Performance of Glass/Cladding of High-Rise Buildings in Hurricane Katrina

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Introduction

On August 29, 2005, Hurricane Katrina made landfall on the coast of Louisiana reported as a Category 4 hurricane. The center of the storm passed approximately 30 miles to the east of New Orleans, Louisiana around 9 AM CDT. In an effort to understand and improve the performance of glass and cladding on tall buildings in urban areas to extreme winds associated with hurricanes, the NatHaz Modeling Laboratory at the University of Notre Dame conducted a field reconnaissance study to assess the damage to the glass and cladding of a number of tall buildings in the Central Business District of New Orleans and surrounding areas. An additional focus of this study was to investigate the effectiveness of vertical evacuation – allowing citizens to escape the flood waters of hurricanes by seeking shelter at higher elevations in engineered structures.

Research Team and Objectives

The Research Team from the NatHaz Modeling Laboratory at the University of Notre Dame included Dr. Ahsan Kareem and Rachel Bashor. Dr. Elizabeth English from Louisiana State University joined the team during its visits to New Orleans to conduct field surveys and interviews of building owners, managers and maintenance personnel as well as residents and visitors who remained in New Orleans during the hurricane. The objectives of the study included: correlating wind induced damage to observed winds; examining the performance of glass and cladding on tall buildings; determining the causes of poor performance; assessing the performance of the buildings for vertical evacuation and the effectiveness of this mode of evacuation in urban areas struck by hurricanes.

Description of Hurricane Winds

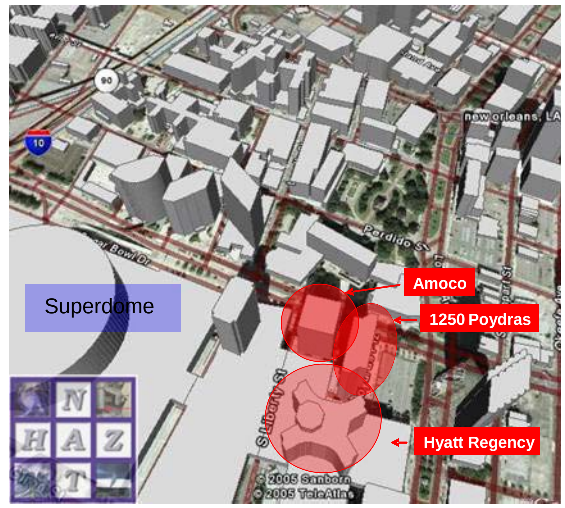
Determining the actual wind speed in New Orleans during the storm passage is somewhat challenging due to the lack of available data. The Florida Coastal Monitoring Program (FCMP) at the University of Florida collected wind data at several locations during the passage of the hurricane through the use of deployable monitoring systems. They estimated the maximum 3-second wind speed for the region south of New Orleans to be 102 mph (46 m/s). Measurements by Texas Tech University for this region estimated the maximum 3-second wind speed to be 82 mph (36 m/s). These measurements, however, were taken north of Lake Pontchartrain and, therefore, do not necessarily represent the wind conditions in the Central Business District of New Orleans. In addition to these sources, information derived from the NOAA Hurricane Research Division of the Atlantic Oceanographic and Meteorological Laboratory places the maximum 3-second wind speed in the New Orleans area about 90 mph (40 m/s). All of the estimates are well below the ANSI A58-1 (1982) design wind of 118 mph and the ASCE 7-05 (2005) design wind of 130 mph for New Orleans, both measured in 3-second gust.

These sources also indicated that the wind was from the northeast for the first part of the storm and then shifted to the west/northwest. These wind directions match the wind field generated by a storm following the path of Katrina. Accordingly, the damage to the buildings was expected to be concentrated on the north face and the northeast and northwest edges of the buildings. Field observations confirmed that damage to buildings occurred mostly on the north and west faces, as expected given the prevailing wind direction of the storm.

