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The Challenges of Structural Stabilization Following the Hurricane Katrina Disaster

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ABSTRACT: Katrina was the third strongest hurricane on record to make landfall in the USA. It struck near New Orleans on 29 August 2005. Its surge was as high as 9.5 meters, devastated the Gulf Coast, and breached New Orleans' levees. The region is one of America's great outdoor museums with imported and local typologies that adapted to the region's climate and geographical conditions. In this paper, the damage experienced due to Katrina is described. The damage in Mississippi is compared to that in New Orleans. Heritage recovery efforts along the Gulf Coast are discussed, and "lessons learned" are provided to prepare for future disasters.

1 CHARACTERISTICS OF WESTERN HEMISPHERE HURRICANES

A hurricane is a tropical cyclone (called a typhoon in Asia) caused by a low-pressure system which generally forms in the Tropics. Hurricanes in the Gulf of Mexico typically form near the coast of Africa and feature a counter-clockwise swirl of wind, with the wind speed decreasing in proportion to the distance from the eye at the center of the storm. Massive domes of water (storm surges) are pushed ahead of these winds.

Hurricanes, like earthquakes, are prone to strike specific regions - with hurricanes associated with regional climatology and proximity to the ocean. They differ from earthquakes in that modern technology provides warning to evacuate areas when a hurricane landfall is anticipated.

The *Saffir-Simpson Hurricane Scale*, developed in 1969, is used by meteorologists in classifying Western Hemisphere tropical hurricanes by the intensity of their sustained winds. Classification Categories 1 through 5 are used to gauge the likely damage and flooding a hurricane will cause upon landfall. Hurricanes, however, rarely fall neatly within a single category and can strengthen or weaken as they evolve.

Hurricane Katrina made landfall as a Category 4 hurricane with winds of 225 km/h near Buras-Triumph, Louisiana on a finger of land jutting out into the Gulf. A few hours later, it made landfall again near the Louisiana/Mississippi border with wind speeds of 200 km/h. High and damaging winds and storm surges smashed the Mississippi coast to the east of New Orleans. The approximate 9.5 meter storm surge recorded in Waveland, MS is the highest ever observed in the United States. The surge penetrated at least 10 km inland in many portions of coastal Mississippi and up to 20 km inland along bays and rivers. Subsequent damage to the coastal regions of Louisiana, Mississippi, and Alabama made Katrina the most destructive and costliest hurricane to ever to hit the USA. Katrina weakened thereafter, losing hurricane strength more than 250 km inland.

2 HISTORICAL OVERVIEW OF THE GULF COAST REGION

New Orleans and the Gulf Coast region boast a treasury of architectural styles of local origin as well as magnificent examples imported from other parts of the world and adapted to the subtropical climate, unique geographical conditions, and culture. Architectural styles span from Colonial plantations, Creole houses, American cottages, shotguns, camelbacks, Victorians, revival styles, bungalows, modern movement, and suburban ranch. However, these styles are defined by layout but not necessarily by building typology. Therefore the discussion below will characterize building typologies, also called construction techniques, rather than styles.

2.1 Pre-Columbian Period

It is believed that the first people entered what is now the lower Mississippi Valley about 12,000 years ago. These Native Americans, principally the Choctaw tribe, were active mound builders from 1000 AD to the arrival of European settlers. Most mounds were rectangular, flat-topped earthen platforms upon which temples or palaces were erected. Though numerous mounds still exist inland, the mounds that were known to exist along the Gulf Coast were almost totally obliterated by building development long ago. Other than the mounds, no other built evidence remains of this culture anywhere in the USA.

2.2 Colonial Period

Spanish claims to the Mississippi River Valley date back to the "discovery" of the North American continent and consequent exploration, which included the lower Mississippi Valley. The Mississippi Valley was explored by René-Robert Cavelier, sieur de La Salle in 1687, and the southern part was soon settled by Canary Islanders who arrived by way of Mexico. The area was further explored in 1700 by Pierre le Moyne, sieur d'Iberville and Jean-Baptiste le Moyne, sieur de Bienville. New Orleans was founded in 1718 by the French under Bienville.

