Speed
A	60 mph
D	90 mph
F	110 mph
G	120 mph
H	150 mph

Table 1 — Asphalt shingle wind resistance classifications by design wind speeds from ASTM 7158.

where the highest winds occurred, however, the replacement rate was reasonably constant, regardless of age.

The previously referenced studies of roof damage in Hurricanes Hugo, Andrew, and Iniki simply provided estimates of the frequency and severity of roof cover damage, but did not attempt any further refinement of the damage data relative to age. These studies focused on the performance of buildings exposed to some of the highest wind speeds in Hurricanes Hugo and Andrew. There was no attempt to broaden the surveys to areas exposed to lower wind speeds and to look at damage levels as a function of wind speed. This study attempts to lay the groundwork for explorations of both of these functional relationships. Ultimately, both relationships need to be clearly established so there is a solid basis for understanding damage risks for current roofing products and for improving products and producing wind ratings that are meaningful for predicting performance in hurricanes and other severe wind events.

The adoption of the 2009 International Residential Code prompted the replacement of ASTM D3161 (modified to 110 mph), which is the older standard used to rate shingles for high-wind applications, with ASTM D7158. This new standard uses a two-step process to develop a rating for the wind resistance of shingles. The new rating process relies on an uplift coefficient for the shingle tab or edge and a direct measurement of the strength of the adhesive bond between the bottom of the top shingle and the top of the bottom shingle. The uplift coefficient is determined for winds blowing over the surface of the shingles and directed perpendicular to the exposed bottom edge of the tab or shingle bottom edge for architectural shingles. The uplift coefficient and the strength of the adhesive bond are used in an engineering analysis to produce

an overall wind speed rating for the shingle application. (See Table 1.)

The IBHS report, “Hurricane Ike: Nature’s Force vs. Structural Strength,” released in 2009<sup>5</sup>, raised questions about the validity of these ratings in real-world applications. This finding was based on the poor performance of

shingles installed on ten homes built to the IBHS FORTIFIED. .for Safer Living® standard and located on the Bolivar Peninsula in Texas (Reinhold), which was battered by Hurricane Ike in 2008. The roof covers on these homes were H-rated (suitable for design wind speeds of 150 mph) but performed poorly despite exposure to three-second gust wind speeds that likely reached only 115 mph during Ike.

The persistent questions about roofing performance have made it the first focus of research at the multiperil IBHS Research Center, which will come online in late 2010. A part of this research will include the validation of results by comparing roofing performance observed in the laboratory with field observations. This study, in conjunction with earlier work and future field investigations following the landfall of hurricanes, will provide the full-scale field observations needed to validate the laboratory tests.

A key question is whether the newer roofs that performed well when exposed to Hurricane Ike’s winds will perform as well in a future storm with similar magnitude winds after they have aged a few more years. A related question is how well these roofs would have performed in Ike if the winds had been stronger and in line with the 100- to 110-mph-gust wind speed rating, which would be required to meet the local design wind speed requirements for the area.

#### STUDY DESCRIPTION

This study was conducted by IBHS in cooperation with the UF and with assistance from the Federal Emergency Management Agency (FEMA), through its contract with the URS Corporation, to investigate damage to shingle roof covers in communities affected by Hurricanes Gustav and Ike. A large number of photos and dam-

age estimates were collected during on-site investigations. In addition, high resolution aerial photography was commissioned by IBHS for the Houma, LA, area following Gustav and by FEMA for certain areas around Houston and Galveston, TX, following Ike. Selected sites for this study were chosen based on the availability of local wind speed data. Since the vast majority of homes in these areas had shingle roofs, this study focused exclusively on the performance of shingle roofs.

The high-resolution aerial photos were analyzed to determine the amount of shingle roof cover damage on each home and the location(s) of that damage. Various local and national Geographic Information Systems (GIS) were used in conjunction with the high-resolution aerial photographs to determine the address and/or parcel number for each of the single-family houses studied. This allowed matching of damage estimates from the aerial photographs with county or city information about the year of construction. The age of the home is used as a proxy for the age of the roofs in this study for houses that were fewer than 15 years old at the time of the hurricanes. However, it was not possible to determine if any of the roof coverings were replaced on any of the homes surveyed and there is a chance that some of the homes in the 10-to-15-year age range may have been reroofed as a result of Hurricane Rita in 2005.

The study objectives were as follows:

1. Quantify the amount of roof damage, if any, for each house; determine where the damage occurred relative to ASCE 7 wind pressure zones and the orientation of the surface or edge, where damage was observed relative to eight compass directions (N, NE, E, SE, S, SW, W, NW).
2. Create a database of roof damage suitable for both immediate and long-term analysis (as future data are added) that includes attributes identifying wind speed(s); wind direction(s); building age; roof shape; and amount, location, and orientation of damage.
3. Identify any trends in the damage observations which could be correlated with age, wind speed, roof shape, changes in codes and standards, ASCE 7 roof pressure zone, and orientation relative to the strongest winds in the storm.

## HURRICANES GUSTAV AND IKE

Immediately following both Hurricanes Gustav and Ike (Figure 1), faculty and students from UF conducted a rapid assessment of damage in the vicinity of mobile meteorological towers that had been deployed in advance of the hurricane. Since both of these storms primarily caused roof cover damage, the emphasis in the ground surveys was placed on determining the extent of this damage.

The survey data were limited to the visible slopes of the roof, and it was frequently only possible to get a good look at three sides of the roof. Consequently, the ground-based data were primarily used to describe overall damage severity and served as a check against the aerial photo analysis.