Observation of Building Damage

The damage to the glass and cladding of tall buildings varied significantly throughout the Central Business District. Many buildings only suffered minor damage - perhaps a few broken windows - whereas several buildings suffered heavy damage to the glass and cladding, especially to the north and west faces. This damage pattern correlated with the prevailing wind directions as the hurricane passed by the city. In New Orleans, the research team documented the condition of the exterior faces of twenty high-rise buildings in the area and toured the damaged areas and rooftops of several buildings including the Hyatt Regency Hotel, the Amoco Building, and the 1250 Poydras Building. These buildings, located near the Superdome (See Figures 1 and 2), sustained significant glass and cladding damage as well as damage to their roofs and rooftop structures and appurtenances.

Figure 1 Location of select buildings investigated by the research team



Buildings in which no apparent damage was observed included: One Shell Square, New Orleans Marriott, One Canal Place, and National American Bank. Buildings in which some damage was observed included: Bank One Center, Crescent City Residences, Energy Center, LL&E Tower, Sheraton New Orleans, 1010 Common, World Trade Center New Orleans, 225 Baronne Street, Entergy Tower, Hibernia Bank Building, Hilton New Orleans Riverside, Loews Hotel, and 1515 Poydras. Buildings that sustained heavy damage included: Texaco Center, Dominion Tower, Hyatt Regency New Orleans, 1250

Figure 2 Damage to Hyatt Regency Hotel and Amoco Building as seen from the roof of City Hall

Poydras Plaza, and Amoco Building. A summary of damage to a selected suite of buildings, identified in Figure 1, is now provided.

Hyatt Regency Hotel

The Hyatt Regency Hotel, located near the Superdome, suffered significant glass and cladding damage, especially on the north face of the hotel (See Figure 3). Nearly every window on the north face of the hotel was broken as it experienced not only high winds during the storm, but also wind with debris accelerating through the canyon formed by the upwind buildings. Some of the falling glass during its downwards trajectory damaged glass at lower levels, initiating a domino effect causing more damage to windows below. Along with the glass damage, the building roof was also significantly damaged. Large portions of the roofing material were torn up and missing. There was evidence of abrasions on certain faces of the various roof structures, including the round center tower, and evidence of façade elements ripped off at several corners. The debris found on the property included gravel, fasteners, and large pieces of glass likely from upwind buildings. In addition, the inside of the hotel was heavily damaged with walls torn down and room contents scattered everywhere (See Figure 4).

Figure 3 East and north faces of Hyatt Regency Hotel.

Figure 4 Inside view of the top, north floor of the Hyatt Hotel: (a) East, (b) Ceiling fan pushed

(a) (b) (c)

Amoco Building

The Amoco Building sustained a large amount of glass and cladding damage as well as damage to the rooftop penthouse (See Figures 2 and 5). A large percentage of the windows were broken and boarded up with plywood. Of the windows that were not covered, many of them showed pitting where a missile had impacted the window. The roof of the Amoco Building originally had a layer of loose pea gravel several inches thick that covered the built-up roof surface completely.

The wind blew off much of the gravel, piling some up along the south parapet and exposing sections of tar. The penthouse structures on the roof suffered considerable damage, as their large beams had been blown off supports and their connections torn out of the cinder block wall. The four columns that supported the penthouse had all been pushed away from the supports - one was missing from the rooftop. It appeared that the bolts that held the steel columns to the concrete bases had been sheared off. Most of the penthouse cladding had been blown off; some large components were found on an adjoining low-rise building south of the Amoco Building.

Figure 5 Rooftop penthouse on Amoco Building was nearly destroyed

1250 Poydras

The building known as 1250 Poydras also suffered damage to the glass and cladding, especially on the north face (See Figure 6). The old gravel roof of this building had been replaced two years ago; however, the roofing membrane had bubbled up in the northeast corner. Additionally, a roof drain had been pulled up. The penthouse was in good condition with exception of the loss of one large door. Overall the roof of 1250 Poydras performed satisfactorily. However, some debris from different sources was found.

Figure 6 West face of 1250 Poydras.

