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HURRICANE IKE DAMAGE SURVEY

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1. INTRODUCTION

The author conducted both aerial and ground damage surveys of the upper Texas coast after Hurricane Ike. The purpose of these surveys was to: 1) determine the height of the storm surge, 2) acquire wind data, and 3) delineate the extent of building damage caused by storm surge and wind. The aerial survey extended from Freeport to Galveston, around Galveston Bay, and included the Bolivar Peninsula. The ground survey covered the same area and included inland areas of metropolitan Houston east to the Beaumont/Port Arthur area.

The author rode out Hurricane Ike in the parking lot of the San Luis Resort on Galveston Island. The resort was built on top of abandoned Fort Crockett and was the highest elevation on the island, approximately 7 m above sea level. There also was a concrete seawall that extended along the shoreline in front of the resort. The 5 m tall seawall was constructed after the infamous Galveston hurricane of 1900.

The author witnessed the storm surge firsthand. Water levels increased gradually throughout the day before the hurricane. Low-lying areas of Galveston Island became submerged 12 to 16 hours prior to the eye making landfall (Fig. 1). Waves superimposed on top of the storm surge undermined building foundations and dismantled building supports. Eventually, many buildings collapsed into the water and broke apart with debris being transported inland. In contrast, buildings immediately behind the seawall survived the hurricane since they were protected from the storm surge and wave action.

When the damaging winds arrived, items most susceptible to wind damage were carports, porch overhangs, and roof coverings. Laminated asphalt shingles and metal roofing outperformed three-tab shingles. A number of buildings with exterior insulation finish systems (EIFS) and vinyl siding also experienced damage.

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Figure 1. Residence on fire as the storm surge inundates Galveston Island well in advance of the hurricane. AP Photo/David J. Phillip.

2. WEATHER BACKGROUND

Hurricane Ike made landfall on Galveston Island around 0700 UTC on the morning of 13 September 2008 (Fig. 2). The estimated peak intensity at landfall on the Texas coast was category two on the Saffir-Simpson scale (Berg 2009). The 75 km wide eye traveled northward across Galveston Bay. The east eyewall passed over eastern portions of Galveston Bay and the Bolivar Peninsula. The west eyewall passed over western portions of Galveston Island and downtown Houston.

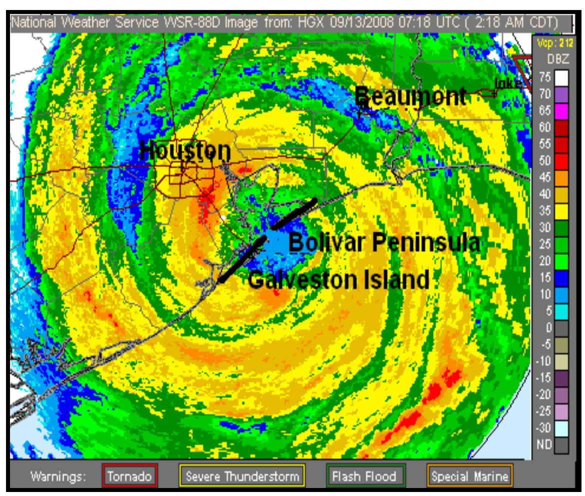

Figure 2. Radar reflectivity image (dBZ) of Hurricane Ike at 0718 UTC on 13 September 2008 as the eye made landfall on Galveston Island.

3. SURGE AND WAVE DAMAGE

The author measured high water marks on the interiors of buildings using a surveyor's level and rod. Generally, water lines were found in rooms that were not breached by wave action. Water lines were composed of dirt and debris deposited when the water level stabilized, much like how dirt rings form in bathtubs (Fig. 3). Water lines were referenced to known benchmarks or topographic features such as road intersections.

High water marks ranged from 3.1 m to 3.7 m on Galveston Island. Around Galveston Bay, high water marks ranged from 3.7 m on the west side of the bay to 4.4 m on the east side of the bay. On the Bolivar Peninsula, high water marks ranged from 3.7 m at the south end to 5.5 m at the north end near the town of High Island. All water marks were adjusted to mean sea level. These high water marks compared well to those measured by the Federal Emergency Management Agency (FEMA 2009).

Figure 3. Example of a high water mark on the interior of a building.

The most common building type on the Bolivar Peninsula and west Galveston Island were wood-framed residences elevated on timber pilings. Typically, elevated floor platforms ranged from two to four meters above grade or four to six meters above mean sea level. Many homes experienced both storm surge and wave action. Homes at the lowest elevations and closest to shore were most likely damaged or destroyed by storm surge and wave action (Figs. 4 through 6).

The author identified four zones of wave damage to buildings: 1) scour, 2) deposition, 3) clean, and 4) debris (Fig. 7). The scour zone was located adjacent to the beach. Sand washed away around pilings and undermined concrete slabs on grade. Roads and sewer systems also were washed away.

Figure 4. Wave action destroyed buildings near the beach (bottom of image) whereas buildings farther inland (top of image) remained intact.

Figure 5. This home lost most of its first elevated floor and several walls due to wave action but, remarkably, did not collapse. By contrast, houses farther inland (in background) were not damaged since wave action was less severe.

Figure 6. Storm surge removed the lower portion of this home leaving the upper portion intact. Generally, buildings at low elevations were susceptible to being damaged or destroyed by storm surge and wave action.

Immediately behind the scour zone was a deposition zone where the storm surge deposited sand on roads, lawns, and beneath elevated homes. In some instances, the sand accumulated several feet deep. Farther inland was a clean zone where fast moving water removed walls and contents from the first story leaving clean slabs. Even farther inland was a debris zone where flotsam, vehicles, building contents, wood debris, etc. from destroyed houses and trees had accumulated in large mats.

Figure 7. Examples of the four wave zones identified by the author in the survey: a) scour, b) deposition, c) clean, and d) debris.

Within the scour zone, the author identified increasing degrees of damage to building foundations (Fig. 8). First, wave action removed sand from around the bases of pilings and from beneath concrete slabs on grade. This action left concrete slabs partially or completely suspended in the air between the pilings. As wave action increased, concrete slabs broke apart. Eventually, enough sand was removed around the bases of the pilings to cause them to lean or topple. In some instances, pilings had shallow depth making it easier for wave action to undermine them.

Degrees of damage to elevated floors increased in all wave zones when waves reached floor level. Initially, wave action rotated or removed blocking between the floor joists. Then, waves uplifted and dismantled floor sheathing as fasteners were incrementally withdrawn from the sheathing. Higher waves uplifted and removed floor joists or pushed them laterally stacking them along the landward sides of the homes. Eventually, enough floor structure was removed resulting in the collapse of the home or leaving the home perched precariously on top of its pilings (Fig. 9). Some houses that fell into the water had floated inland and came to rest on sand hills beside the Intracoastal

Figure 8. Increasing degrees of damage to foundations of elevated wood-framed residences in the scour zone: a) partial scouring of sand beneath slab on grade, b) complete scouring of sand and collapse of slab on grade, c) removal of slab on grade and leaning of the pilings, and d) total loss of piling support.

Figure 9. Increasing degrees of damage to flooring on elevated wood-framed residences: a) rotation of blocking, b) uplift of flooring, c) landward stacking of floor joists, and d) complete loss of the floor structure.

Waterway. In each instance, the destruction of flooring began on the seaward sides of buildings where wave impact forces were greatest.

Large mats of floating debris were generated by the destruction of wood-framed structures. The floating debris acted as battering rams to damage or destroy other buildings farther inland. Abrasions were found on the seaward sides of pilings and trees indicating where they were repeatedly impacted by floating debris.

Floors that were removed by wave action left walls hanging from their top plates. In some instances, waves pushed the bases of seaward walls inward and landward walls outward, creating hinge lines at the tops of the walls (Fig. 10).

