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Hurricane Katrina: An Overview of Damage to Timber Structures

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ABSTRACT

On August 29, 2005, hurricane Katrina made its second landfall as a Category 3 storm in South-Eastern Louisiana. Levees separating Lake Pontchartrain and several canals from New Orleans were breached a few days after the storm had passed, subsequently flooding 80% of the city and many areas of neighboring parishes for weeks. The storm is estimated to have caused over $81.2 billion (in 2005 U.S. dollars) in damage. Whether damage to a structure was caused by wind or flood waters has been a subject of great importance to homeowners with insurance for only wind or water.

Structures away from the immediate vicinity of levee breaches contained structural damage caused by floodwaters that was primarily due to the lack of connection between the timber structure and the foundation. In many instances the combination of rising and moving floodwaters swept structures off of their piers. The standing floodwaters from canals containing harmful chemicals and brackish water from Lake Pontchartrain caused corrosion problems in nails, screws, and other connectors.

Wind induced structural damage was observed primarily in the removal or loosening of roof decking from the underlying framing. Building claddings also suffered significant damage, especially where the stiffness of the cladding was significantly different than that of the underlying structure, such as brick cladding on a timber house.

KEYWORDS

Wind damage, Flood damage, Wood structure

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1 INTRODUCTION

On August 29, 2005, Hurricane Katrina made its second landfall as a Category 3 storm in South-Eastern Louisiana. Levees and floodwalls along Lake Pontchartrain and the outfall and navigational canals breeched, causing the city to flood. Due to a variety of factors, including the approach of Hurricane Rita a few weeks later, parts of the city were not drained of water until a month later.

This paper is intended to provide an overview of the damage caused by Hurricane Katrina, and present some design advice and practices that can be learned. It is not intended to serve as a complete catalog of damage nor a complete design guideline for construction in hurricane prone regions, nor does it address the social and economical implications of the damage caused.

2 FLOOD DAMAGE

Flowing floodwaters in the vicinity of breeches caused a good deal of damage similar to that caused by the storm surge which preceeds a hurricane as it makes landfall. Building materials were also affected by long term sumbersion in the brackish water from Lake Pontchartrain.

2.1 Rapidly Moving Waters

The most readily apparent damage was in the immediate vicinity of the levee breeches. Timber frame structures which were inadequately tied to their foundations were often lifted off their foundations by water passing under the raised floors and/or pushed horizontally. A one story timber framed structure is shown in Fig. 1. There was no evidence of a mechanical connection between this structure and the foundation piers which used to support the floor framing, shown in Fig. 2. This particular structure showed a poor foundation layout, where the concrete masonry unit (CMU) piers were set on a very small concrete "spread footing." In other instances, sill plates were firmly attached to the concrete foundation with anchor bolts; however, the wall studs framing into the bottom sill plates were only attached with toe nails, as seen in Fig. 3. These toe nails were unable to resist the horizontal forces imposed by the flowing waters.

Figure 1. One story timber frame structure pushed away from the concrete porch.

Figure 2. Foundation pier without evidence of mechanical connection.

Figure 3. Sill plate attached to knee wall with anchor bolt.

When a structure was adequately attached to the foundation, the rapidly flowing floodwaters often induced failure elsewhere in the structure. Entire sections of wall were destroyed by flowing water. These walls were standard load bearing portions of the timber frame structure. Walls which had brick cladding appeared to be more protected from lower velocity flowing water; however, in the immediate vicinity of a breech brick clad walls exhibited similar damage to walls clad with timber weatherboards or vinyl siding. Often, failures were clearly initiated in the vicinity of large door or windows, indicating that unsecured or unprotected openings provided a weak point in the structure which allowed propagation of more significant damage. Some examples are shown in Figs 4 & 5.

Figure 4. Brick clad wall damaged in vicinity of a levee breech.

Figure 5. Wall clad with vinyl siding damaged in vicinity of a levee breech.

As a result of the damage caused by the floodwaters and the potential for portions of the city to flood, structures in New Orleans that were substantially damaged, substantially improved, or new construction must meet new elevation requirements. These structures must be elevated to either the Base Flood Elevation (BFE) or at least 3 feet above the higest exsiting adjacent grade elevation at the existing site. The Base Flood Elevation (BFE) represents the average floodwater elevation for a 100 year flood event. These new requirements adopted in the region assumes the U.S. Army Corps of Engineers is actively repairing and improving the flood control systems.

ASCE 24-05 Flood Resistant Design and Construction requires enclosures below the BFE to either have breakaway walls or have openings designed to allow equalization of hydrostatic pressure between the interior and exterior of the enclosure. The asthetics of raising structures is of concern to many residents. An example of a recently elevated house is shown in Fig. 6.

Figure 6. Structure recently elevated to above the BFE.

2.2 Long Term Submersion

There was a wide range of observed damage attributed to the long term submersion in the brackish waters of Lake Pontchartrain. Some homes remained partially under water for up to four weeks. While we focus on structural materials in this paper, it is worthy to note the severe mold issues that arose on drywall.

The paper layer remained wet for an extended period of time after the flood waters receeded, and grew mold in most instances. This mold was not seen on walls that were covered with plaster or cement board. This mold may be a significant health hazard.