Possible Scenarios

The gathered evidence suggests that the majority of the damage was likely caused by wind-borne debris. The wind-borne debris included pea gravel, rooftop appurtenances, siding, and penthouse structures which became airborne and caused significant damage to the glass and cladding of the surrounding buildings. The finding of gravel, glass shards, pitted glass and other debris on or inside buildings supports this scenario. The breakage patterns to the spandrel glass supports the missile impact theory due to the appearance of impact-induced pitting with cracks that spread from the impact point (See Figure 7 and 8). Given the orientation of the buildings in relation to the damaged areas and the availability of wind-borne debris from upwind buildings, it is conjectured that the main debris source was the gravel roofs and appurtenances of upwind buildings.

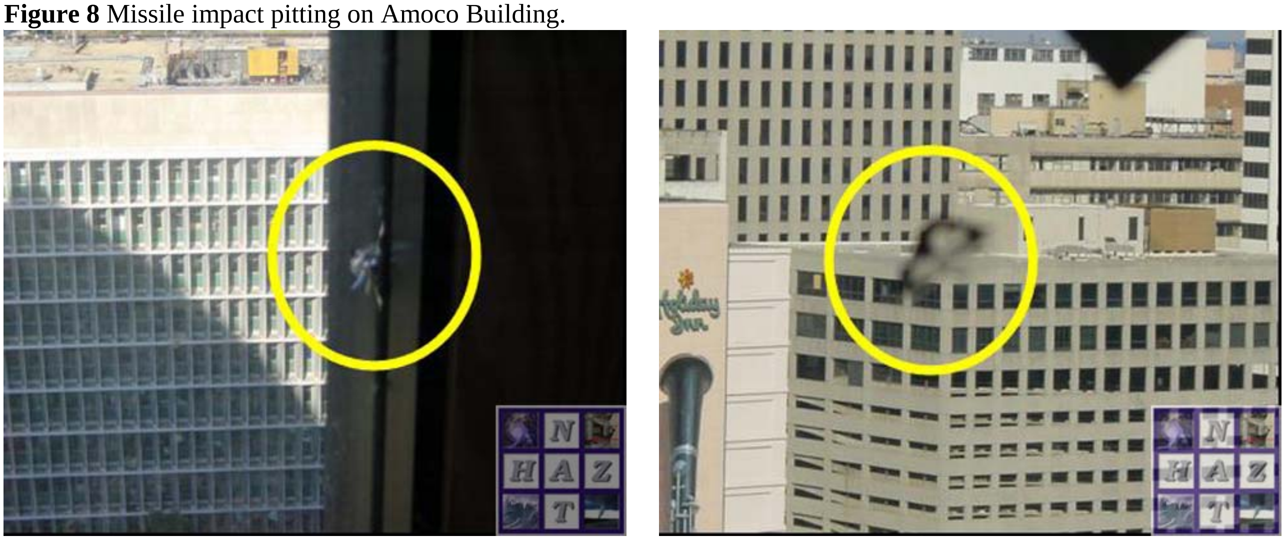
Another cause of damage can be contributed to poor connections and lack of redundancy. This applies mostly to roof top structures. Nearly all of the damaged penthouses had missing siding at the corners associated with high levels of suction. For example, the round tower on the roof of the Hyatt was missing siding on the corners of the north face. Also, miscellaneous fasteners were found on the roof of the Hyatt among the debris. Another example of inadequate connections and bracings was the penthouse on the Amoco Building.

Figure 7 Broken window on north face of Hyatt Regency Hotel, likely caused by missile impact.

Vertical Evacuation

The team assessed the feasibility of vertical evacuation during a hurricane with building managers and occupants. During the passage of the storm, about 3,000 people were in the Hyatt Regency Hotel. The majority of which were local residents with the rest being tourists and employees. Despite the considerable damage that the building experienced, the hotel was able to feed, provide water, and generally keep order in the ballrooms. The staff also maintained communications with the guests, which was important in providing a sense of security and awareness of the building’s condition. The biggest problem was the loss of air conditioning.

Figure 8 Missile impact pitting on Amoco Building.



(a) (b)

In another area of town, about 1,000 guests stayed in the Sheraton Hotel, which suffered minimal glass damage. