ON THE PERFORMANCE OF BUILDINGS

IN HURRICANES

A STUDY FOR THE SAFFIR-SIMSPON SCALE COMMITTEE

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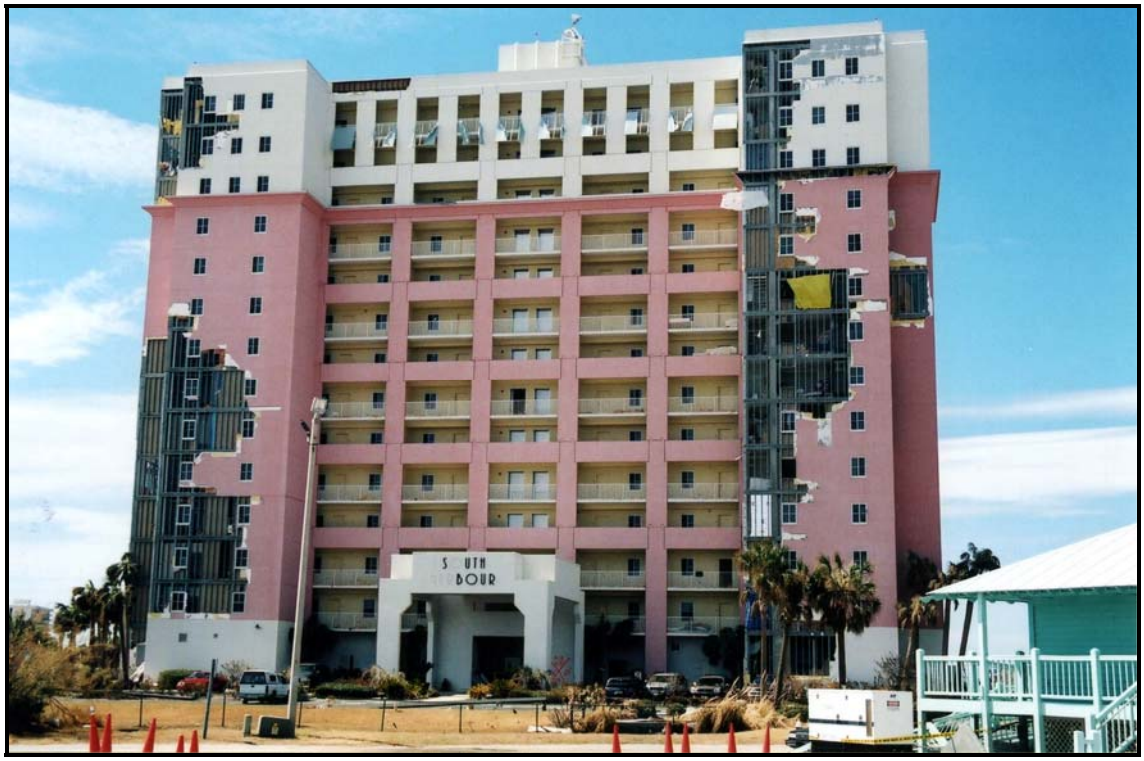
October 18, 2009



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INTRODUCTION

Over the past 30 years, the author has surveyed building damage in 30 hurricanes beginning with Hurricane Allen (1980). Many of these hurricanes, the author has experienced firsthand by riding out the storms in hotels, vehicles, or parking garages. Within weeks after each hurricane, ground and sometimes aerial surveys were performed to document the performance of buildings and measure the heights of the storm surge using levels, rods, and benchmarks. Then, the author spent several months in the disaster areas conducting individual inspections to hundreds of structures. To date, the author has amassed tens of thousands of images of hurricane damage to buildings and has written and assembled numerous references with regard to building performance in hurricanes.

One thing that is clear is that not all buildings perform the same in a hurricane and that certain types of buildings, or their components, fail at relatively low wind speeds. This is especially true if there are poor attachments at critical connections. Certainly there have been a number of building improvements due to code upgrades in Florida and a few other states, after Hurricane Andrew, which has resulted in better building performance in subsequent hurricanes.

In the author's study of storm surge, it has become obvious there is not a direct relationship between the magnitude of the wind and the height of the storm surge. There are many reasons for this including the size of the hurricane, angle of its attack to the shoreline, coastal topography, bathymetry, etc. Thus, the Saffir-Simpson scale, which correlates wind speed to the height of the storm surge, has a high error rate. For example, a relatively weak hurricane like Iwa in Hawaii in 1982 had a surge of about 20 feet MSL with wind gusts of about 85 MPH. In contrast, a strong hurricane like Charley in Florida in 2004 had a surge of about 8 feet MSL with wind gusts of about 135 MPH. Thus, it is the author's opinion that the storm surge portion of the scale should be detached from the wind portion. Refer to Figure 1 and Table 1.

In this study, I selected 20 hurricanes that affected more densely populated areas, reviewed thousands of photographs, and numerous references to ascertain the general performance of certain building types in hurricanes. The word "general" means there is considerable variability in the performance of particular building types due to other factors such as the quality and condition of components and their attachments, wind direction, duration of the wind, and openness of the building to the wind, etc. As a disclaimer, these are general statements with probabilities. They do not necessarily mean that a particular building is or is not damaged. In order to determine that, specific site inspections must be performed.

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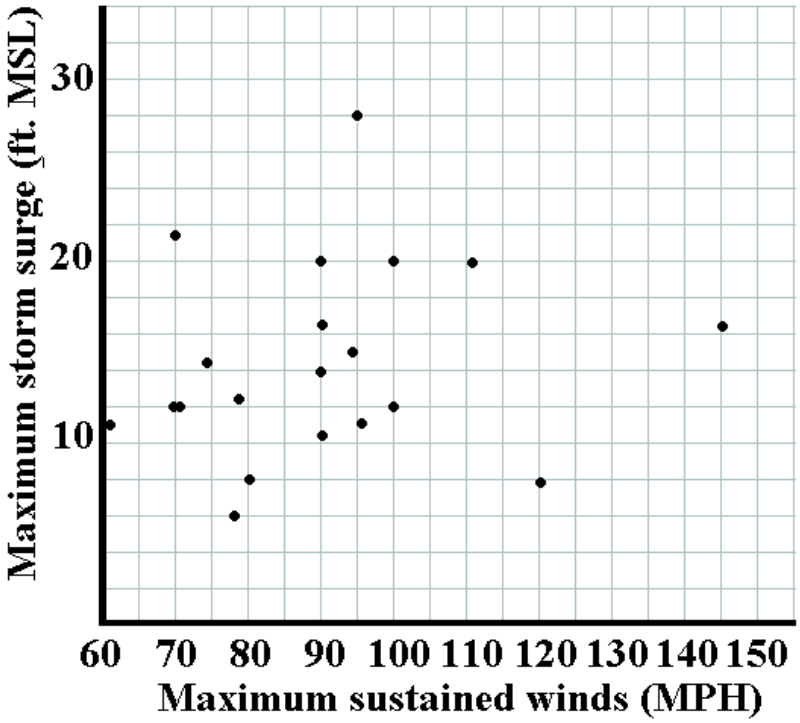

Figure 1. Plot of peak storm surge with maximum sustained (1-minute) winds for 20 hurricanes. The wide dispersion demonstrates there is poor correlation between wind and surge levels.