Figure 10. Increasing degrees of damage to elevated wood-framed residences in Hurricane Ike: a) damage to a seaward wall, b) loss of seaward walls and part of the floor, c) partial collapse of a house, and d) completely destroyed house with only timber piles remaining.

The United States Geological Survey (USGS 2008) deployed a temporary monitoring network of 117 pressure transducers (sensors) at 65 sites in Texas and Louisiana to record the timing, areal extent, and depth of the storm surge generated by Hurricane Ike. A sensor in the middle of the Bolivar Peninsula recorded a maximum storm surge of approximately 4.7 m above mean sea level with peak wave heights 1.2 m higher. Thus, elevated floors of coastal buildings had to be at least 6 m above mean sea level to escape the storm surge and wave action.

The author observed a number of homes that survived Hurricane Ike on the Bolivar Peninsula and west Galveston Island. Such homes were inland from the scour zone and had elevated floors more than 6 m above mean sea level (Fig. 11). Well built-homes had hurricane straps at vital connections, solid wall sheathing, and hip type roofs covered with metal or laminated type asphalt shingles. Several homes had window and door shutters.

According to the Institute for Business and Home Safety (IBHS 2009), ten of their 13 *Fortified* homes survived Hurricane Ike on the Bolivar Peninsula with no serious damage. These homes were elevated on steel-reinforced concrete columns with the first floor level being approximately 10 m above mean sea level, well above the level of the storm surge and wave action. However, three *Fortified* homes were destroyed when struck by neighboring non-*Fortified* homes pushed off their foundations by the storm surge.

Figure 11. A well-built house that survived Hurricane Ike was elevated above the level of the storm surge and wave action. Also, the home was located inland, with no scouring around the pilings.

4. WIND DAMAGE

Numerous wind recording stations survived Hurricane Ike (Berg 2009). Texas Tech University's Hurricane Research Team (TTUHRT) deployed twenty "sticknets". These "sticknets" had wind sensors mounted on 2.25 m tripods and recorded data at one second intervals. In addition, the Florida Coastal Monitoring Program (FCMP) deployed five, 10 m tall instrumented towers. Maximum three-second wind gusts reported by both groups were 52 m s^{-1} on the east side of Galveston Bay between Monroe City and Winnie, TX (IBHS 2009).

According to the Atlantic Oceanographic and Meteorological Laboratory (AOML 2008) H* wind analysis, Hurricane Ike had sustained (one-minute) winds of 36 m s^{-1} on Galveston Island and 40 m s^{-1} on the Bolivar Peninsula at 10 m above open terrain.

Wind damage to residential buildings was limited mostly to cladding items such as roof shingles, vinyl or hardboard siding and to unprotected windows. In rare instances, portions of roof decks were removed and gable ends were pushed either inward or outward. Roof structures usually were strapped to the wall top plates, and therefore, few roof structures blew off (Fig. 12). The author observed one residence in Webster, TX that had lost its roof revealing rafters and roof joists eaten by termites.

Metal buildings occasionally lost overhead doors which sometimes led to loss of metal cladding. Exterior insulation finish systems (EIFS) were torn away on a number of apartment buildings and motels. Flying debris broke window glass in a few skyscrapers in downtown Houston.

Figure 12. Increasing degrees of wind damage to elevated wood-framed residences in Hurricane Ike: a) loss of roof shingles, b) loss of a porch covering, c) partial loss of the roof structure, and d) total loss of the roof structure.

5. TIMING OF WIND AND WATER

The National Ocean Service (NOS 2009) had 12 tide gauge stations in Louisiana and 13 in Texas at the time of Hurricane Ike. Some stations measured both wind and water levels. One such station was at Eagle Point in San Leon, TX on the west side of Galveston Bay (Fig. 13). Data recorded at this station indicated that water levels began rising the day before Hurricane Ike made landfall. Water levels were 1.5 m at 1600 UTC on 12 September 2008 and rose steadily to 3.64 m at 0624 UTC on 13 September 2008. Maximum (one-minute) sustained winds were 39.9 m s^{-1} from the northeast (029 degrees) at 0612 UTC in the north eyewall and 38.3 m s^{-1} from the southwest (213 degrees) at 1006 UTC in the south eyewall. Winds went calm briefly at 0812 UTC while the eye passed. Thus, the peak storm surge occurred near the time of maximum winds.