In 1763, the Louisiana Territory was ceded to Spanish control. It reverted back to French control in 1801, and was sold to the United States in 1803. New Orleans and the Mississippi Coast cities grew rapidly, with influxes of Americans, French, and Creoles. New Orleans, as a principal port, had a leading role in the slave trade, while also having a prosperous community of francophone *gens de couleur libres* (free persons of color), mostly from the West Indies.

The earliest French buildings (late 17th Century) were small log cabins banded together with stockade fences for common defense against hostile Native Americans. The houses were patterned after those in Quebec and Normandy. The main construction technique was *poteaux en terre* (posts in the ground) constructed of logs placed vertically into the ground spaced 10 to 12 cm apart. A similar technique, *poteaux sur solle* (posts on a sill) placed the logs on a wooden or stone sill. *Boussilage*, composed of clay and Spanish moss or deer hair, was placed between the logs.

Later a more refined technique, *colombage* (half timber construction), was adopted. The frame of the structure was constructed of vertical timber posts and the space between them filled with *bousillage*. In some, the spaces were filled with brickwork in a technique called *briquette-entre-poteaux* (bricks between posts). Fires that swept through New Orleans in 1788 and again in 1794 consumed French colonial and small wooden structures, thus removing remnants of these early typologies. They can still be found in rural areas along the Mississippi River.

During the Spanish period and into the early 1800s the most popular method of construction was brick masonry covered with stucco. In some cases the brickwork was used on the first floor only, and the second level was constructed using *colombage*. Brick structures from this era are rare as the brick used was low fired and did not prove to be durable. The oldest buildings of the New Orleans *Vieux Carré* are of this type of construction.

2.3 Antebellum Period

The period between 1830 and the American Civil War was the most glamorous and prosperous for the Gulf Coast. The area hosted wealthy cotton and sugar cane planters, and all related commerce was centered on New Orleans until the advent of the US Railways removed its trade monopoly between the Northeast and Midwest. Early in the American Civil War, New Orleans

was captured by the Union Army, and this event spared the city from the destruction suffered by other Confederate American cities.

By the 1840s wood-frame building construction had become ubiquitous on the Gulf Coast. Southern Pine, a strong and durable softwood, grows in a vast band across the Southern United States from East Texas to Virginia. Water and steam-powered saw mills and nail-making plants were being established throughout the country. One of the largest lumber mills in the country was located in Bay St Louis, Mississippi between New Orleans and Gulfport. Today wood-frame buildings of this era represent the majority of extant historic structures on the Gulf Coast.

At about this time the practice of erecting structures on masonry piers became prevalent in the region and lasted until after the Second World War. By raising houses slightly, insect problems were greatly curtailed, chronic dampness was abated, and frequent flooding of the ground after rainstorms was not as great a concern.

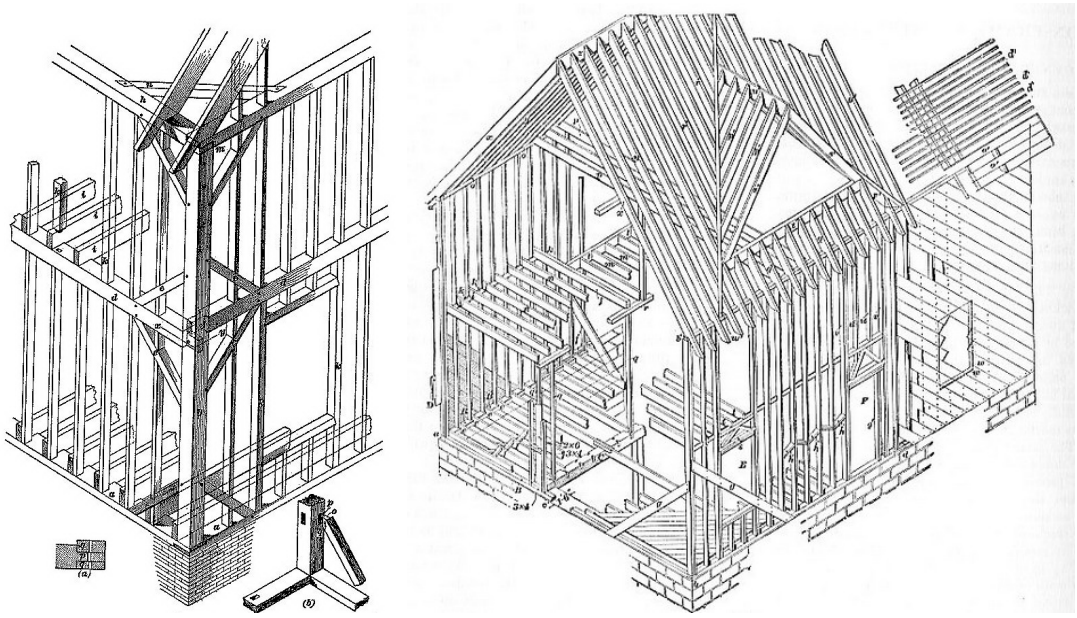
Braced-framing, a German and British import, was a common form of building construction during the antebellum era, see Fig. 1a. This construction was characterized by heavy timber posts at the corners of the building, which extend continuously from a heavy foundation sill to a heavy girt at the floor or roof line. Diagonal braces were used at the corners of the frame to lend lateral support to the structure. Studs were installed between the corner posts. These were mortised into the sills and girt at regular intervals. The main framing members were connected by mortise and tenon, and fastened with wood pegs and tree nails.

Another form of construction, *Madriers debout* (standing planks), developed about this time and was utilized into the 20th Century, see Fig. 1c. Specific to New Orleans and vicinity, these structures are composed of large planks oriented vertically and set directly onto a wooden sill. The exterior siding and interior finishes, typically wood bead board, were applied directly to the boards. The planks are said to be from flatboats that floated down the Mississippi River and were then disassembled, thus rendering the name of "barge board building."

Balloon framing was developed during the 1830s and was a distinctly American construction technique that fulfilled the requirements of a young and rapidly expanding country, see Fig. 1b. It offered several advantages for wood-frame construction and was characterized by an economical use of wood, rapid construction, and limited skill required by workers. Relatively unskilled workmen were able to erect balloon framed buildings quickly because the labor-intensive mortise and tenon connection was supplanted by the use of cut nails. The stability relies on the external sheathing rather than triangular bracing.

2.4 Post Civil War to Modern Day

Balloon framing fed the Victorian building area following the American Civil War and was utilized well into the 20th Century. The growth of New Orleans, much of which is below sea level, was restricted by the surrounding swamps. The delta on which it is located is composed of weak organic and alluvial soils. Construction of the levees between New Orleans, the Mississippi River, and Lake Pontchartrain began in 1879. Pumping of ground water into canals, begun at this time, was greatly improved in the early 20th century. The formerly swampy lands compressed like a sponge when the water was removed. The area further subsided after the current levee system was erected in the 1940s and 1950s.



(a) (b)

Figure 1a : Diagrammatic sketch of the *braced-framing* technique (left). Figure 1b : Diagrammatic view of a *balloon framing* technique (right).

Figure 2 : Contemporary view of a *madriers debout* framing technique on a building where clapboard siding is removed to reveal standing plank construction

Following the Second World War, residential construction moved away from balloon framing to platform framing. Brick once again became a common building material. Buildings, now not subjected to seasonal flooding, were no longer erected on piers but were set on slabs-on-grade, sometimes underpinned by wood piles.

3 CHARACTERISTICS OF DAMAGE FROM HURRICANE KATRINA

Hurricane Katrina was an unusually wide storm. The accompanying storm surge affected a coastal area of more than 200 km in length, mostly in the state of Mississippi, with the greatest surge height at Waveland, which was near the eye of the hurricane. The range of historical constructions affected by the storm was substantially broader than those that were previously designated as historic (listed). The vast majority were privately owned houses and commercial buildings, rather than publicly-owned landmarks. Many are in lower income areas. The storm affected the Gulf Coast and New Orleans in different ways as described below.