TABLE 1: SUMMARY OF HURRICANE SURVEY EVENTS 1980-2008

Year	Hurricane	Wind Speed#1 mph	Wind Speed#2 mph	Storm surge (ft)
1980	Allen	65 g 92 Corpus Christi	100 g 125 Port Mansfield	12 Port Mansfield
1982	Iwa	65 g 85 Lihue	75 g 95 Poipu	20 Poipu
1983	Alicia	71 g 102 Galveston		12 Sea Isle
1985	Elena	90 g 122 Biloxi	96 g 136 Dauphin Island	10.5 Biloxi
1989	Hugo	78 g 98 Charleston	96 g 120 Bulls Bay	20 Bulls Bay
1992	Andrew	145 g 175 Homestead		16.9 BK Headquarters
1992	Andrew	80 g 100 Louisiana		8 Cocodrie
1992	Iniki	111 g 143 Poipu		20 Poipu
1995	Opal	55 g 70 Pensacola	70 g 100 Navarre	21.5 Miramar Bch.
1996	Fran	67 g 86 Wilmington	70 g 90 Topsail Beach	12 Carolina Bch.
1998	Georges	61 g 79 Gulfport		10.8 Pascagoula
2002	Lili	74 g 99 Kaplan		12.3 Calumet
2004	Charley	111 g 130 Punta Gorda	120 g 145 N. Captiva Isl.	8 Fort Myers Bch.
2004	Frances	77 g 95 Port St. Lucie		6 Cocoa Bch.
2004	Ivan	90 g 120 Perdido Key		14 Perdido Key
2005	Dennis	90 g 121 Navarre		11 Navarre
2005	Katrina	96 g 125 Pass Christian		28 Waveland
2005	Rita	94 g 116 Port Arthur		15 Cameron
2008	Gustav	77 g 93 Houma		12.5 Bay Gardene
2008	Ike	75 g 93 Galveston	90 g 116 Bolivar	16.5 Anahuac

HURRICANE ALLEN- Corpus Christi, TX - AUGUST 10, 1980

1 minute sustained wind speed at 33 feet in open terrain: 65 MPH (CRP), 100 MPH Port Mansfield est.
3-second peak wind gust at 33 feet in open terrain: 92 MPH (CRP), 125 MPH Port Mansfield est.
Peak storm surge: 12 feet MSL (measured at Port Mansfield)

Survey: A ground survey was conducted from Corpus Christi to Port Mansfield to Brownsville, TX.

Wood-framed residences: In general, residences performed well during the above wind speeds. Common damage included the removal of asphalt roof coverings and poorly attached metal panels. A small percentage of porch coverings, awnings, and other canopies sustained damage. A small number of poorly attached roofs, sections or roofs, or gable ends were removed at Port Mansfield.

High Rise buildings: There was a problem with the displacement of roof gravel and flying debris which broke numerous unprotected (no shutters) windows in the Guaranty Band Building and Spohn Hospital in Corpus Christi.

Unreinforced brick masonry buildings: These buildings performed well during the above wind speeds with damage limited primarily to certain built-up type roof coverings. Occasional overhead door failures were noted.

Concrete masonry unit (CMU) buildings: These buildings performed well during the above wind speeds with damage primarily to certain built-up type roof coverings. Occasional overhead door failures were noted.

Metal buildings: In general, metal buildings performed well. A small percentage of steel buildings had cladding removed from windward corners, rakes, and eaves. A few canopies or overhangs were flipped or rolled back. More common were failures of overhead doors and unprotected windows.

Manufactured housing: There was occasional damage to the roofs on manufactured homes, carports, and sunrooms. A small number of unanchored homes slid off their block foundations, rolled, or overturned, especially in open terrain. Destruction of manufactured homes did occur in the Port Mansfield area where wind speeds were about thirty percent higher than in Corpus Christi.

Other: Occasional damage was noted to signs, weak or rotted trees, and fences in the area. Light standards and palm trees along the Shoreline Blvd. in Corpus Christi remained intact at the above wind speeds.

HURRICANE IWA- Kauai, HI - November 23, 1982

1 minute sustained wind speed at 33 feet in open terrain: 65 MPH (LIH), 75 MPH Poipu (est.)
3-second peak wind gust at 33 feet in open terrain: 85 MPH (LIH), 95 MPH Poipu (est.)
Peak storm surge: 20 feet MSL (measured at Poipu Beach)

Survey: A ground survey was conducted from Lihue to Poipu to Barking Sands. Overall, the damage was similar to that in Corpus Christi during Hurricane Allen in 1980.

Wood-framed residences: The vast majority of wood-framed residences performed well during these wind speeds. These were typically homes with single-wall construction. Common damage was the removal of roof coverings (typically asphalt shingles and metal panels) which resulted in rainwater entry. Cedar shake roofs performed well. Certain poorly attached metal roofs were removed. Porch coverings, awnings, and other canopies also sustained damage at these wind speeds.

Unreinforced brick masonry buildings: The vast majority of these buildings survived the hurricane with damage limited mainly to roof coverings.

Concrete masonry unit (CMU) buildings: In general, these buildings performed well during the storm with common damage to the roof coverings.

Metal buildings: In general, metal buildings performed well. However, occasional damage involved cladding being removed from windward corners, rakes, and eaves. A few canopies or overhangs were flipped or rolled back. Some overhead doors had failed.

Manufactured housing: No manufactured homes were observed on the island during the survey.

Trees: Numerous broken branches and toppling of shallow-rooted trees were noted. Considerable damage was done to the rows of Eucalyptus trees in the “Tree Tunnel” on the way to Poipu.

Other: Occasional damage was noted to signs and fences on the island.

HURRICANE ALICIA- Galveston, TX - AUGUST 18, 1983

1 minute sustained wind speed at 33 feet in open terrain: 71 MPH (GLS)
3-second peak wind gust at 33 feet in open terrain: 102 MPH (GLS)
Peak storm surge: 12 feet MSL (measured at Sea Isle on Galveston Island)

Survey: A ground survey was conducted from Galveston to Houston to Freeport, TX. Overall, the damage was similar to that in Corpus Christi during Hurricane Allen in 1980.

Wood-framed residences: The vast majority of wood-framed residences performed well during these wind speeds. Common damage was the removal of asphalt roof coverings which resulted in rainwater entry. Clay and concrete tiles were removed from windward roof corners, eaves, and rakes especially where they had little or no attachment. A small number of porch coverings, awnings, and other canopies sustained damage. A small number of poorly attached roofs were removed. A small number of poorly built elevated homes were destroyed on the western portion of Galveston Island, failing where wall bottom plates were straight nailed into their floor platforms.

High Rise buildings: There was a problem with the displacement of roof gravel and flying debris which resulted in breaking unprotected (no shutters) windows in many downtown Houston buildings. Occasional damage to EIFS facades was noted. A portion of the EIFS façade failed on the Flagship Hotel and end wall failure was noted on an east facing EIFS façade on an office building in Galveston.

Unreinforced brick masonry buildings: The vast majority of these buildings survived the hurricane with damage limited mainly to roof coverings. However, isolated failures of brick facades were observed on Galveston Island especially where brick ties had corroded or were not installed.

Concrete masonry unit (CMU) buildings: In general, these buildings performed well during the storm with common damage to the roof coverings. However, a few CMU buildings with wood-framed roofs, did collapse on Galveston Island and in Baytown. Failure initiated at poor roof/wall connections or from internal pressure when windward doors or unprotected windows had failed.

Metal buildings: In general, metal buildings performed well. However, occasional damage involved cladding being removed from windward corners, rakes, and eaves. A few canopies or overhangs were flipped or rolled back. Some overhead doors had failed. A few unreinforced brick facades around metal buildings had collapsed as the steel-frame flexed.

Manufactured housing: The majority of manufactured homes survived with damage to roofing, carports, or sunrooms. However, there were isolated manufactured homes in rural, open country north of Galveston that were destroyed. These homes had little or no attachment to the ground.

Trees: Numerous broken branches and toppling of shallow-rooted trees were noted on and around Galveston up to Houston. Pine trees were most prone to snapping or uprooting.