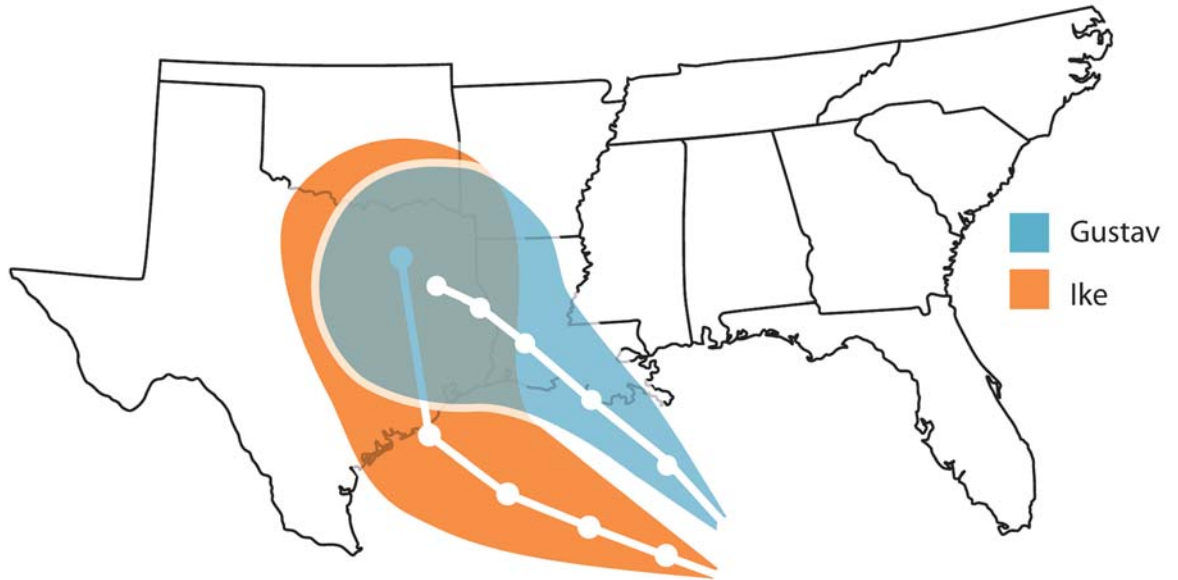


Figure 1 — Affected areas of Hurricanes Gustav and Ike.

### Hurricane Gustav

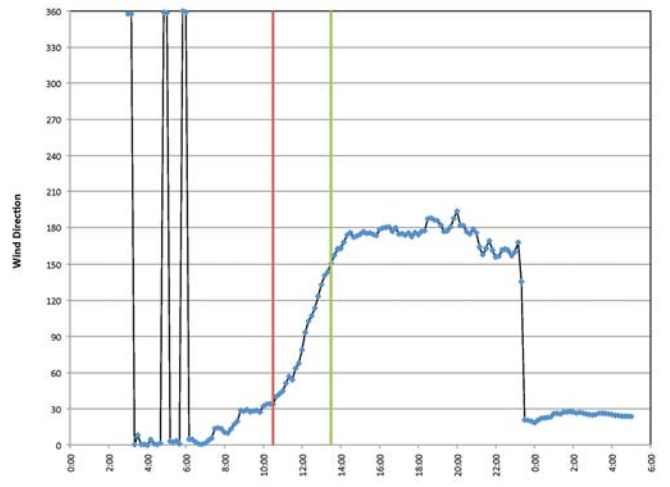
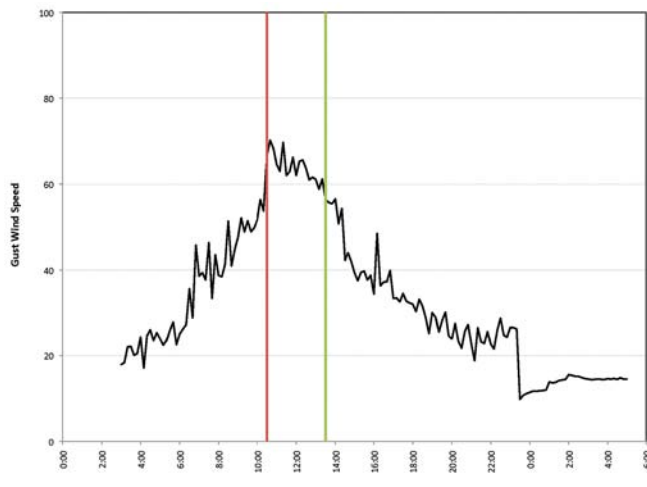
Hurricane Gustav was the second most destructive hurricane in the 2008 Atlantic season and caused an estimated \$3.5 billion in insured damage. It reached the Louisiana coast on the morning of September 1, making landfall near Cocodrie. Researchers from IBHS and UF con-

ducted a study to define the severity of the winds and wind-related roof cover damage throughout the areas around Houma, LA. Five Florida Coastal Monitoring Program (FCMP) mobile-instrumented towers were deployed to capture wind data, and three towers (T1, T2 and T3) were erected within the Houma city limits. The mobile towers



RCI, Inc.  
800-828-1902  
[www.rci-online.org](http://www.rci-online.org)

T1



T2

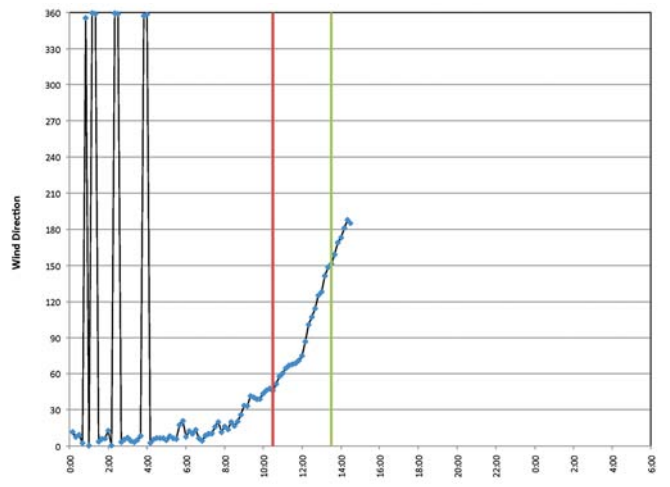
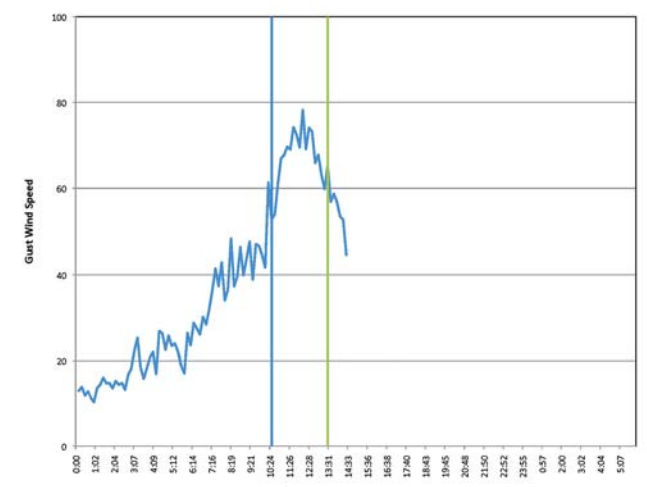


Figure 2 — Wind speed and wind direction recorded by towers T1 and T2 during Hurricane Gustav.

recorded wind speed and direction for the time period during which the highest winds from Hurricane Gustav affected the area (Figure 2). The maximum gust wind speed captured by any of the mobile towers was 78 mph. The higher wind speeds occurred for wind directions ranging from northeast through southeast.