3.1 Mississippi Gulf Coast

The physical damage in Mississippi is far beyond that in New Orleans, but this fact was not covered in the media because New Orleans offered a more compelling human story. There were tens of thousands of coastal buildings that were completely destroyed by the surge and winds, including the entire towns of Waveland and Long Beach. Hundreds of listed historic structures were severely damaged or destroyed. In addition there are at several thousand properties that are eligible for listing that are in need of some level of structural stabilization. The following conditions were observed:

- Entire structures were swept away in the surge, leaving only their foundations. In many cases the foundations themselves, built on sand, were undermined and were no longer usable. It was difficult to locate the missing structures in numerous cases because they became part of the debris field (composed of hundreds of structures).
- Within the surge area, first and second level bearing walls of the structures that remained standing, including wood frame and masonry, were knocked out, see Fig. 2.
- Many houses were knocked off their foundations but otherwise remained intact in a warped state.
- Much of the surge-related damage occurred from debris driven by the flood waters. Examples included wood planks from docks, road pavement, building debris, and shipping containers. There were six floating casinos, constructed on huge metal barges that broke loose from their moorings and floated inland, impacting smaller structures and crushing everything in their paths.
- Inland and away from the surge high winds peeled roofing and roof structures from buildings; peeled away siding; knocked some prefabricated structures off of their foundations; destroyed large freeway advertisements; and damaged windows and doors.
- Estimates of severely damaged and destroyed buildings (all types) are on the order of 60,000 in Mississippi.

Figure 2 : A typical scene of destruction, west Gulfport, Mississippi, showing the debris field and first-floor damage to one of the few standing structures. A structural engineer (right) surveys the damage.

3.2 New Orleans

The damage in New Orleans was of a different character. The winds, quite high in Chalmette to the east, were not so great in New Orleans itself. The storm surge affected the levees rather than the building stock. Historic and older residential buildings - wood frames structures raised on masonry piers - suffered more from flood than wind damage.

- Though not hurricane-related conditions, some pre-existing conditions are important to understand as they relate to hurricane damage. Older wood frame structures are typically out-of-plumb due to soil subsidence that has been exacerbated by more than 80 years of mechanical drainage of the swamps that used to surround New Orleans. These out-of-plumb conditions were worsened by extensive termite damage.

- A handful of collapses entailed two-story wood frame structures. In all observed cases the lower level gave way under the weight of the upper story; the upper structure was an addition; and the lower level had been weakened by termite decay, see Fig. 3a.
- Several houses were observed where an entire wall collapsed outward leaving the house interior open to the elements. In each case the wall that collapsed was non-load bearing, and the structure was still intact. These walls had collapsed because they were no longer securely fastened into the rest of the structure due to termite decay.
- Roof membranes were damaged on numerous structures due to the wind. Clay tile roofs faired rather well because they were not continuously connected. Asphalt shingle roofs tended to peel off in large sheets. Metal roofs faired the poorest of all - when they became compromised due to the wind they tended to peel away in a single sheet. In a few cases the roof sheathing or the roof structure itself was also torn from the building. Siding was also damaged, though plastic and aluminum overcladding fared much worse than wood.
- Several burned structures were observed. These were fires that were left unchecked due to the flooding that restricted access to the property.
- Mold, mildew, and other organic growth were rampant inside homes that were left sealed and filled with water-logged contents. Organic growth grew on carpeting, wallpaper, and furnishings. The growth propagated readily on construction materials that utilized paper and glue such as drywall, particle board, and plywood. Growth did not readily attack old growth timber and plasters. Wood floors were typically warped.

Figure 3a : This row of houses in New Orleans, were originally one story wood frame buildings. Termite damage caused one to buckle (left) at the lower level, causing all four to collapse in succession

Figure 3b : In this historic church in New Orleans the water was 2 meters deep and was not drained away for a week. Three months after the storm, no clean-up had begun, leading to growth of mold and fungi.

4 ASSESSMENT SURVEYS

Following the Hurricane, time was of the essence for heritage recovery efforts. Decay of building materials in the hot and humid climate would occur rapidly, especially considering wet debris and sediment accumulation on the floors, see Fig. 3b. The rapid response, however, had to be tempered with the understanding that recovery had to first focus on the human condition - the search for survivors and the feeding and housing of the homeless.

Technical surveys were performed as volunteer, partial-volunteer, and academic exercises. Involved organizations included federal and regional governmental bodies; Association for Preservation Technology (APT), the American Institute for the Conservation of Historic & Artistic Works (AIC); US/ICOMOS; the World Monuments Fund; Mississippi Heritage Trust; Preservation Resource Center of New Orleans; Tulane University; and University of Florida to name a few. The Mississippi Heritage Trust, the Association for Preservation Technology, and

the Mississippi Department of Archives and History established a local heritage recovery assistance center in Biloxi, called Preservation House, to coordinate technical assistance and funding, and as a base of operations for the survey work.