Other: Occasional damage was noted to signs, billboards, and fences in the area. A small number of gas station canopies were destroyed.

HURRICANE ELENA- BILOXI, MS - SEPTEMBER 2, 1985

1 minute sustained wind speed at 33 feet in open terrain: 90 MPH (BIX), 96 (Dauphin Island)
3-second peak wind gust at 33 feet in open terrain: 122 MPH (BIX), 135 (Dauphin Island)
Peak storm surge: 10.5 feet MSL (measured at Biloxi)

Survey: A ground survey was conducted from Pensacola Beach, FL to Gulf Shores and Dauphin Island, AL to Biloxi and Waveland, MS.

Wood-framed residences: The vast majority of wood-framed residences performed well during these wind speeds. Common damage was the removal of asphalt roof coverings which resulted in some rainwater entry. A small number of porch coverings, awnings, and other canopies sustained damage. A few poorly attached roofs were removed. Several poorly built elevated homes were destroyed on Dauphin Island, failing where wall bottom plates were straight nailed into their floor platforms.

High Rise buildings: There was a problem with the displacement of roof gravel which resulted in breaking of unprotected (no shutters) windows in certain downtown Biloxi buildings.

Unreinforced brick masonry buildings: The vast majority of these buildings survived the hurricane with damage limited mainly to roof coverings. However, isolated failures of brick facades were observed in Biloxi especially where brick ties had corroded or were not installed. A building had collapsed in Pascagoula when its load bearing masonry wall toppled.

Concrete masonry unit (CMU) buildings: In general, these buildings performed well during the storm with common damage to metal and built-up gravel roof coverings.

Metal buildings: In general, metal buildings performed well. However, occasional damage involved cladding being removed from windward corners, rakes, and eaves. A few canopies or overhangs were flipped or rolled back. Some overhead doors had failed. A few unreinforced CMU facades around metal buildings had collapsed as the steel-frame flexed.

Manufactured housing: There were many manufactured homes that sustained damage to roofing, carports, or sunrooms. A smaller percentage of unanchored manufactured homes were rolled, flipped or destroyed from Pascagoula to Gautier to Biloxi. Damage to manufactured homes was more widespread than in other hurricanes I had surveyed in the past.

Precast Concrete Buildings: In general, these buildings performed well. However, a few double-tee wall panels fell on an engineered building at Ingall's Shipyard in Pascagoula.

Trees: Numerous broken branches and toppling of shallow-rooted trees were noted along the MS coast. Pine trees were prone to being snapped or uprooted while the large oaks did better. Some trees impacted residences causing considerable structural damage. Falling pine trees were a serious hazard.

Other: Occasional damage was noted to signs, billboards, and fences in the area. A small number of gas station canopies were destroyed. A small number of steel light poles were bent or rotated about their bases. Empty rail cars toppled at the Ingall's Shipyard in Pascagoula. Metal cladding on shopping center facades were displaced from Pascagoula to Biloxi.

HURRICANE HUGO- CHARLESTON, SC - SEPTEMBER 22, 1989

1 minute sustained wind speed at 33 feet in open terrain: 78 MPH (CHS), 100 MPH Bulls Bay est.
3-second peak wind gust at 33 feet in open terrain: 98 MPH (CHS), 120 MPH Bulls Bay est.
Peak storm surge: 20 feet MSL (measured in Bulls Bay)

Survey: A ground survey was conducted along the South Carolina coast including barrier islands.

Wood-framed residences: The vast majority of wood-framed residences performed well during these wind speeds. Common damage was the removal of asphalt roof coverings which resulted in some rainwater entry. A small number of porch coverings, awnings, and other canopies sustained damage. A few poorly attached roofs were removed. There were several poorly built elevated homes destroyed on Folley Beach, Sullivan's Island and the Isle of Palms, failing where wall bottom plates were straight nailed into their floor platforms. Certain houses on shallow concrete piers toppled.

High Rise buildings: Window failures were noted in high rise hotels and office buildings.

Unreinforced brick masonry buildings: The vast majority of these buildings survived the hurricane with damage limited mainly to roof coverings. However, isolated failures of brick facades were observed in Charleston especially where brick ties had corroded or were not installed.

Concrete masonry unit (CMU) buildings: There were several CMU buildings that had partially or completely collapsed when overhead doors failed or wood trusses were uplifted from the tops of the walls. In the later, poor anchorage was found failed buildings between the trusses and tops of the CMU walls (i.e. J-bolts in grouted cells –no bond beams).

Metal buildings: There were several metal buildings that lost their cladding and several had end wall failures or complete failures. Many overhead doors had failed. A few unreinforced CMU facades around metal buildings had collapsed as the steel-frame flexed.

Manufactured housing: Many manufactured homes sustained damage to roofing, carports, or sunrooms. A small percentage of unanchored manufactured homes had shifted, rolled, or flipped especially when out in the open.

Trees: Extensive damage was noted to pine trees especially in the Francis Marion Forest northeast of Charleston where wind speeds were about twenty percent higher. Pine trees were snapped or uprooted. Many trees impacted residences causing considerable structural damage. One house in particular I recall had more than one dozen impacts.

Other: Damage was noted to signs, billboards, and fences in the area. A small number of gas station canopies were destroyed. Steel light poles at the local stadium fell over rotating about their pier caps. The concrete bases were not attached to the pier caps.

HURRICANE ANDREW - FLORIDA - AUGUST 24, 1992

1 minute sustained wind speed at 33 feet in open terrain: 145 MPH (estimated)
3-second peak wind gust at 33 feet in open terrain: 175 MPH (estimated)
Peak storm surge: 16.9 feet MSL (measured at BK Headquarters measured)

Survey: Aerial and ground surveys were conducted from Fort Lauderdale to Miami to Key Largo.

Wood-framed residences: The vast majority of wood-framed residences sustained damage to their asphalt roof coverings. Concrete tiles that were not anchored well (secured with mortar patties) were removed from roofs and showered homes downwind with flying debris. Several poorly built wood-framed residences sustained considerable structural damage involving the removal of roof and/or wall cladding and/or collapse. Residences with ladder rake details and scissor trusses performed poorly. Window glass not protected by shutters was frequently broken by flying debris.

Concrete block-stucco (CBS) residences: The majority of CMU residences performed well. However, most residences had failures of the roof covering with some decking displaced. Gable ends were notably weak and were pushed inward or outward depending on the wind direction. A small percentage of residences had manufactured wood-trusses fail where they were strapped to the bond beams.

Pre-cast double-tee structures: A small percentage of double-tee roofs were uplifted such that the panels fell into the building and/or had the top portion of the tee broken at midspan. A large boat storage facility constructed with double-tee walls collapsed breaking at the foundation line.

Pre-cast tilt-up wall structures: The vast majority of these structures remained intact but had roof and overhead door failures. Flying roof gravel broke unprotected windows downwind.

Concrete masonry unit (CMU) buildings: The vast majority of these buildings had damage to their roof coverings whereas a small percentage of them had collapsed.

Metal buildings: Many steel framed structures lost their cladding and a small percentage actually collapsed failing where the columns were secured to the concrete slab foundations.

Manufactured housing: Complete devastation was noted in several parks with shedding of metal cladding and destruction of the wooden box on top of the steel frames. Steel frames that were well anchored remained in place. However, those frames that were not anchored shifted, rolled, or were tossed.

High rises: A large number of EIFS facades failed, especially on high rise condominium and office buildings affected by the northern eyewall. Many windows were broken by flying debris.

Trees: Entire forests of trees in soft sandy soil were uprooted on Key Biscayne and Virginia Key.

Towers/Poles: Several guyed steel framed radio towers had collapsed but water towers remained. Free standing light fixtures at Cleveland Indians stadium were bent or toppled. Some hollow spun concrete power poles were broken whereas many wood power poles were toppled or broken.

Other: Many small and medium aircraft were flipped or tossed at Tamiami Airport. Several automobiles had shifted, rolled, or flipped. Cyclone fences were bent at Cleveland Indians stadium in Homestead.

HURRICANE ANDREW - LOUISIANA - AUGUST 24, 1992

1 minute sustained wind speed at 33 feet in open terrain: 80 MPH (estimated)
3-second peak wind gust at 33 feet in open terrain: 100 MPH (estimated)
Peak storm surge: 8.0 feet MSL (measured at Cocodrie)

Survey: A ground survey was conducted of the Louisiana coast (including the LaPlace tornado.)

Wood-framed residences: Several wood-framed residences sustained damage to their asphalt roof coverings allowing rain water entry. A few poorly built, elevated wood-framed residences sustained considerable structural damage involving the removal of roof and/or wall cladding and/or collapse at Cypremort Point, LA.

Brick masonry structures: Most brick masonry structures performed well with some damage to built-up roofing. A few such buildings did collapse when wood beams were lifted out of their wall sockets in Jeanerette, LA.

Concrete block-stucco (CBS) residences: No CBS homes were in the surveyed area.

Pre-cast double-tee structures: No such structures were found in the surveyed area.

Pre-cast tilt-up wall structures: No such structures were found in the survey area.

Concrete masonry unit (CMU) buildings: These buildings performed well in the above wind speeds with damage primarily to asphalt and metal roof coverings.

Metal buildings: These buildings performed well in the above wind speeds with damage primarily to metal roof coverings and overhead doors.

Manufactured housing: Several manufactured homes sustained damage to roofing, carports, or sunrooms. A small percentage of unanchored manufactured homes had shifted, rolled, or flipped especially when out in the open.

Trees: Numerous broken branches and toppling of shallow-rooted trees were noted in the coastal region. Pine trees were prone to being snapped or uprooted.

Towers/Poles: There were many wood power poles that were pushed over in the soft, marshy soil. A smaller number of wood poles snapped.

HURRICANE INIKI- KAUAI – SEPTEMBER 11, 1992

1 minute sustained wind speed at 33 feet in open terrain: 111 MPH (Poipu area)
3-second peak wind gust at 33 feet in open terrain: 143 MPH (Poipu area)
Peak storm surge: 20 feet MSL (measured at Poipu Beach)

Survey: A ground survey was conducted around the entire island. Overall, the degree of damage to buildings was worse than in Hurricane Iwa in 1982.

Wood-framed residences: Many wood-framed residences sustained damage at these wind speeds, although, most of these homes were single-wall construction. Common damage was the removal of roof coverings (typically asphalt shingles and metal panels) which resulted in rainwater entry. Cedar shake and anchored tile roofs performed well. Poorly attached metal and tile roofs were removed. Many homes lost roof decking or the roof structure due to poor attachment. Porch coverings, lanais, awnings, and other canopies sustained damage at these wind speeds. Unprotected windows were sometimes broken by flying debris and internal pressure contributed to the loss of the roof/walls.

Unreinforced brick masonry buildings: The vast majority of these buildings survived the hurricane with damage limited mainly to roof coverings.

Concrete masonry unit (CMU) buildings: In general, these buildings performed well during the storm with common damage to the roof coverings. A few masonry buildings collapsed in Lihue. Failure typically occurred when wood roofs were uplifted.

Metal buildings: There were several steel framed structures that lost their metal cladding in Lihue. Overhead door failures were common.

In general, metal buildings performed well. However, occasional damage involved cladding being removed from windward corners, rakes, and eaves. A few canopies or overhangs were flipped or rolled back. Some overhead doors had failed.

Manufactured housing: No manufactured homes were observed on the island during the survey.

Poles: Numerous wooden power poles were downed across the entire island. Electric power was out for months.

Trees: Considerable damage was done to all types of trees on the island including the Eucalyptus trees in the “Tree Tunnel” where most branches were broken.

HURRICANE OPAL- SANTA ROSA ISLAND, FL - OCTOBER 4, 1995

1 minute sustained wind speed at 33 feet in open terrain: 55 MPH (PNS), 70 MPH (Navarre est.),
3-second peak wind gust at 33 feet in open terrain: 70 MPH (PNS), 100 (Navarre est.),
Peak storm surge: 21.5 MSL (measured east of Miramar Beach)

Survey: A ground survey was conducted along the Florida coast from Fort Walton Beach to Pensacola including Santa Rosa Island.

Wood-framed residences: Wood-framed residences performed well during these wind speeds. Most homes had little to no damage. Occasionally, damage was found to three-tab asphalt shingles, metal roofing, tile roofing, vinyl siding, and vinyl soffits. A small number of porch coverings, awnings, and other canopies sustained damage. A small number of homes on Santa Rosa Island had more serious roof damage such as loss of gable ends and decking. Falling trees caused considerable damage to homes further inland.

High Rise buildings: Window failures were noted in high rise hotels, offices, and condominium buildings along the coast. Small portions of EIFS facades were removed on some motels.

Unreinforced brick masonry buildings: These buildings performed well during the above wind speeds. Only isolated failures of brick facades were observed where brick ties had corroded or were not installed.

Concrete masonry unit (CMU) buildings: These buildings performed well during the above wind speeds. Damage was limited primarily to roof coverings, overhead doors, and windows.

Metal buildings: These buildings performed well during the above wind speeds. Only isolated failures of gable ends, roof corners, or end walls were observed. A few unreinforced CMU facades around metal buildings had collapsed as the steel-frame flexed.

Manufactured housing: Many manufactured homes sustained damage to roofing, carports, or sunrooms. A small percentage of unanchored manufactured homes had shifted, rolled, or flipped especially when out in the open.

Trees: Extensive damage was noted to pine trees. Many trees impacted residences causing considerable structural damage.

Other: Damage was noted to signs, billboards, and fences in the area. A small number of gas station canopies were destroyed.

HURRICANE FRAN - SEPTEMBER 5, 1996

1 minute sustained wind speed at 33 feet in open terrain: 67 MPH (ILM), 70 MPH Topsail Beach (est.)
3-second peak wind gust at 33 feet in open terrain: 86 MPH (ILM), 90 MPH Topsail Beach (est.)
Peak storm surge: 12 feet MSL at Carolina Beach (est.)

Survey: A ground survey was conducted along the North Carolina coast from South Carolina border to Surf City including the barrier islands.

Wood-framed residences: Wood-framed residences performed well during these wind speeds. Most homes had little to no damage. Occasionally, damage was found to three-tab asphalt shingles, vinyl siding, and vinyl soffits. A small number of porch coverings, awnings, and other canopies sustained damage. Unprotected windows were sometimes broken by flying debris. The worst damage occurred when trees fell on homes.

Unreinforced brick masonry buildings: These buildings performed well in the above wind speeds with damage limited mainly to roof coverings.

Concrete masonry unit (CMU) buildings: These buildings performed well in the above wind speeds with damage limited mainly to roof coverings.

Metal buildings: Steel framed structures performed well at the above wind speeds. However, there were occasional overhead door failures. A hangar at the Wilmington airport sustained significant structural damage when the large door failed. Sheet metal was removed and girts and purlins were bent.

Manufactured housing: The majority of manufactured homes performed well at the above wind speeds. There were occasional roof and siding damages as well as damage to carports.

Trees: Considerable damage was noted to pine trees within ten miles around Wilmington.

Other: Damage was noted to signs, billboards, and fences in the area. Several gas station canopies were destroyed. However, considerable corrosion was frequently found in the steel supports. Steel light poles remained undamaged along Long Beach, Yaupon Beach. A few church steeples were toppled.