After the storm, the UF faculty and students who deployed the towers split up into five teams and investigated damage to a

total of 933 houses spread among the five yellow areas of Houma shown in Figure 3. The information collected included address, type of roof cover, roof shape, roof pitch, wall type, and estimated average amount of roof damage as a percentage of the visible roof area. The data on the extent of the roof cover damage were generally recorded in 5% increments of the visible roof-surface area.

Summary data for damage frequency and severity obtained from the ground survey are listed in Table 2 and shown in Figure 4. Of the 933 houses investigat-

ed, 602 (65%) suffered some level of roof cover damage. The average roof cover damage per home was 7.7%. Of the 602 homes with roof cover damage, the average roof cover damage was 11.9%.

**Hurricane Ike**

Hurricane Ike was the most destructive hurricane in 2008 and caused an estimated \$12.5 billion in insured property damage. Ike was significant due to the size of its cloud mass, the integrated kinetic energy it contained, and the fact that it produced high winds for an extremely long period of



Figure 3 — Area division of field investigation of roof cover damage in Houma, LA.

Percentage of Roof Area Damaged	Number of Homes	Percentage of Total Homes
< 1%	332	36%
1% to <5%	345	37%
5% to <15%	135	14%
>15%	121	13%

Table 2 — Building survey and damage ratio statistics from Houma, LA, ground surveys.

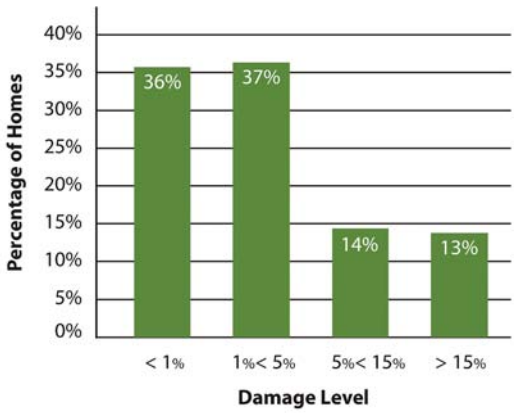


Figure 4 — Distributions of damage severity for homes with roof cover damage.

time throughout much of the affected area. IBHS and researchers from UF, Texas Tech University, Florida International University, Louisiana State University, and Clemson University set up mobile towers and other wind instruments in advance of the storm's landfall. Some support for these deployments was provided by FEMA through a contract with URS.

Baytown, TX, a community with 882 single-family homes constructed between 1996 and 2008, was surveyed, mainly by investigation teams from UF. This community is located 1.5 miles south of Interstate 10 and east of and adjacent to State Highway 146. The community lies between the indicated positions of mobile towers T2 and T3 shown in Figure 5. The eye of the storm passed directly over this community. T2 was located to the northwest of the community, and T3 was located to the southeast of the community.

The maximum three-second gust wind speed measured by T3 was 88 mph and occurred during the passage of the northern eye wall of the storm. For this portion of the storm, the wind directions were from the north-northeast through the east-northeast. The corresponding highest wind speeds measured at T2 were about 77 mph. After the eye had passed, the strongest winds in the southern eye of the storm were on the order of 75 mph at both tower loca-

tions, and the wind direction was approximately from the south through south-southwest as shown in Figures 6A-6E. The lower wind speeds recorded at T2, during the passage of the northern part of the eye, were the result of T3's being exposed to winds after they had passed over a portion of the community. During the latter part of the storm, the winds at both mobile tower locations were approaching over similar terrain.

### AERIAL PHOTO ANALYSIS AND DATABASE Use of Aerial Photography in Investigation

A more comprehensive assessment of the roof cover damage was conducted using high-resolution aerial photographs. The photographs made it possible to more accurately locate the areas where damage occurred, relative to both typical roof wind-pressure zones defined in modern building codes and compass orientation. For Hurricane Gustav, IBHS purchased post-hurricane high-definition oblique aerial photographs of Houma, LA, from AirReldan,