The most easily observed type of damage was the rusting of metal fasteners, which can be seen above in Fig. 3. Other metal hardware, such as lintels in brick cladding over windows, exhibited some signs of rusting, which could lead to further water ingress if not repaired along with the rest of the structure.

The timber members became saturated in many cases. Timber structural members which were restrained or under load while saturated suffered damage to their grain structures. Many timbers became twisted or warped while in this saturated condition; many remained so upon eventual drying. Tounge and groove hardwood floors were the most visible example of this type of damage.

Some red brick walls which were submerged in the brackish waters showed a degradation in the mortar, which was apparent when the mortar was scraped with a knife blade. Calcium leaching has been shown to degrade the material properties of cementitious materials [Heukamp et al. 2005]. The high porosity of the red bricks and insulation board along the inside of red brick exterior walls likely trapped moisture, which extended the amount of time past flood subsidence that leaching could occur.

It is important to note that damage caused by long term exposure to brackish water, such as the corrosion, warping, and leeching described above, may not be readily apparent. Post disaster inspections of structures exposed to these elements should keep a special look out for these effects as they may otherwise go undetected until they fail in some future, perhaps less extreme condition.

3 WIND DAMAGE

On August 29th, 2005 Hurricane Katrina passed over New Orleans with maximum sustained winds estimated to be around 105 mph (170 km/h) [Knabb et al. 2005]. It is important to keep in mind while observing and analyzing damage from high winds that several factors affect the wind speeds near structures such as height above the ground, type of terrain surrounding the structure, dependence of measured wind speed on averaging time, and turbulence features such as flow separation and vortex shedding around a structure.

3.1 Lack of Uplift Load Path Continuity

The most spectacular form of this failure was the removal of entire sections of roof. Figure 7 shows the removal of a church roof from the supporting walls. Large uplift pressures on the overhangs helped contribute to the failure in this case; however, there was no evidence of tie downs between the roof rafters and the supporting walls.

Cases were also oberved where porches and carports, which were open to the wind, lifted up off of the support columns. If structurally attached to the primary structure, the porch or carport would cause damage to the primary structure when it collapsed. An example of a collapsed porch is shown in Fig. 8.

Figure 7. Removal of a church roof from the supporting walls.

Figure 8. Porch collapsed from uplift forces and lack of tie downs.

3.2 Poor Construction Practices

It is sometimes difficult to separate poor construction practices from poor design practices. The decision to construct a building with a gabled roof instead of a hipped roof in a high wind area would be an example of a poor design practice. The lack of adequate fasteners attaching the sheathing to the structure or fasteners driven through the sheathing and missing the underlying framing would be an example of poor construction practices. Often builders use pneumatic nailguns, which do not provide feedback to the user whether or not the nail entered a structural member. Figure 9 shows decking nails that missed the supporting rafter. Figure 10 shows poorly fastened sheathing that was blown off of a gabled end wall. It is important to realize that while some construction practices are poor, they may be typical and accepted for a particular region.

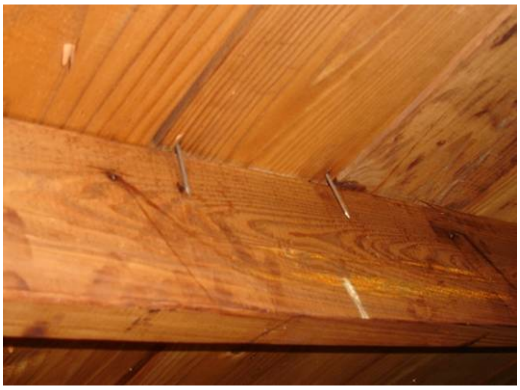

Figure 9. Decking nails that missed the supporting rafter.

Figure 10. Poorly fastened sheathing that was blown off of a gabled end wall.

Another poor construction practice that was observed throughout property inspections was the reduced number of fasteners in hurricane ties. The majority of ties are engineered to have a nail in each hole; a reduced number of fasteners means a reduced load capacity for the anchor. Many contractors do not install the full compliment of fasteners because they must be installed by hand and not with a pneumatic nailgun (it is very difficult to line up the nail with the hole in the connector).

Lack of oversight on small timber framed buildings during the construction process can lead to poor quality and many of the errors previously explained. Some local goverments have instituted inspection processes which can reduce the amount of errors and increase overall quality; for example, Jefferson

Parish in Southern Louisiana requires the design engineer to inspect and approve the construction before the interior gypsum board and other wall and floor coverings are installed.

4 UPLIFT AND LATERAL LOAD PATH DESIGN

Wind design has evolved significantly recent years. The design of timber structures for high winds can be easily completed utilizing manufactured connections and tie downs. Story offsets and geometric irregularities (such as large dormers or porch awnings, which are common in New Orleans) make wind analysis and design more difficult than a simple rectangular building with a gabled or hipped roof. An overview of typical uplift and lateral load paths is shown in Fig. 11.