HURRICANE GEORGES- SEPTEMBER 28, 1998

1 minute sustained wind speed at 33 feet in open terrain: 61 MPH Gulfport
3-second peak wind gust at 33 feet in open terrain: 79 MPH Gulfport
Peak storm surge: 10.8 feet MSL at Pascagoula

Survey: A ground survey was conducted along the Mississippi Coast from Pascagoula to Pass Christian. I actually drove along the shoreline during landfall. This was one of the weaker hurricanes experienced as I was able to drive along the coastal highway throughout the event.

Wood-framed residences: Wood-framed residences performed well during these wind speeds. Most homes had little to no damage. Occasionally, damage was found to three-tab asphalt shingles, metal roofing, vinyl siding, and vinyl soffits. A small number of porch coverings, awnings, and other canopies sustained damage. Unprotected windows were sometimes broken by flying debris. The worst damage occurred when trees fell on homes.

Unreinforced brick masonry buildings: These buildings performed well in the above wind speeds with damage limited mainly to roof coverings.

Concrete masonry unit (CMU) buildings: These buildings performed well in the above wind speeds with damage limited mainly to roof coverings.

Metal buildings: Steel framed structures performed well at the above wind speeds. However, there were occasional overhead door failures.

Manufactured housing: The majority of manufactured homes performed well at the above wind speeds. There were occasional roof and siding damages as well as damage to carports.

Trees: Considerable damage was noted to pine trees.

Other: Damage was noted to signs, billboards, and fences in the area. A few gas station canopies were destroyed. Some wood power poles were leaning.

HURRICANE LILI- OCTOBER 3, 2002

1 minute sustained wind speed at 33 feet in open terrain: 74 MPH (Kaplan)
3-second peak wind gust at 33 feet in open terrain: 99 MPH (Kaplan)
Peak storm surge: 12.3 MSL at Calumet

Survey: A ground survey was conducted south of I-10 from Morgan City to Crowley down to Hwy 14. This was another weak hurricane as I was able to drive along Highway 14 during the event.

Wood-framed residences: Wood-framed residences performed well during these wind speeds. Most homes had little to no damage. Occasionally, damage was found to three-tab asphalt shingles, metal roofing, vinyl siding, and vinyl soffits. A small number of porch coverings, awnings, and other canopies sustained damage. Unprotected windows were sometimes broken by flying debris. The worst damage occurred when trees fell on homes.

Unreinforced brick masonry buildings: These buildings performed well in the above wind speeds with damage limited mainly to roof coverings. However, the front load bearing wall failed on a building in Eunice.

Concrete masonry unit (CMU) buildings: These buildings performed well in the above wind speeds with damage limited mainly to roof coverings.

Metal buildings: The vast majority of steel framed structures performed well at the above wind speeds. However, there were several buildings that lost metal clad roof panels as well as overhead doors.

Manufactured housing: Most manufactured homes performed well at the above wind speeds. There were occasional roof and siding damages as well as damage to carports. Destroyed manufactured homes were observed in open, rural areas and these homes had little to no ground attachment.

Trees: Considerable damage was noted to trees. Many branches were broken and trees were uprooted in soft, saturated soil.

Other: Damage was noted to signs, billboards, and fences in the area. A few gas station canopies were destroyed. Many wood power poles were toppled in the soft, saturated soil.

HURRICANE CHARLEY - FLORIDA – AUGUST 13, 2004

1 minute sustained wind speed at 33 feet in open terrain: 111 MPH Punta Gorda, 120 MPH N. Captiva
3-second peak wind gust at 33 feet in open terrain: 130 MPH Punta Gorda, 145 MPH N Captiva (est.)
Peak storm surge: 8 feet MSL (measured on Fort Myers Beach)

Survey: Aerial and ground surveys were conducted in southwest Florida including the barrier islands of Captiva, Sanibel, Pine Island, and Fort Myers Beach.

Wood-framed residences: Well-built homes sustained little to no damage. However, many homes built prior to post-Andrew building codes sustained considerable structural damage involving the removal of roof and/or wall cladding and/or collapse due to failure of nailed connections. Many gable ends failed. Considerable damage was noted to tile roofs, especially those that were not secured well (i.e. mortar paddies). Metal roofs performed best but there were still occasional failures due to poor connections. Three-tab asphalt shingles did not perform well but laminated type shingles did better. Window glass that not protected by shutters were sometimes broken by flying debris. Vinyl siding and soffits frequently failed.

Concrete block-stucco (CBS) residences: In general, CBS homes performed better than wood-framed homes and had less roof failures. Observed roof failures were in older homes where clipped rafters actually split or nails were pulled out.

Pre-cast tilt-up wall structures: The vast majority of these structures remained intact but had roof covering and overhead door failures. Flying roof gravel broke unprotected windows downwind.

Concrete masonry unit (CMU) buildings: The vast majority of these buildings had damage to their roof coverings and a small percentage of them collapsed. Building damage increased when windward doors or windows failed.

Metal buildings: Most of the steel-framed buildings performed well, but we did observe a significant number of buildings which sustained substantial damage and even collapsed. Overhead door and canopy failures were common as well as end wall failures.

Manufactured housing: Substantial damage occurred to manufactured homes in several parks with the loss of roofs or sidewalls, even though frames remained well anchored. Failure of carports and sunroom additions also were common.

Trees: Considerable damage was noted to trees of all types, especially on North Captiva and Capitva Islands where forests were stripped of leaves or uprooted. Many buildings were damaged by falling trees.

Towers/Poles: Numerous wood power poles were downed but most steel street lights survived. Tall light poles at the Port Charlotte Sports Complex toppled. Also, tall steel light poles collapsed on I-75 where the highest winds occurred.

Other: Most swimming pool enclosures were damaged with screens torn or the entire structure collapsed. Several gas station canopies had toppled or roof panels were shredded. A few automobiles were flipped but this was more common in Hurricane Andrew.

HURRICANE FRANCES – EAST FLORIDA COAST – SEPTEMBER 14, 2004

1 minute sustained wind speed at 33 feet in open terrain: 77 MPH, Port St. Lucie
3-second peak wind gust at 33 feet in open terrain: 95 MPH, Port St. Lucie
Peak storm surge: 6 feet MSL at Cocoa Beach

Survey: A ground survey was conducted along the east Florida coast from Cocoa Beach to Jupiter Beach.

Wood-framed residences: Wood-framed residences performed well during these wind speeds. I had conducted a roof performance study of 375 roofs and found that 73 percent of three-tab shingle roofs sustained wind damage compared to only 33 percent of laminated type asphalt shingles. Also, 35 percent of tile roofs sustained wind damage, but no metal roofs were found to be damaged. Some vinyl siding and vinyl soffits were displaced. Several porch coverings, awnings, and pool enclosures sustained damage. Unprotected windows were sometimes broken by flying debris. The worst damage occurred when trees fell on homes.

Unreinforced brick masonry buildings: These buildings performed well in the above wind speeds with damage limited mainly to roof coverings.

Concrete masonry unit (CMU) buildings: These buildings performed well in the above wind speeds with damage limited mainly to roof coverings.

Metal buildings: The vast majority of steel framed structures performed well at the above wind speeds. However, there were some metal buildings that lost metal clad roof panels as well as overhead doors as observed at the Ft. Pierce power plant.

High rises: Portions of EIFS facades had failed on a few coastal motels and condominium buildings.

Manufactured housing: Most manufactured homes performed well at the above wind speeds. However, damage was common to carports and sunroom additions. Some poorly anchored homes had shifted off their supports.

Poles/Lights: Many wood power poles had snapped especially when the wires caught flying debris. Occasional light standards had fallen.

Trees: Damage to trees consisted of broken branches with a small number that were uprooted.

