Lessons from Hurricane Irma: Is it Wind or is it Flood?

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DONAN

Quick Facts

- 30 years engineering experience
- 30 years forensic engineering experience
- Bachelor's Degree, Civil Engineering – University of Kentucky

Expertise

- Structural damage from wind, flood, and multiphase
- Flat damage to commercial and industrial roofs
- Corrosion of structural investigations

Experience

- Bridge Design and Inspection
- Roofline Design
- Flood Construction

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1. Wind
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   - Wind speeds were higher on the coasts.

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   - Wind speeds were higher on the coasts.
2. Storm Surge
   - The storm surge caused significant structural damage in the Keys and southwest properties in Saint Augustine.
   - Flooding in southeast Florida and Jacksonville was primarily from rising water.

• Hurricane Irma made landfall as a Category 4 hurricane on September 10, 2017 on Cudjoe Key, Florida. The maximum estimated sustained wind speeds were approximately 130 mph.
• Irma made a second landfall on Marco Island, Florida as a Category 3 hurricane with wind speeds of approximately 115 mph, striking Naples as a Category 3 hurricane.
• Irma gradually weakened to a tropical storm near Gainesville, Florida.
• Tropical force winds (39 to 73 mph) impacted the entire state of Florida. Tropical force winds also affected Alabama, Georgia, South Carolina, North Carolina, and Tennessee.
• Hurricane force winds (74+ mph) affected the Keys and most of southern Florida.

• According to the National Hurricane Center, Irma was the 5th costliest hurricane in U.S. history (numbers adjusted for inflation).
• By most estimations, 2017 was the costliest hurricane season in U.S. history (2018 data not included).
• Hurricane Irma was the most powerful hurricane to make landfall in Florida since 2005 and the most catastrophic since Hurricane Andrew in 1992.

<table>
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<th>Rank</th>
<th>Tropical Cyclone</th>
<th>Location</th>
<th>Year</th>
<th>Category</th>
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1. Wind
   - Structural damage from wind was limited primarily to the Keys and Florida’s southwest coast.
   - Wind speeds were higher on the coasts.

2. Storm Surge
   - The storm surge caused significant structural damage in the Keys and oceanfront properties around Saint Augustine.
   - Flooding in southwest Florida and Jacksonville was primarily from rising water.

3. Rain
   - Some areas received 10 to 15 inches of rain.
   - Rainfall caused some inland flooding.

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Common Scopes for Engineers:

- Determining the extent of damage from wind or flood.
- Differentiating between wind and flood damage.
- Differentiating between pre-existing and hurricane-related damage.
- Determining if water intrusion is the result of a storm-related opening in the structure.

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Quick Review of How Wind Affects a Structure

- Winds generate two components acting on and around the building:
  1. Pressure against the building
  2. Impact from wind borne debris.

- Wind damage:
  1. Wind pressure increases with increasing height.
  2. Damage is from top to the bottom and from the outside to the inside.
  3. Before structural damage occurs, damage is expected to weaker, non-structural components such as roof coverings and siding.
  4. The foundation is typically the last place structural damage occurs.

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1. Wind
   - In general, building materials performed as expected. Building code changes since Hurricane Andrew have improved the performance of building materials, especially roof coverings. The improvements reduced damage from cascading failures (windborne debris from one building failure resulting in failure of downwind structures).
   - Older buildings were more easily damaged. In other words, buildings built to current code performed better.
   - In some areas with high winds, significant damage would occur to one building while neighboring buildings would have minimal damage.

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   - Damage was from the top down, inside out.

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   - Roof decking and exterior wall coverings failed on this house in the Keys.
1. Wind
- Roof failure often led to failure of walls and other components.
- Damage was from the top down, inside out.
- Roof covering failures typically initiated at roof edges, hips, and ridges, often as a result of inadequate attachment.
- Failure typically started on the windward side.
- Tile roofs were damaged in high-wind areas. The damage was most common on the windward side.

Clay tile roof in Cudjoe Key, Florida

Quick Review of How Flood Affects a Structure

Five Main Causes of Structural Damage:
1. Hydrodynamic forces (horizontal)
2. Hydrostatic forces (horizontal and vertical)
3. Buoyant forces (vertical)
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Five Main Causes of Structural Damage:

1. Hydrodynamic forces (horizontal)
2. Hydrostatic forces (horizontal and vertical)
3. Buoyant forces (vertical)
4. Frictional forces (scour)
5. Flood-induced settlement (not actually a force)

- Settlement can occur from flooding when soil becomes saturated and compresses.
- Damage is typically exhibited by vertical, diagonal, or stair-step cracks in walls and unlevel floors.
- The cracks are often wider at the top.

2. Storm Surge

- Elevated structures performed well during the hurricane.
- Most of the damage was to ground-level areas.
- Most of the structural damage from the surge was to ground-level buildings on the waterfront facing the incoming surge.
- As a general rule, structures even several hundred feet inland did not experience significant structural damage from the storm surge, consistent with the flood zone designations.
- The main cause of damage was impact from waves and waterborne debris.
- Wind damage was typically to the roof and/or upper stories.
- Scour was a minimal problem (unlike Sandy).

