Building for Extreme Events

Lessons Learned from Hurricane Katrina

By William L. Coulbourne, P.E.

Hurricane Katrina struck the U.S. Gulf Coast on August 29, 2005 as a Category 3 hurricane near Pass Christian, Mississippi with sustained wind speeds near 120 mph (from National Weather Service report dated 12/20/05). Importantly, less than 24 hours before landfall, Katrina was a Category 5 hurricane with wind speeds near 175 mph and a central pressure as low as 902 milibars, making it one of the strongest hurricanes in history. The hurricane surge generated by the intense wind speeds, the low central pressure and the shallow shelf of the gulf at the landfall location, created surge elevations that were as high as 30 ft, the highest ever recorded in this part of the U.S.

The damage figures associated with Katrina are staggering. Nearly 500,000 residential buildings were severely damaged or destroyed. About 450,000 people have been displaced. The economic losses are over $125 billion, with nearly $45 billion in insured losses. The residents of Mississippi, Louisiana, and to some extent Alabama, have scattered looking for a place to rebuild and start their lives again. As engineering professionals, what do we learn from an event like this? How can we do more to design hazard resistant structures? Certainly the flooding was extreme and caused massive amounts of debris as the water swept buildings off their foundations, washed through first and sometimes second floors, caused barges to float ashore and damage reinforced concrete parking garages and historic hotels. The wind was not as extreme in magnitude, but still caused considerable damage. We can learn a lot from observing resultant damage evidence in buildings built to strong building codes.

The hurricane effects did not just occur near the shore. There were significant effects very far inland, some caused by hurricane surge and some caused by wind. There was damage to residential, commercial and industrial buildings. There was damage to critical facilities. Many communities in the hurricane ravaged areas had no building codes in effect for residential or commercial buildings that were not state-owned; many communities had no building officials or code enforcement office to encourage stronger building, or act as an advocate for hazard-resistant construction techniques. All of these varied results give us plenty of lessons to learn.

There were some buildings and parts of the infrastructure that survived; some even fared better than that. Those buildings built to up-to-date wind standards and at an elevation above the hurricane surge or flooding elevations did very well. The most robust structural buildings with sufficient redundancy to survive even when a major building element was destroyed performed acceptably. In other cases, many owners ignored hurricane history. Some believed that Hurricane Camille, that hit this same area in 1969, was the once in a lifetime event and that they would not be impacted by a hurricane like Camille again. Katrina proved that living in areas subject to storm events like hurricanes and flooding meant accepting some risk, and that such a devastating event can in fact occur with some frequency.

The wind from this hurricane created a lot more damage than should be expected based on observed wind speeds. By and large, this was barely a building code wind event in a small area yet many failures occurred. The very highest winds observed in Long Beach, MS were approximately 130 mph (3-second gust), while the wind speed in St. Tammany Parish, LA was approximately 120 mph. These observed speeds are close to ASCE 7 and IBC building code requirements (from post-event analysis performed by Applied Research Associates). The failures included uplift of roofs (*Figure 1*) and shearing failure in walls (*Figure 2*).

The roof uplift failure in *Figure 1* was caused by a lack of connections between the roof framing and the exterior wall. Wind got under the indented porch and combined with the uplift on the roof surface to lift the roof trusses. The lack of continuity in the wall construction on the left side of the building caused the wall to peel out at the corner and twist the window. There were numerous examples of this common roof to wall failure mode, such as:

Figure 1: Roof Uplift Failure, Long Beach, MS

- A lack of any connector between the roof truss and wall
- A connector field made from sheet metal and fastened with either 16d nails or roofing nails
- A connector installed but with an insufficient number of fasteners

In addition, there were many instances of inadequate roof sheathing nailing, which allowed the plywood sheathing to peel off the roof exposing the interior to water damage. There were examples of staples that had only one leg of the staple attached to the rafter, nails that completely missed the rafter, and nails used to only attach the corners of the sheathing with no nails in the field of the sheathing.

The shear wall failure in *Figure 2* was caused by a lack of attachment. The sheathing was attached with staples that were widely spaced, and those that were present did not have both legs of the staple attached to the framing. The front wall was approximately 1 foot out of plumb from top to bottom of the wall. There were hold down brackets installed at the ends of the shear wall. The shear wall for a 120 mph (3-sec gust) wind speed should be fastened to the framing with approximately the equivalent of 8d nails spaced 4- to 6-inches on center along the edges. Exact spacing, of course, depends on shear load and the length of the shear wall useable in the wind direction being considered.