Other: Damage was noted to signs, billboards, and fences in the area. A few gas station canopies were destroyed. Many wood power poles were toppled. A steeple had toppled on a church in Cocoa Beach.

HURRICANE IVAN – GULF SHORES, AL – PENSACOLA, FL – SEPTEMBER 15, 2004

1 minute sustained wind speed at 33 feet in open terrain: 90 MPH (est. at Perdido Key, FL)
3-second peak wind gust at 33 feet in open terrain: 120 MPH (est. at Perdido Key, FL)
Peak storm surge: 14 feet MSL at Perdido Key, FL

Survey: Ground and aerial surveys were conducted from Fort Walton Beach, FL to Dauphin Island, AL.

Wood-framed residences: Well built wood-framed residences performed well during these wind speeds. However, roof damage was common especially for asphalt roof shingles as well as poorly attached tile roofs. Anchored metal roofs performed best. Vinyl siding and vinyl soffits were occasionally displaced. Several gable end failures were noted. The worst damage included the loss of roof and wall sections especially on elevated beachfront homes due to poor attachment leaving floor platforms in place. Many porch coverings, awnings, and pool enclosures sustained damage. Unprotected windows were sometimes broken by flying debris. In wooded areas, many homes were struck by falling trees.

High rises: Flying debris, such as roof gravel, broke numerous windows in downtown Pensacola high rises. Many coastal motels and condominium buildings sustained considerable damage to their EIFS facades.

Unreinforced brick masonry buildings: These buildings performed well in the above wind speeds with damage limited mainly to roof coverings. A few buildings had collapsed walls due to insufficient or corroded brick ties. Many overhead doors had failed.

Concrete masonry unit (CMU) buildings: These buildings performed well in the above wind speeds with damage limited mainly to roof coverings. A few buildings did have collapsed walls.

Metal buildings: The vast majority of steel framed structures performed well at the above wind speeds. However, there were some metal buildings that lost metal clad roof and wall panels especially when overhead doors failed. A few, poorly built metal buildings collapsed.

Manufactured housing: Most manufactured homes performed well at the above wind speeds. However, damage was common to carports and sunroom additions. Some poorly anchored homes had shifted off their supports.

Trees: There was substantial damage to trees, particularly pines. Many pine trees were snapped or uprooted. Larger oaks also had toppled especially older, rotted trees.

Other: Damage was common to signs, billboards, and fences. A few gas station canopies were destroyed. Many wood power poles were toppled, however, steel power poles remained upright.

HURRICANE DENNIS – NAVARRE, FL – JULY 10, 2005

1 minute sustained wind speed at 33 feet in open terrain: 90 MPH (Navarre, FL)
3-second peak wind gust at 33 feet in open terrain: 121 MPH (Navarre, FL)
Peak storm surge: 11 feet MSL estimated at Navarre Beach, FL

Survey: Ground and aerial surveys were conducted from Fort Walton Beach, FL to Pensacola, FL.

Wood-framed residences: Well built wood-framed residences performed well during these wind speeds. However, roof damage was common especially for asphalt roof shingles as well as poorly attached tile roofs. Anchored metal roofs performed better. Vinyl siding and vinyl soffits also were occasionally displaced. Several gable end failures were noted. The worst damage included the loss of roof and wall sections especially on elevated beachfront homes due to poor attachment leaving floor platforms in place. Many porch coverings, awnings, and pool enclosures sustained damage. Unprotected windows were sometimes broken by flying debris. In wooded areas, many homes were struck by falling trees. The damage was similar to Ivan but in a much smaller area.

Unreinforced brick masonry buildings: These buildings performed well in the above wind speeds with damage limited mainly to roof coverings.

Concrete masonry unit (CMU) buildings: These buildings performed well in the above wind speeds with damage limited mainly to roof coverings.

Metal buildings: The vast majority of steel framed structures performed well at the above wind speeds. However, there were some metal buildings that lost metal clad roof and wall panels especially when overhead doors failed.

High Rises: Many coastal motels and condominium buildings sustained considerable damage to their EIFS facades just like in Ivan.

Manufactured housing: Most manufactured homes performed well at the above wind speeds. However, damage was common to carports and sunroom additions. Some poorly anchored homes had shifted off their supports.

Trees: Damage to trees consisted of broken branches with a small number that were uprooted.

Other: Damage was noted to signs, billboards, and fences in the area. A few gas station canopies were destroyed. Many wood power poles were toppled, however, steel poles remained upright.

HURRICANE KATRINA – MISSISSIPPI COAST – AUGUST 29, 2005

1 minute sustained wind speed at 33 feet in open terrain: 96 MPH (est. Pass Christian, MS)
3-second peak wind gust at 33 feet in open terrain: 125 MPH (est. Pass Christian, MS)
Peak storm surge: 28 feet MSL at Waveland, MS

Survey: Ground and aerial surveys were conducted from Pensacola, FL to New Orleans, LA.

Wood-framed residences: Well built wood-framed residences performed well during these wind speeds. However, roof damage was common especially for asphalt roof shingles as well as poorly attached tile roofs. Anchored metal roofs performed better. Vinyl siding and vinyl soffits were occasionally displaced. Occasional gable end failures were noted and a small number of poorly attached roofs were removed. Many porch coverings, awnings, and canopies sustained damage. Unprotected windows were sometimes broken by flying debris. In wooded areas, many homes were struck by falling trees. The damage was similar to Ivan but in a wider area. In a study of 8119 residences, less than 15 percent sustained structural wind damage.

Unreinforced brick masonry buildings: These buildings performed well in the above wind speeds with damage limited mainly to roof coverings. There were a few façade collapses due to insufficient or corroded brick ties.

Concrete masonry unit (CMU) buildings: These buildings performed well in the above wind speeds with damage limited mainly to roof coverings. Occasional overhead door failures were observed.

Metal buildings: The vast majority of steel framed structures performed well at the above wind speeds. However, there were some metal buildings that lost metal clad roof and wall panels especially when overhead doors failed. A few steel frames had collapsed. In a study of 1212 metal buildings, 11 percent sustained cladding damage with less than one percent having partial collapse.

High Rises: Many coastal motels, casinos and condominium buildings sustained considerable damage to their EIFS facades.

Manufactured housing: Most manufactured homes performed well at the above wind speeds. However, damage was common to carports and sunroom additions. Some poorly anchored homes had shifted off their supports. In a study of 1678 manufactured homes, less than 10 percent sustained structural damage. The low number was due in part to their inland, usually wooded locations where wind speeds were lower.

Trees: Many pine trees were uprooted or snapped with a smaller number of oaks being uprooted.

Other: Damage was common to signs, billboards, and fences in the area. In a study of 96 gas station canopies, only 11 percent sustained some damage with three percent being destroyed. A small percentage of wood power poles were toppled even along the coast. However, tall steel light poles were toppled on I-10 at one intersection in Bay St. Louis.

HURRICANE RITA – SE TEXAS and SW LOUISIANA – SEPTEMBER 24, 2005

1 minute sustained wind speed at 33 feet in open terrain: 94 MPH (Port Arthur, TX)
3-second peak wind gust at 33 feet in open terrain: 116 MPH (Port Arthur, TX)
Peak storm surge: 15 feet MSL at Cameron, LA (est.)

Survey: Ground surveys were conducted in southwest LA and southeast TX, south of I-10.

Wood-framed residences: In general, wood-framed residences performed well during these wind speeds. However, roof damage was common especially for asphalt roof shingles as well as poorly attached tile roofs. Anchored metal roofs performed better. Vinyl siding and vinyl soffits were occasionally displaced. Occasional gable end failures were noted and a small number of poorly attached roofs were removed. Many porch coverings, awnings, and canopies sustained damage. Unprotected windows were sometimes broken by flying debris. In wooded areas, many homes were struck and damaged by falling trees.

Unreinforced brick masonry buildings: These buildings performed well in the above wind speeds with damage limited mainly to roof coverings. There were a few façade collapses due to insufficient or corroded brick ties.

Concrete masonry unit (CMU) buildings: These buildings performed well in the above wind speeds with damage limited mainly to roof coverings. Occasional overhead door failures were observed along with a few "fill-in" walls.

Metal buildings: The vast majority of steel framed structures performed well at the above wind speeds. However, there were some metal buildings that lost metal clad roof and wall panels especially when overhead doors failed. Some end wall collapses were noted.

High Rises: Breakage of window glass was common especially downwind of gravel roofs.

Manufactured housing: Most manufactured homes performed well at the above wind speeds. However, damage was common to roofs, carports, and additions. Some poorly anchored homes had shifted off their supports especially in open, rural areas.

Trees: Considerable damage was done to trees, especially pines. Large numbers of pine trees were snapped or uprooted in coastal forests along the TX/LA border.

Other: Damage was common to signs, billboards, and fences in the area. Several gas station canopies toppled or were shredded. Numerous wood power poles were broken or toppled including some double wood poles. Also, some steel latticed towers had crumpled.

HURRICANE GUSTAV – SOUTHERN LOUISIANA –SEPTEMBER 1, 2008

1 minute sustained wind speed at 33 feet in open terrain: 77 MPH (Houma, LA)
3-second peak wind gust at 33 feet in open terrain: 93 MPH (Houma, LA)
Peak storm surge: 12.5 feet MSL at Bay Gardene, LA (est.)

Survey: A ground survey was conducted in southern Louisiana south of I-10.

Wood-framed residences: In general, wood-framed residences performed well during these wind speeds. However, asphalt roof shingle damage was common. Anchored metal roofs performed better. Vinyl siding and vinyl soffits were occasionally displaced. Occasional gable end failures were noted and a small number of poorly attached roofs were removed. Certain porch coverings, awnings, and canopies sustained wind damage. Unprotected windows were sometimes broken by flying debris. In wooded areas, several homes were struck and damaged by falling trees.

Unreinforced brick masonry buildings: These buildings performed well in the above wind speeds with damage limited mainly to roof coverings. However, there were a few façade collapses due to insufficient or corroded brick ties.

Concrete masonry unit (CMU) buildings: These buildings performed well in the above wind speeds with damage limited mainly to roof coverings. Occasional overhead door failures were observed along with the collapse of a few "fill-in" walls.

Metal buildings: The vast majority of steel framed structures performed well at the above wind speeds. However, some metal buildings lost metal roof and wall panels especially when overhead doors failed. Some end wall collapses were noted made from either metal panels or CMU.

Manufactured housing: Most manufactured homes performed well at the above wind speeds. However, damage was observed to roof coverings, carports, and additions. Some poorly anchored homes had shifted off their supports and rolled especially in open, rural areas.

Trees: Typical damage to trees involved loss of leaves and branches. Occasional shallow rooted trees were snapped or uprooted.

Other: Damage was common to signs, billboards, and fences in the area. Numerous wood power poles were broken or rotated in the soft, saturated soil. A small number of gas station canopies toppled or lost metal cladding.

HURRICANE IKE – GALVESTON, TX – SEPTEMBER 12, 2008

1 minute sustained wind speed at 33 feet in open terrain: 75 MPH (GLS), 90 MPH Bolivar area
3-second peak wind gust at 33 feet in open terrain: 93 MPH (GLS), 116 MPH Bolivar area
Peak storm surge: 16.5 feet MSL at Anahuac, TX

Survey: Ground and aerial surveys were conducted from Freeport to Galveston, around Galveston Bay to the Bolivar peninsula to Port Arthur, TX including the cities of Houston and Beaumont and their suburbs.

Wood-framed residences: In general, wood-framed residences performed well during these wind speeds. However, common damage included displaced three-tab asphalt shingles as well as concrete or clay tile roofs while anchored metal roofs performed better. Vinyl siding and vinyl soffits were occasionally displaced. Occasional gable end failures were noted and a small number of poorly attached roofs and walls were removed. Several porch coverings, awnings, and canopies sustained wind damage. Unprotected windows were sometimes broken by flying debris. In wooded areas, several homes were damaged by falling trees.

Unreinforced brick masonry buildings: These buildings performed well in the above wind speeds with damage limited mainly to roof coverings. However, there were several façade collapses due to insufficient or corroded brick ties.

Concrete masonry unit (CMU) buildings: These buildings performed well in the above wind speeds with damage limited mainly to roof coverings. Occasional overhead door failures were observed along with the collapse of a few “fill-in” walls.

Metal buildings: The vast majority of steel framed structures performed well at the above wind speeds. However, some metal buildings lost metal roof and wall panels especially when overhead doors failed. Some end wall collapses were noted made from either metal panels or CMU.

Manufactured housing: Most manufactured homes performed well at the above wind speeds. However, damage was observed to roof coverings, carports, and additions. Some poorly anchored homes had shifted off their supports and rolled especially in open, rural areas.

High Rises: Certain high rise buildings in downtown Houston had glass broken due to the impact of flying debris including metal panels and roof gravel. Several EIFS facades had partial failures on motels and office buildings throughout the region.

Trees: Typical damage to trees involved loss of leaves and branches. Occasional shallow rooted trees were snapped or uprooted. A small percentage of pine trees were snapped or broken.

Other: Damage was common to signs, billboards, and fences in the area. Numerous wood power poles were broken or rotated in the soft, saturated soil. A small number of gas station canopies toppled or lost metal cladding.

SUMMARY

For sustained one minute sustained winds of 55 to 73 MPH at 33 feet (3-sec gusts 75 to 95 MPH):

- Wood-framed residences perform well usually with no structural damage. More common damage can involve the removal of three-tab asphalt shingles and unanchored tiles. Vinyl siding and soffit panels can be displaced. Aluminum porch coverings, carports, and awnings are susceptible to being deformed or displaced.

- Unreinforced brick and concrete masonry buildings perform well at these wind speeds with damage limited primarily to poorly attached roof coverings. There can be isolated façade collapses especially if brick ties are non-existent or corroded. Failure of overhead doors can occur and unprotected windows can be broken by flying debris.

- Metal buildings perform well at these wind speeds. Canopies or overhangs are susceptible to being flipped or rolled back. Failure of overhead doors can occur and unprotected windows can be broken by flying debris.

- Manufactured houses perform well at these wind speeds with occasional damage involving the removal of the roof covering, and damage to carports or sunrooms. Unanchored, single-wide homes can slide or roll especially if broadsided by the wind and in open terrain.

- Tree damage can involve displaced leaves/needles and branches. Pine trees are susceptible to being snapped or broken and falling trees can damage houses and vehicles. Signs, billboards, and fences are susceptible to being damaged at these wind speeds. A small number of gas station canopies can be loose panels. Wood power poles can rotate in soft soil or weak poles can snap. Steel light standards typically are not damaged.

- High Rise buildings will perform well at these wind speeds, although glass facades can be prone to impact of flying debris such as small gravel. Poorly attached EIFS facades can fail.

HURRICANES SURVEYED:
Allen (1980) in Corpus Christi, TX
Iwa (1982) in Lihue, HI
Alicia (1983) in Galveston, TX
Opal (1995) in Pensacola, FL
Fran (1996) in Wilmington, NC
Georges (1998) in Biloxi, MS

For sustained one minute sustained winds of 74 to 95 MPH at 33 feet (3-sec gusts 96 to 115 MPH):

- Wood-framed residences perform well usually with no structural damage. More common damage can involve the removal of three-tab asphalt shingles and unanchored tiles. Vinyl siding and soffit panels can be displaced. Aluminum porch coverings, carports, and awnings are susceptible to being deformed or displaced.