The severity and type of damage to a particular building depended on several factors including the quality of original construction, elevation above mean sea level, and proximity to the shore. Therefore, specific site inspections were necessary to delineate wind and water damage.

6. SUMMARY

The author conducted both aerial and ground damage surveys of the upper Texas coast, including Galveston Bay, after Hurricane Ike. Observed wind damage typically involved damage to roof coverings and siding with rare instances of partial or complete removal of the roof structure. Such wind damage was associated with maximum three-second wind gusts between 40 and 52 m s^{-1}.

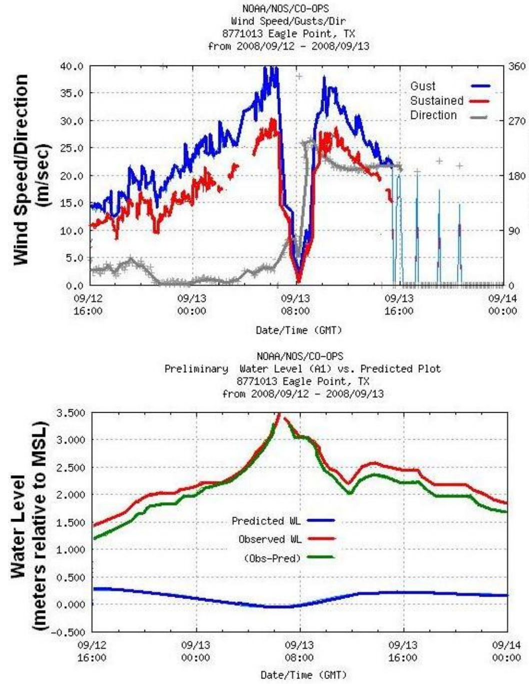

Figure 13. Wind (upper graph) and water levels (lower graph) at Eagle Point in San Leon, TX during Hurricane Ike showing the peak storm surge occurred near the time of maximum winds.

Damage caused by storm surge and wave action was extensive, especially on the Bolivar Peninsula where hundreds of homes were destroyed. The elevation of the first floor level above the water level and distance from shore were critical factors in determining whether buildings survived the storm surge and wave action. Buildings with the best chance of survival during this hurricane were at or above 6 m above mean sea level.

As Marshall (2006a and b) found in previous storm surveys, damage to buildings caused by storm surge and wave action has different characteristics than wind-caused damage. Buildings damaged by storm surge and wave action were dismantled from below. In contrast, buildings damaged by wind had the greatest damage at roof level. The magnitudes of forces differ greatly between wind and wave. However, in both instances, building deficiencies were exploited by the storm. Such deficiencies included inadequate pile embedment and poor attachment of walls to floors and roofs to walls.

The author identified four zones of wave damage to buildings near the shore: 1) scour, 2) deposition, 3) clean, and 4) debris. The scour zone was adjacent to the beach. Sand was washed from around pilings and beneath concrete slabs on grade. Immediately behind the scour zone was a deposition zone where sand was deposited on roads, lawns, and beneath elevated homes. Farther inland was a clean zone where moving water removed walls and contents from the first story leaving clean slabs. Finally, there was a debris zone where flotsam, vehicles, building contents, and wood debris from destroyed homes and trees had accumulated in large mats.

Analysis of wind and water levels from various sources indicated that the storm surge preceded and accompanied the strongest winds. Water levels began rising along the coast well in advance of the hurricane even while winds were blowing offshore. The storm surge flooded low-lying evacuation routes approximately 12 to 16 hours before Hurricane Ike made landfall. Those people who decided to stay to see where the hurricane was heading became trapped by rising water levels.

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