Surveys were typically performed by two-person teams with two to three teams in a group. Each group needed to include at least one qualified historic architect and one qualified structural engineer. Finding local and available technical experts was difficult; however, professionals were available nationwide as volunteers or as paid consultants. Finding qualified engineers with the sensibilities required to work on historical constructions was another difficult task.

Survey supplies were not out of the ordinary. However, due to the extent of damage, survey teams had to have good maps, GPS systems to locate properties in debris fields, protective boots and gloves, and food and water. Time had to be allotted to empathize with the local community. Cellular phones proved invaluable where service had not been interrupted by the storm. Lodging was difficult until hotels and houses were reopened.

One unanticipated difficulty with the surveys was the plethora of survey forms that were developed and used by different parties and the consequent challenges of developing comparative data. Forms provided the opportunity to collect data on physical conditions in a fairly standardized manner. Some of the forms encouraged collection of heritage data as well. Once the data were collected, the storage and dissemination of the information to stakeholders was an even greater challenge.

Another difficulty entailed the design and erection of temporary shoring that would be critical for stabilizing and ultimately repairing damaged historic buildings. In the US, there is no government funding or response mechanism for temporary stabilization. Also, America is a litigious society and culpability is inherent with any temporary stabilization performed by a professional. For volunteer efforts, such responsibility was too much to expect of a professional engineer. In some cases, individual engineer volunteers were specifically authorized by the local building officials, thus providing legal immunity. Stabilization on private property was sometimes accomplished by involving paid consulting engineers with licensure in the state, and by identifying qualified contractors willing to take on the work. Structural moving contractors were especially effective in stabilizing structures because of their experience in bracing, shoring, and lifting traditional structures.

3 CONCLUSIONS

The goal of heritage recovery efforts is to save as many historical constructions as possible, and to retain cultural memory, continuity of culture, and a sense of place in this devastated region. To prepare for heritage recovery in the future along the Gulf Coast or elsewhere in the United States, the following lessons learned should prove invaluable:

- The physical damage caused by a major hurricane can overwhelm the most advanced emergency response systems. Volunteer efforts are essential.
- An extensive understanding of building typologies and heritage values as well as local resources is essential for the region in which heritage recovery is to take place.
- The cooperation of local, state, federal, and non-profit organizations is critical to successfully respond to future disasters.
- Volunteers can be effect in heritage recovery; however, there are substantial difficulties in using volunteers – there is no place to put them, and it can take one person full time to organize and manage four volunteers. In an emergency situation, the excess resources are not available locally.
- A standardized form should be adopted for use by all technical teams involved in heritage recovery to regulate and raise the quality of the end product. Good reporting is essential in establishing comparative databases, understanding local physical conditions, predicting future phenomenon and mechanisms of failure, and planning for future disasters.
- Accurate pre-storm inventories of listed structures, which can be made available after the event in an accessible form such as GIS, are essential.

- Broader legal mechanisms need to be developed to protect volunteer engineers so that temporary shoring can be put into place without undue liability.
- There is a risk of heritage loss by good-intentioned but uninformed volunteers during the removal of debris or selective demolition.
- There is a potential for owners and civic leaders to interpret “unsafe” designation as a mandate for demolition.
- Debate alleged value of demolishing historic properties and building new rather than salvage as this perception will endanger built heritage. Value in these instances must encompass heritage values and not just monetary value.
- Identify appropriate mitigation strategies for historic properties to assure a higher survival rate in the next major hurricane. For example, improving structural connectivity, particularly to the foundations, is important for resisting the effects of storm surge.
- Mitigate decay and deterioration that existed prior to the catastrophic event but has become worsened due to that event. For example repair of termite decayed structural elements may become necessary.
- Historic structures that have floated from their foundations and have possibly become warped can be stabilized and placed back on their foundations and not just tagged for demolition. This has been very successful in some areas because the wood frame buildings have proved to be robust and ductile.
- Contents, wood floors, and drywall that are subjected to floods will not be salvageable. However it is a myth that, if mold is present, the building can not be salvaged. With proper drying and treatment with disinfectant such as bleach, these buildings can be salvaged. In flood damaged areas, historic properties tend to naturally shed the skins of latter renovations during the trauma, leaving the original structure partially or totally intact.