- Unreinforced brick and concrete masonry buildings perform well at these wind speeds with damage limited primarily to poorly attached roof coverings. There can be isolated façade collapses especially if brick ties are non-existent or corroded. Failure of overhead doors can occur and unprotected windows can be broken by flying debris.

- Metal buildings perform well at these wind speeds. Canopies or overhangs are susceptible to being flipped or rolled back. Failure of overhead doors can occur and unprotected windows can be broken by flying debris.

- Manufactured houses perform well at these wind speeds with occasional damage involving the removal of the roof covering, and damage to carports or sunrooms. Unanchored, single-wide homes can slide or roll especially if broadsided by the wind and in open terrain.

- Tree damage can involve displaced leaves/needles and branches. Pine trees are susceptible to being snapped or broken and falling trees can damage houses and vehicles. Signs, billboards, and fences are susceptible to being damaged at these wind speeds. A small number of gas station canopies can be loose panels. Wood power poles can rotate in soft soil or weak poles can snap. Steel light standards typically are not damaged. Screens can be damaged in swimming pool enclosures especially from falling debris. A small number of swimming pool enclosures collapse.

- High Rise buildings will perform well at these wind speeds, although glass facades can be prone to impact of flying debris such as small gravel. Poorly attached EIFS facades can fail.

NOTE: The degree of damage is basically the same for each building type listed, just more of widespread.

HURRICANES SURVEYED:
Elena (1985) in Biloxi, MS
Hugo (1989) in Charleston, SC
Andrew (1992) in Louisiana
Lili (2002) in Louisiana
Frances (2004) in Port St. Lucie, FL
Ivan (2004) in Pensacola, FL
Dennis (2005) in Navarre, FL
Rita (2005) in Port Arthur, TX
Gustav (2008) in Louisiana
Ike (2008) in Galveston, TX

For sustained one minute sustained winds of 96 to 110 MPH at 33 feet (3-sec gusts 116 to 135 MPH):

- The vast majority of wood-framed residences perform well. However, a small number of residences can have gable end failures, removal of roof decking, or the entire roof structure removed if poorly attached. In a study of 8119 residences in Katrina, less than 15 percent of homes sustained structural wind damage. More common damage can involve the removal of asphalt shingles and unanchored tiles. Aluminum porch coverings, carports, and awnings can be destroyed.

- The vast majority of unreinforced brick and concrete masonry buildings perform well at these wind speeds with damage limited primarily to poorly attached roof coverings. There can be isolated façade collapses especially if brick ties are non-existent or corroded. Failure of overhead doors can occur and unprotected windows can be broken by flying debris.

- The vast majority of metal buildings perform well at these wind speeds. However, isolated damage can occur to metal clad roof and wall panels especially if overhead doors fail or windows are broken. A few steel frames can collapse. In a study of 1212 metal buildings in Katrina, 11 percent sustained cladding damage with less than one percent having partial collapse.

- Structural damage can occur to manufactured homes. Unanchored, single-wide homes can slide or roll especially if broadsided by the wind and in open terrain. More common damage can include the displacement of the roof covering, carports, and sunroom additions. In a study of 1678 manufactured homes in Katrina, less than 10 percent sustained structural damage.

- Many trees are uprooted or snapped, especially pines. Falling trees can damage houses and vehicles. Signs, billboards, and fences are susceptible to being damaged at these wind speeds. A small number of gas station canopies can suffer structural damage. In a study of 96 gas station canopies in Katrina, 11 percent sustained some damage with three percent being destroyed. Wood power poles can be toppled with a small number of steel light standards damaged. A higher percentage of swimming pool are damaged/collapse.

- High Rise buildings perform well at these wind speeds, although glass facades can be prone to impact of flying debris such as small gravel. Poorly attached EIFS facades can fail.

HURRICANES SURVEYED:
Hurricane Allen (1980) in Port Mansfield, TX
Hurricane Elena (1985) on Dauphin Island, AL
Hurricane Hugo (1989) in Bulls Bay, SC
Hurricane Katrina (2005) in Pass Christian, MS
Hurricane Ike (2005) on Port Bolivar, TX

For sustained one minute sustained winds of 111 to 130 MPH at 33 feet (3-sec gusts 136 to 155 MPH):

- Well-built wood-framed residences perform well. However, homes with poor roof/wall connections can sustain partial or complete roof removal. Gable end failures occur. More common damage involves the removal of asphalt shingles and unanchored tiles. A higher percentage of vinyl siding and soffit panels are removed. Also, a higher percentage of aluminum porch coverings, carports, and awnings are destroyed.

- The vast majority of unreinforced brick and concrete masonry buildings perform well at these wind speeds. However, a higher percentage of façade collapses can occur especially if brick ties are non-existent or corroded. Failures of overhead doors are more common along with broken windows from flying debris.

- The vast majority of metal buildings perform well at these wind speeds. However, a higher percentage of damage occurs to metal clad roof and wall panels especially if overhead doors fail or windows are broken. Also, a higher percentage of steel frames collapse.

- Structural damage is more likely manufactured homes. Unanchored, single-wide homes can slide or roll or vault especially if broadsided by the wind and in open terrain. More common damage includes the displacement of the roof covering, carports, and sunroom additions.

- A higher number of trees are uprooted or snapped, especially pines. Signs, billboards, and fences are more frequently damaged at these wind speeds. A higher percentage of gas station canopies suffer structural damage. More widespread damage occurs to wood power poles and steel light standards.

- High Rise buildings perform well at these wind speeds, although glass facades are prone to impact of flying debris such as small gravel. EIFS facades are more likely to fail.

HURRICANES SURVEYED:
Hurricane Charley (2004) in Punta Gorda, FL
Hurricane Iniki (1992) in Lihue, HI

For sustained one minute sustained winds of 131 to 155 MPH at 33 feet (3-sec gusts 156 to 175 MPH):

- Wood-framed residences: The vast majority of wood-framed residences sustained damage to their roof coverings. Concrete tiles that are not anchored well (secured with mortar patties) are removed from roofs and shower homes downwind with flying debris. Poorly built wood-framed residences can sustain considerable structural damage involving the removal of roof and/or wall cladding and/or collapse. Window glass not protected by shutters is frequently broken by flying debris.

- Concrete block-stucco (CBS) residences: The majority of CMU residences perform well. However, most residences will have failures of their asphalt roof covering with some decking displaced. Gable ends can be pushed inward or outward depending on the wind direction. A small percentage of residences will have roof failures where wood trusses are strapped to the bond beams.

- Pre-cast tilt-up wall structures: The vast majority of these structures remain intact but are likely to have roof and overhead door failures. Flying roof gravel can break unprotected windows.

- Concrete masonry unit (CMU) buildings: The vast majority of these buildings are likely to have damage to their roof coverings whereas a small percentage of them collapse.

- Metal buildings: Many steel framed structures suffer loss of cladding with a small percentage actually collapsing.

- Manufactured housing: Complete devastation is likely with shedding of metal cladding and destruction of the wooden box on top of the steel frames. Steel frames that are well anchored remained in place. However, those frames that are not anchored shift, roll, or are tossed.

- High rises: A large number of EIFS facades fail and flying debris breaks windows.

- Trees: Entire forests are flattened.

- Towers/Poles: Large number of wood poles, concrete poles, and steel towers are toppled. Free standing and guyed radio/television towers collapse.

- Other: Many small and medium aircraft are flipped or tossed. Several automobiles shift, roll, or are flipped. Cyclone fences were bent over.

HURRICANES SURVEYED:
Hurricane Andrew (1992) Homestead, FL

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