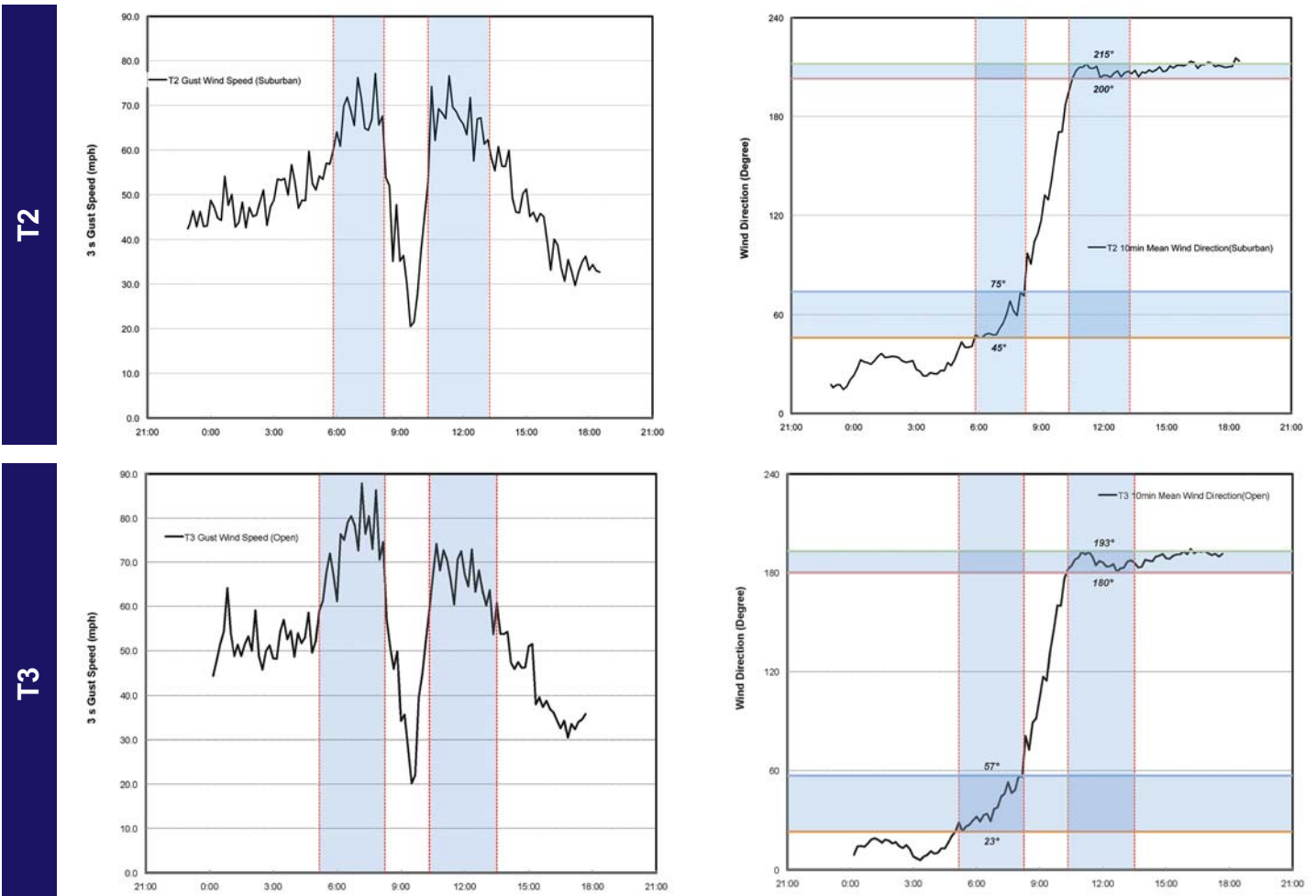


Figure 5 — Wind speed and wind direction recorded by towers T2 and T3 during Hurricane Ike.



A. Widespread damage to roof shingles.



B. A large number of shingles blown off.



C. Heavy damage as a result of shingle and sheathing loss.



D. Wind uplift of individual tabs and shingles.



E. Sealant bonds.

Figure 6 — Typical types of damage to roof shingles observed by on-site investigation teams.



A.



B.



C.



D.



E.

Figure 7 — High-definition aerial photographs provided by FEMA/Pictometry International Corp.

Inc. The view restrictions of the oblique aerial photographs made it possible to view all of the necessary orientations for only 388 single-family houses with shingle roofs.

For Hurricane Ike, the research was enhanced through the IBHS partnership with FEMA and its contractors, through which IBHS was able to obtain access to 6-in ground-sample distance (GSD) imagery acquired by FEMA and Pictometry International Corp. following the storm.<sup>6</sup> The images afforded researchers vertical as well as oblique photography views (*Figures 7A-7E*), including but not limited to the sides of buildings, which fostered the capability of performing accurate measurements of building features. Additionally, Pictometry provided researchers a program and a Web application that could be used to locate, view, measure, and save Pictometry images. This program was used to assess the roof cover damage from Hurricane Ike.

#### Database

The complete data set for this study includes 1,412 single-family homes. The majority of the homes in this sample (1,024) were affected by Hurricane Ike. The remaining homes in the sample (388) were affected by Hurricane Gustav. All of the homes in the data set that were affected by Hurricane Gustav are located in Houma, LA. The homes affected by Hurricane Ike came from two unincorporated areas of Chambers County, TX. One area is a community with 882 single-family homes in Baytown and lies approximately six miles northwest of Trinity Bay. The second area is Beach City, which runs along the northwest coast of Trinity Bay. The Beach City data set includes all of the homes in Beach City constructed between 1996 and 2008, according to Chambers County records. The Baytown and Beach City areas studied are about six miles apart and nearly the same distance

Hurricane Ike		Hurricane Gustav		
City	Baytown	Houma, Aerial		Houma, Ground
Total homes	145	879	338	933
Year of construction	1996-2008	1996-2008	1935-2000	Unknown
Avg. age at time of storm	7.5 years	5 years	24 years	Unknown
Damaged homes	62	329	193	602
Damage rate	43%	37%	50%	65%
Avg. damage per home	1.5%	2.0%	4.5%	7.7%
Avg. damage per damaged home	3.5%	5.4%	9%	11.9%

Table 3 — Summary statistics for the data set.

from Hurricane Ike's track. Eighty percent of the Beach City houses are within one-half mile, and 92% are within a mile of the coast of Trinity Bay. The Baytown community studied is about six to seven miles from the coast of Trinity Bay.

The data fields collected for each house include age of the home, roof shape, amount of roof cover damage in different roof pressure zones, and the orientation of the damage areas relative to one of eight compass points. The age of construction was determined from one of several databases, including county or city records when available and Zillow, an online real estate records source.

Wind load design specifications of ASCE 7 define wind loads on residential roofs using three different zones:

- Zone 1 is the field or middle area of the roof;
- Zone 2 is the perimeter area at the eave, edge, and ridge; and
- Zone 3 is the corner area and eave/edge and edge/ridge intersections.

In high-wind events, these zones experi-

ence different levels of uplift, which increase from low-level wind loads in Zone 1 to the highest wind loads in Zone 3. Earlier studies have suggested that roof cover damage is greatest at corners, edges, and ridges (Rickborn). If true, it would suggest that the current test methods, which employ winds blowing over a flat panel covered with shingles, may not provide the most critical loading. This could be a reason for discrepancy between expected and observed shingle performance in real-world conditions. To further explore this finding, the roof covering damage in the homes surveyed for this study was recorded by zone and orientation of the zone relative to compass directions, so that any correlation between damage location and wind direction could be investigated.

#### PERFORMANCE OF SHINGLE ROOF COVER

##### Overall Damage Statistics

Table 3 provides a general summary of the data sets obtained from the aerial photo analysis. The difference in the average damage between the Gustav and Ike data

sets, which is illustrated by the last two rows of Table 3, may be due in part to the range of ages in the years of construction. The Beach City and Baytown data sets include homes affected by Ike that were constructed between 1996 and 2008, while the Houma data contains homes affected by Gustav that were constructed as early as 1935 but none built after 2000. The ground survey damage estimates for the 933 homes surveyed in Houma produced somewhat higher average damage areas than the estimates obtained from the aerial photos. The differences may be due in part to the tendency to report damage at 5% increments and to a different and unknown difference in the age distribution of the homes in the data sets.