Figure 2: Shear Wall Failure, St. Tammany Parish, LA

Stronger building codes and compliance with best practices for high wind areas would have prevented these types of failures. There was significant building envelope failures with roof shingle loss, siding damage, soffit damage, wide spread glazing damage in New Orleans (where wind speeds were between 100 to 110 mph) and brick façade failures. New buildings being erected today exhibit some of the same shortcomings; there is generally a lack of attention to detail and a lack of knowledge about the importance of continuous load paths for build-

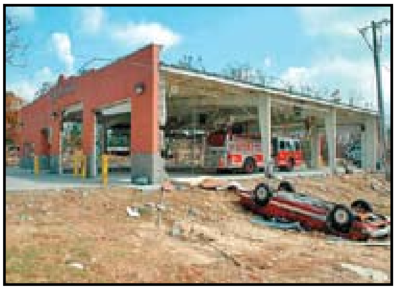

Figure 3: Storm Surge Damage, Gulfport, MS

ings, and insufficient attention paid to the building envelope. This must change if we expect to reduce damage and save lives the next time an event of this magnitude hits this area – and it will (it's all a matter of when, not if).

The flooding, of course, was extreme – storm surge depths of 25 to 30 feet in Mississippi and nearly 12 feet as far east as Mobile Bay, AL. Water overtopped and failed the flood protection levee system around New Orleans. The lessons are numerous, and they include:

- Build higher
- Robust systems can survive
- Consider flooding extremes even in back bay areas that seem very far from the primary flooding source
- Don't assume that flood protection structures will always protect
- Owners must assume some risk for living in places subject to extreme events

Critical facilities were impacted as much as any other building type. Frequently, critical facilities (emergency operations centers, fire and police stations, etc.) are located in buildings that were not originally designed for the important functions now housed in them. Some of these facilities were located in floodplains and were damaged or isolated by the hurricane surge (*Figure 3*). Some lost parts of the building envelope and thus were damaged by wind driven rain. Some were occupied throughout the hurricane and some occupants nearly drowned from rising water. Others were abandoned during the hurricane, and thus occupants were endangered as they moved to another building during peak high winds and as water rushed inland.

Communities may not be able to afford a new building for their most critical functions, but each building that is chosen for such important duty should be thoroughly inspected and an evaluation made of the potential consequence of using the building during and/or after a design event. Operational plans should be developed that address the limitations of the building to wind and flood hazards, and clearly identify alternate site locations should evacuation be necessary. Loss of these critical functions resulted in the inability of the local jurisdictions to actively participate in the response and recovery efforts.

A final observation on flood protection systems and structures is they may create space for people to live in hazard-prone areas near city centers, recreational sites, or other scenic areas but these structures create the illusion of always being protected from a significant flood threat. The failure of the New Orleans levee system is just one example of this illusion. If we insist as a nation on spending money and creating space for people to live near these flood protection systems, then we should at least recognize the associated risk with doing so and require at a minimum:

- Buildings should be elevated so that some level of overtopping or failure of the system would not affect all those who live behind the protection
- Building owners must have insurance protection so taxpayers are not fiscally responsible
- A maintenance system must be in place that in fact encompasses the entire flood protection system so it's treated as a single protective entity, not a series of entities
- The level of overall protection of the system should represent a major flood event with a low probability of occurrence, to reduce the number of events that impact those located behind the protection
- Probabilistic modeling of storm surge levels that provides more accurate estimates of 100, 500 and 1000-year mean recurrence interval events

So now what must happen to rebuild the miles of coastline and the hundreds of neighborhoods and downtown areas so this level of damage does not occur again? If we focus on what we already know how to do, which is:

- build strong buildings
- build in locations that we know reduce the risk of being affected by such an event again
- enact stronger building codes
- enforce those stronger codes with thorough inspection programs, and
- educate all parts of the design and construction community including building officials, contractors, engineers and architects, material suppliers and homeowners on the importance of sound construction in high wind and flood areas, then a significant and positive change will have occurred in these states from this one event. ▪

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