3. Rain

The primary issue with water intrusion was:
- Determining if the water intrusion was the result of a storm-related opening.
- Determining if the water intrusion was from rain or flood.

Case Study 1: Wind vs Surge

- Commercial property on Big Pine Key, Florida, with 10+ buildings.
- Experienced high winds and storm surge.
- Buildings on the property had wind and surge damage.
- Scope was to determine what damage was from wind and what damage was from the storm surge.
- Understanding the building’s exposure to wind and surge is important.
Understanding the building’s location relative to the center of the hurricane is important. Understanding the storm’s intensity when it affected this property is important (Category 4). The highest wind speeds and the highest storm surge are on the right-hand side of the hurricane. The counter-clockwise rotation of the storm drives water toward this property.

### Case Study 1: Wind vs Surge

**North**
- Maximum Wind Speed = 132 mph

**West, leeward side**
- On the east, windward side, the walls and roof are missing.
- Grade-level enclosure walls (break-away walls) are missing, but piers and stairs are not damaged.

**East, windward side**
- Missing roof and walls
- North side
- Piers and stairs are not damaged

**Other critical information:**
- Photographs taken immediately after the event can provide critical information.
- Collaterals are critical:
  - Interior high-water mark were 3 feet above grade, exterior impact marks were about 5 feet above grade.
  - The upper level floor framing is about 8 feet above grade.
  - Buildings closer to the shore (incoming surge) have more severe damage on the lower levels but not more damage on the upper levels.

**Conclusions:**
- The lower-level enclosure was damaged by the storm surge.
- The upper-level roof and walls were damaged by wind.

**Lessons Learned:**
- Some structures were damaged by both wind and storm surge.
- Typically, sufficient evidence existed to distinguish between wind and storm surge.
- Data from NOAA (NHC, NWS, etc.) and the USGS are important in understanding what happened at a particular property.
- Evidence (photographs) taken immediately after the storm is critical to determining the cause of damage.
Case Study 2: Pre-Existing Damage

- Residential property Summerland Key, Florida.
- Experienced high winds and storm surge.
- Elevated structure on concrete piles.
- The south section is two story. The north section is one story and is older.
- The lowest level is approximately 10 feet above grade.
- Scope was to determine what damage was from wind and flood; was the interior water intrusion the result of a storm-created opening.

Case Study 2: Pre-Existing Damage

- Similar location to previous property.
- Irma was a Category 4.
- NWS reported 120 mph wind approximately 5 miles northeast of this property.
- A USGS survey point, 0.8 mile south of this property, was 1.3 feet above the ground, elevation 4.2 feet.
- The owner's representative reported that about 2 feet of water was on the property.
- This property elevation is 0 to 5 feet.
- The property is on the east side of the island and is less susceptible to storm surge than properties on the south side.

Case Study 2: Pre-Existing Damage

- No collateral of wind (down trees, broken windows or doors, etc.) or storm surge (displaced soil, high-water marks, etc.).
- Tree reportedly struck the roof on the back-left side. The tree was removed before the site study.
- The ground-level enclosure walls are not displaced.
- The columns are not leaning or displaced, but they have vertical cracks on the older section only.

Case Study 2: Pre-Existing Damage

- One roof panel is bent at the back-left corner, in the area of the reported tree impact.

Case Study 2: Pre-Existing Damage

- The cracks are up to ¼ inch wide.
- The columns are not cracked separated at the grade-level slab or the floor above.
- The owner's representative said the cracks were the result of wind.

Case Study 2: Pre-Existing Damage

- One plumbing vent boot is deteriorated.
- The remainder of the roof panels are not lifted, bent, fractured, or missing.
- One plumbing vent boot is deteriorated.
Case Study 2: Pre-Existing Damage

Analysis:
- The vertical cracks in the columns are not consistent with lateral or vertical forces that would be associated with wind or storm surge.
- The collaterals do not indicate that floodwater or wind with sufficient velocity to cause structural damage occurred on this property.
- Before structural damage would occur to the columns, damage would be expected to the ground-level enclosure (storm surge) or roof (wind).
- A supportable scientific explanation exists for the column cracks.

Case Study 2: Pre-Existing Damage

Conclusion:
- The house was not structurally damaged by wind or storm surge.
- The vertical cracks in the columns are from corrosion of the steel reinforcement and are not a result of the hurricane.
- No storm-caused opening are in the house, and the water intrusion is not the result of a storm-caused opening.
- Any water intrusion that occurred as a result of the hurricane is from either deficiencies in the building envelope, wind-driven rain, or both.

Lessons Learned:
- Recognize common problems in a specific area (vertical cracks and spalling in concrete columns).
- Understand how wind and water forces act on a structure. This can help explain why the damage is or is not the result of the storm.
- If the damage is not from the storm, discovering the actual cause, and being able to support that with science, is important.
- The storm revealed underlying deficiencies (e.g., flashing, inadequate nailing, etc.) that may never have been a problem before the storm. Window installation was a common problem (water intruding around windows).

Questions?