When one compares homes of the same age, the average damage per exposure for homes in the Houma data set is similar to that of the combined Baytown and Beach City data sets. This is illustrated in Figure 8.

The majority of homes in the Hurricane Ike data set were constructed after 2001,



Figure 8 — Average damage by age and location of homes.

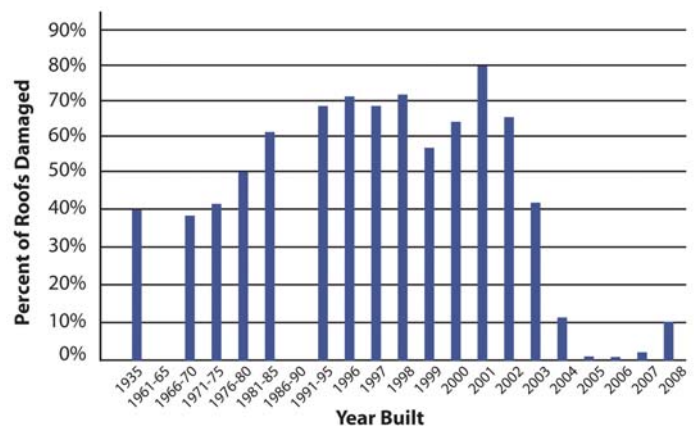


Figure 9 — Roof cover damage rate by the year of construction.

		Zone 1	Zone 2	Zone 3
<b>Damage rate</b>		39%	40%	25%
<b>Average damage for damaged homes</b>		7.3%	6.3%	9.0%
<b>Average damage for all homes</b>	Hip	2.8%	2.4%	1.9%
	Gable	3.2%	3.3%	3.9%
	Total	2.8%	2.5%	2.2%

Table 4 — Damage rates and average damage area for shingle roof covers by zones.

and they received considerably less damage on average as compared to older homes. Unfortunately, because none of the Houma homes were constructed after 2000, it was not possible to determine if newer homes in that area experienced the same reduction in damage.

Figure 9 presents the entire data set, including homes constructed after 2000 (for which there are no homes in Houma) and homes built prior to 1996 (for which there are no homes in Baytown or Beach City). Additionally, the data set contains no homes constructed from 1986 to 1990 and only three homes constructed from 1961 to

1965, none of which was damaged.

The analysis showed a significant decline in the damage rate beginning with homes constructed in 2002 and later. By 2005, the decline reached the point where very few homes built in 2005 or later experienced any observable level of roof cover damage. The damage rate also gradually declines with increasing age for homes built prior to 1996. This trend may be a result of the roof replacement rate on some older homes beginning in 1991 and increasing with each successive set of older homes.

The houses in the data set experienced a wide range of damage, from no losses of

roof covering to the maximum loss of 56% of the roof covering. In order to compare the number of houses with no or only slight damage to those that had more significant damage, each house was assigned a damage level classification ranging from 1 (no damage) to 5 (roof collapse). The definition and description of damage levels are summarized in Table 4.

The majority of homes constructed in 2002 or later suffered minimal damage. Few homes built in 2004 or later had roofs with damage to more than 1% of the covering.

Homes constructed in 1998 had the highest percentage of roofs with damage Levels 3 and 4. For homes built prior to 1998, there was a general trend of declining damage with each consecutive group of homes until the data set that included homes built from 1966-1970, perhaps reflecting an increasing occurrence of roof replacement beginning in 1997. Homes built in 1997, however, would have only been 11 years old at the time of Ike. Still, if the age of the roof is a dominant risk factor, it is possible that the homes built in 1997 and before could have been reroofed as a result of sustaining damage from Hurricane Rita in 2005.



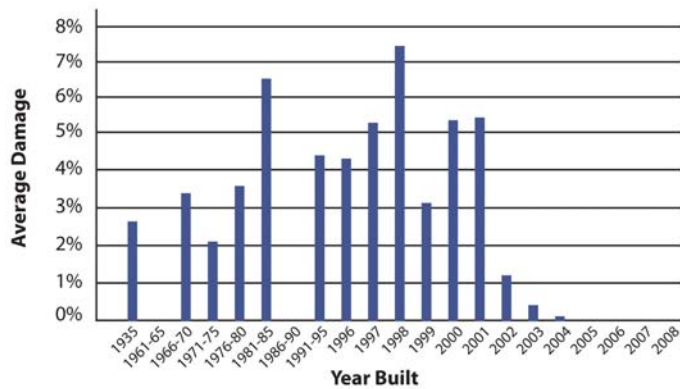


Figure 10 — Average damage area as a percentage of total roof area by year of construction.

Average areas of roof cover damage by year of construction are presented in Figure 10. The damage area percentage is based on all homes in the data set, including those with no damage.

### Aging Effects and Code Changes

Two factors appear to have been involved in the sharp decline in the average damage sustained by houses built in 2002 and later in Baytown and Beach City. These newer homes received an average of just 0.3% damage compared to the average of 4.9% damage for all older homes in this area. This may be due to limited exposure to the aging effects of weather, but the homes also may have benefited from the strengthening of building code requirements that

accompanied the adoption of the International Residential Code (IRC) in 2000. It is possible that high-wind-rated roof coverings were used on these homes since the IRC provisions require the installation of roof covers with a design wind speed rating that is appropriate for the area.

### Age Effects on Damage

This study afforded researchers an opportunity to examine the effects of aging in high-wind conditions. As roofing materials age, they become more susceptible to damage under these types of conditions. The data set includes homes that were constructed between 1935 and 2008. The age of the home, obtained by county property records, was used as a proxy for the age of the roof since explicit data on the roof age was not available.

Although asphalt shingle roofing materials come with warranties that range from 20 to 45 years and there are significant differences among the products, these figures frequently do not provide an accurate assessment of expected roof life. Roofing materials often require repair or replacement years before their warranties would suggest, particularly in hurricane-prone regions such as the Texas and Louisiana Gulf Coast.

Even without any exposure to another damage source, the effect of aging itself can result in a lifespan of 10 to 15 years for some roofing products. Despite the need, it's unlikely that most homeowners with roofs of this age will take steps to replace their roofs. For newer homes, it is possible to assume that the age of the roof is the age of the home. However, at a certain point in the lifespan of a home—often beginning at 15 years—the roof gets replaced, and the

### Damage by Roof Zone

As noted earlier, any damage to the roof covering was recorded by roof pressure zones as defined by ASCE 7<sup>7</sup> to facilitate the investigation of correlations between damage location and uplift pressure. Table 5 presents the damage rate and average amount of roof cover damage for each of the three ASCE 7 roof pressure zones. The results are based on all the data for both hurricanes.