Structural sheathing and structural sub-flooring plays an important role in resisting lateral wind forces through diaphragm action. The sheathing thickness, size and amount of fasteners must be designed so that the diaphragm can adequately resist the imposed loads. Openings in floor diaphrams need to be engineered so as not to interfere with the lateral resistance of these diaphragms.
The State of Louisiana will soon move to the 2006 versions of the International Building Code and International Residential Code. All new construction will be required to be designed to the high wind levels required in these codes which should help to mitigate some of the damage discussed in this paper. Although local permitting processes differ, most additions, repairs, and major remodelling will also be required to meet these new high wind requirements.

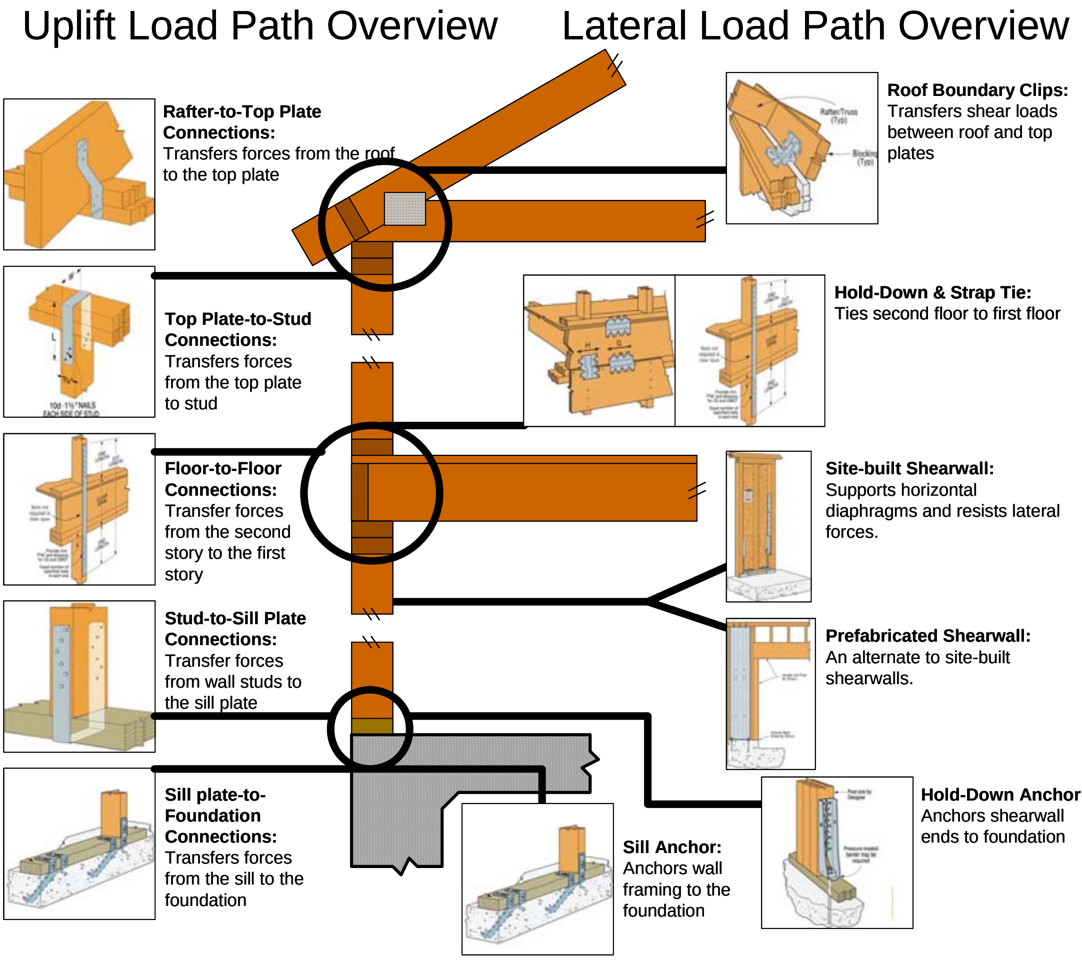

Figure 11. Overview of uplift and lateral load paths [Adapted from Simpson 2006].

With the recent passage of House Bill No. 558, owners in Louisiana can also expect to see discounts in their insurance premiums if they retrofit their buildings to resist high winds. While the details are still being developed, there is a possibility of partial premium discounts for partial retrofit. This legislation is intended encourage owners to retrofit older buildings, which are typically exempt from the more current building codes which include design for high wind resistance. These measures should prove to be a significant incentive to improve existing structures as insurance premiums have more than tripled for some residents of New Orleans, while coverage has declined.

5 CONCLUSIONS

Large scale disasters like hurricane Katrina subject timber structures to a combination of destructive forces from both flood water and wind. Damage from these forces varies significantly and can be mitigated with different improvements to the structures, which can be addressed in local building codes. Building codes and construction requirements change over time. As we learn more about the forces imposed upon structures by natural and manmade disasters with magnitudes such as Hurricane Katrina, it is imperative to take these lessons and apply them to future designs and building practices. Accordingly, the State of Louisiana and its parishes have been adpoting and updating building codes and practices as a direct result of Hurricane Katrina, and have been taking steps to encourage owners to upgrade existing buildings which are exempt from the new codes.

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