While the frequency of damage was similar for Zones 1 and 2 and significantly less for Zone 3, when it did occur in Zone 3, it was more severe. Separation of damage by roof shape indicates that gable roofs are more likely to experience roof cover damage than hip roofs. The difference is most significant for Zones 2 and 3.

Level	Description
Level 1 (Satisfactory Performance)	Roof system displays good performance in the storm. No obvious damage is observed to the shingles. There are some small pieces of shingles missing. The total area of loss of roof cover is less than 1%.
Level 2 (Slight Damage)	There are a lot of small pieces of roof cover blown off in the storm. The total area of loss of roof cover is more than 1% and less than 5%. (One to 5 shingles would be damaged in a typical 10-ft square.)
Level 3 (Moderate Damage)	The loss of roof cover is more than 5% of the total area. Whole pieces of roof cover have been blown off by the storm. The roof sheathing is typically exposed.
Level 4 (Heavy Damage)	The roof cover is heavily damaged. The loss is more than 15% of total roof area. Some roof sheathing may be blown off, but the roof system still can provide effective lateral support for structure.
Level 5 (Collapsing)	Significant structural damage to the roof, possibly including a partial or total collapse of the roof. The roof system cannot effectively provide lateral support for the building's walls.

Table 5

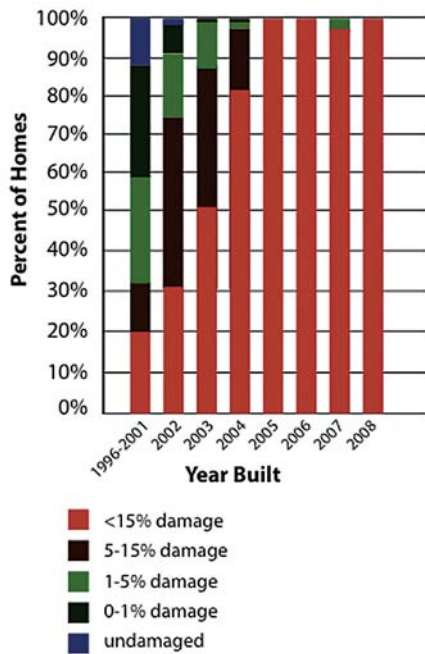


Figure 11 — Average damage by year in Houma data set.

assumption is no longer valid.

Figure 11, the graph depicting average roof damage, shows that the clearest pattern of damage increasing with age occurs in homes constructed from 1998 to 2008. The newest homes (those constructed between 2005 and 2008) sustained almost no damage. Average damage per exposure increases modestly with age, beginning with homes constructed in 2004 and continuing through homes constructed in 2002. This is followed by a large increase in damage for older homes, beginning with those constructed in 2001 and peaking in homes constructed in 1998.

The following information illustrates how well this damage trend and aging pattern holds when each data set is presented individually.

Figure 12 shows the average damage by year in the Houma data set, which contained no homes constructed after 2000. This data set shows no pattern of increasing damage with age. In fact, average damage per

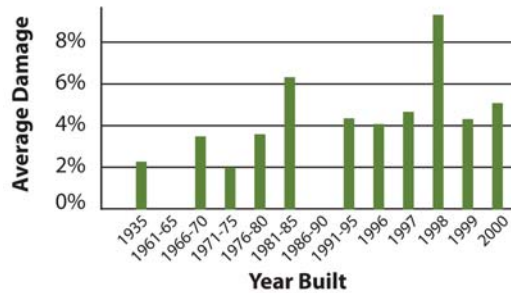


Figure 12 — Average damage by year in the Houma data set.

exposure tends to decrease slightly with age, likely due to the fact that the age of the homes in Houma is no longer a reliable proxy for the age of the roof.

The age of the homes in this study that were affected by Hurricane Ike in Texas ranges from one to 12 years, and therefore the age of the home is more likely to reflect the age of the roof. Figures 13 and 14 represent the average damage per exposure by year individually for the Baytown and Beach City communities. Each graph shows a sudden increase in average damage for homes constructed in 2001, followed by a general trend of increasing damage for homes built in prior years.

One interesting trend was that the average damage per exposure peaks for Baytown homes built in 1998, but declines for those constructed in 1997 and 1996. Aerial photography analysis showed this decline may be due more to the location of the homes and the density of the tree cover surrounding them than to their age. These homes are located at the west side of the community and are surrounded by other houses and high-density woods that may

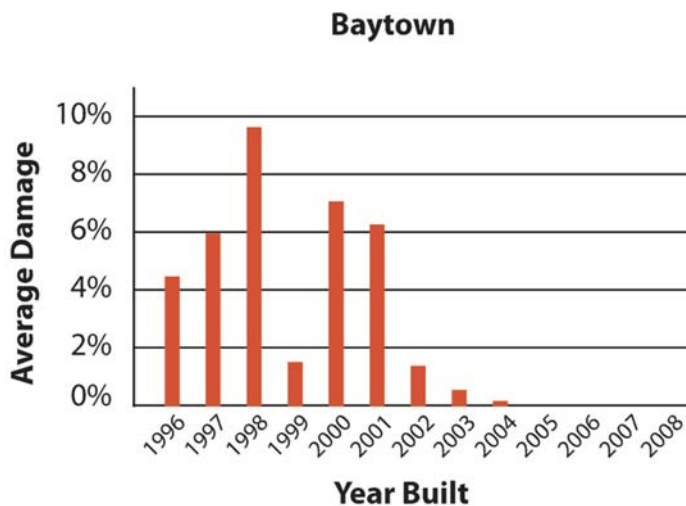


Figure 13 — Average damage by year in Baytown.

have shielded them from the higher winds.

### Effect of Wind Direction

Wind effects, including uplift pressures and flow near the roof surface, depend on wind direction, roof pitch, and surrounding conditions. Generally, large suction occurs on leading roof corners, edges, and ridge areas. Prior research studies following hurricanes have found that greater demands can be expected to occur at these locations on the roof.

This study also sought to assess the effects of wind directionality on the vulnerability of these areas.

The Baytown data set was divided into three groups based on year of construction: homes built in 2005 or later, homes built from 2002 to 2004, and homes built prior to 2001. The average damage on different roof areas of each group was calculated for eight directions, and results are shown in Figure 15. The high wind speeds recorded by mobile towers in Hurricane Ike for Baytown homes were concentrated at east-northeasterly and south-southwesterly directions. While damage was observed on nearly all roof surfaces for older homes, the average damage on roof areas facing the incident wind directions is higher than for other roof areas. The distributions and damages observed clearly demonstrate that roofs on older homes were more sensitive to wind direction than roofs on newer homes.

### Relationship to Earlier Studies

It should be emphasized that the data obtained in this study corresponded to relatively low wind speeds with the measured peak gusts in the area ranging between 75 and 88 mph. As wind speeds increase, so do the frequency and severity of the damage.

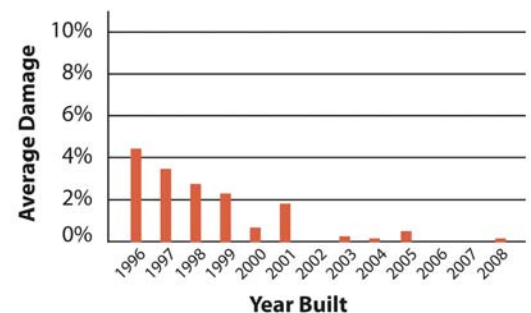
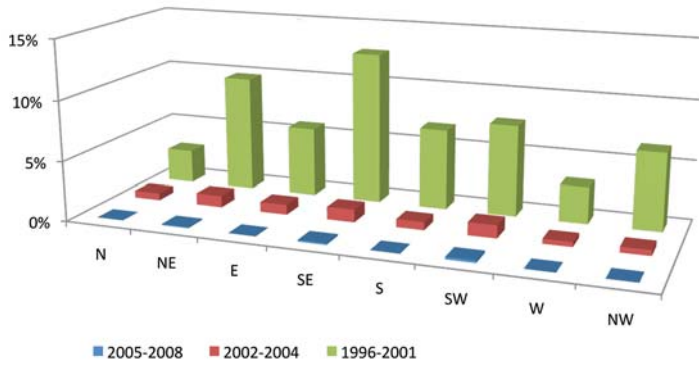
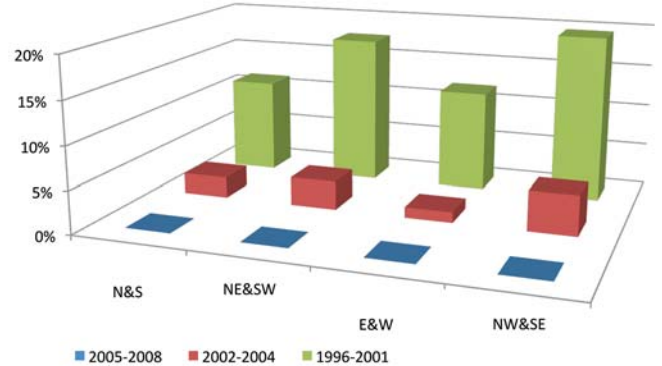


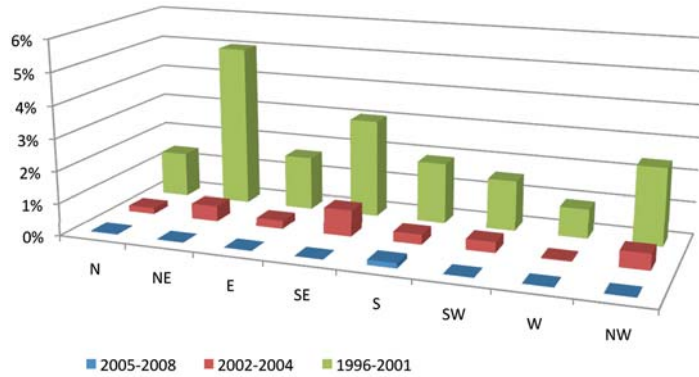
Figure 14 — Average damage by year in Beach City.



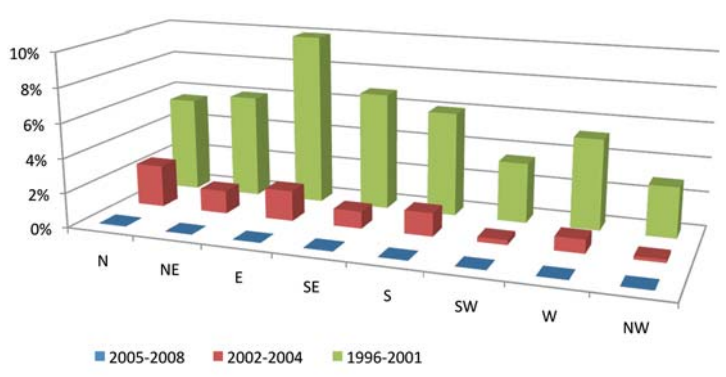
Average damage areas for Zone I (center area).



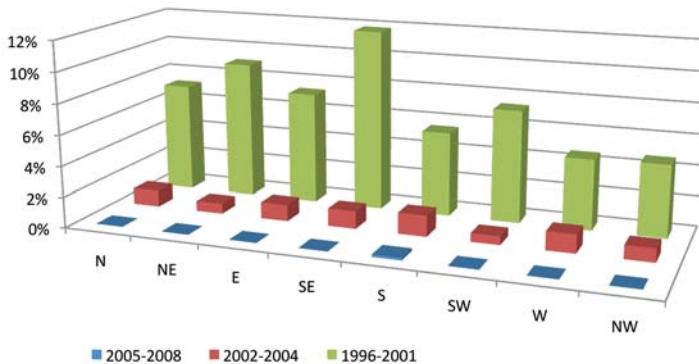
Average damage area along roof ridge.



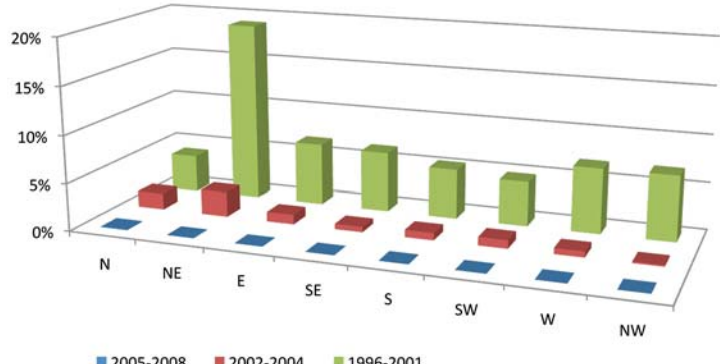
Average damage areas along roof eaves.



Average damage area for Zone III (corner area).



Average damage area near ridge end.



Average damage areas along gable edges.

Figure 15 — Average damage on different roof areas of Baytown homes.

The analysis of damage presented in this study used a fairly fine breakdown of damage levels into smaller area increments, in part, because the winds were relatively low. The change in roof damage area statistics associated with increased wind speeds is illustrated in Figure 16.

The damage classifications and overall results for Hurricanes Gustav and Ike were as follows:

Damage ≤ 1% of the roof area	Frequency = 73%
1% < damage < 5% of the roof area	Frequency = 11%
5% < damage < 15% of the roof area	Frequency = 11%
Damage > 15% of the roof area	Frequency = 5%

Or, divided into the categories reported for Hurricane Hugo (Rickborn), as shown here:

Little or no damage	Frequency = 58%
Damage < 15%	Frequency = 37%
15% < damage < 40%	Frequency = 4%
Damage > 40%	Frequency = 1%

In comparison, roof cover damage observations for Hurricane Hugo, where three-second gust wind speeds in the areas studied ranged between 110 and 135 mph (Rickborn), used the following damage classifications and produced the following results:

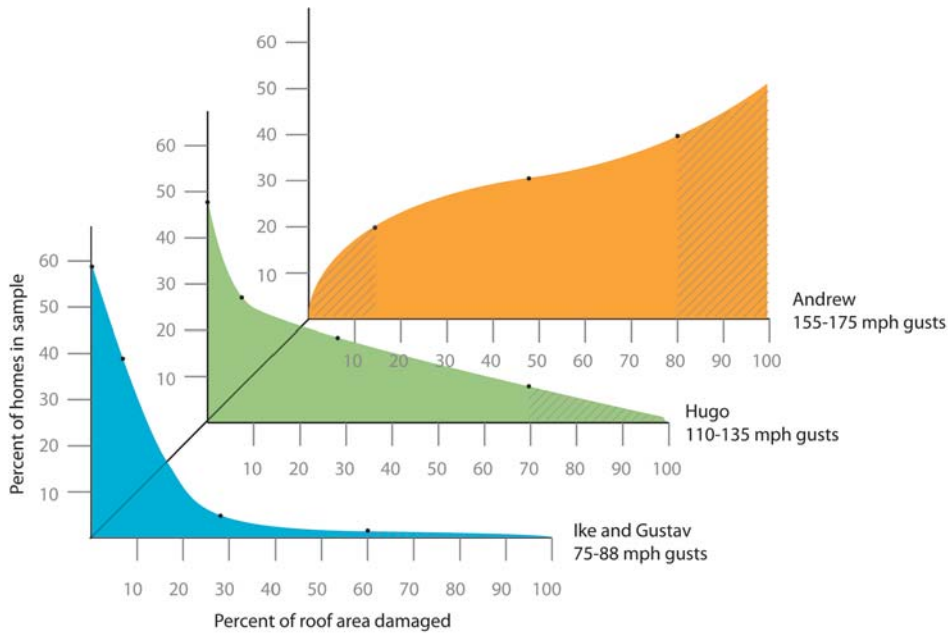


Figure 16 — Simplified illustration of the variation in roof cover damage vs. gust wind speed.

Damage ≤ 1% of the roof area	Frequency = 49%
1% < damage < 5% of the roof area	Frequency = 26%
5% < damage < 15% of the roof area	Frequency = 18%
Damage > 15% of the roof area	Frequency = 7%

The analysis of roof cover damage for Hurricane Andrew (NAHB Research Center), where three-second gust wind speeds likely exceeded 155 mph and possibly reached 175 mph in some areas, used the following damage classifications and produced these results:

Damage < 33%	Frequency = 18% to 23%
33% < damage < 67%	Frequency = 23% to 30%
Damage > 67%	Frequency = 36% to 47%

These numbers offer dramatic evidence of the rapid increase in damage frequency and amount of damage expected as wind speed increases. Clearly, this study for Hurricanes Gustav and Ike just begins to address the issues associated with shingle performance in high winds. More research is needed, both in terms of field investigations for events where new wind-rated products are exposed to higher wind speeds and in a controlled environment such as the new IBHS Research Center, where effects of aging and wind speed can be investigated on demand for a variety of products.

#### SUMMATION


The major findings of this study are as follows:

1. When subjected to 75- to 88-mph winds, newer roof covers installed after adoption of the 2002 International Building Code exhibited much less wind damage than did older roofs in the same area.
2. The areas where the most frequent roof cover damage were observed did not correspond to the areas where the highest roof uplift pressures would be expected (ASCE 7 roof Zones 2 and 3). Roof cover damage was observed to occur at similar frequencies for Zones 1 and 2 despite the fact that Zone 2 typically experiences much higher uplift pressures than Zone 1. Roof cover damage was observed to occur at the lowest frequencies in Zone 3, where uplift pressures are typically the highest. These results suggest that the equalization of pressures, which is the foundation of



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current test methods for evaluating shingle performance in high winds, is reasonable.

3. To develop models that will accurately predict the performance of shingle roofs in high-wind conditions, a better understanding is needed of the impact of product changes, the effects of aging, and what current test methods and rating systems mean in terms of real-world performance.
4. More attention must be given to providing backup water intrusion protection to reduce losses when roof covers fail. This should be a priority, given the frequent damage to roof coverings and the dominant role roof cover damage and subsequent internal water damage play in increasing hurricane losses.
5. Roof cover damage was widespread in Hurricanes Gustav and Ike and not limited to those surfaces that predominantly faced into the wind. Older roofs exhibited a greater tendency for more extensive damage on surfaces, edges, and corners that faced the prevailing strong winds.
6. Aerial photography-based analysis is an effective and economical method to assess performance of roof covers in strong wind events. An emphasis should be placed on securing high-resolution aerial photography following future storms.
7. More field research is needed in events with stronger winds and in laboratory settings where aging, roof geometry, wind speeds, and wind directions can be easily varied and controlled. 

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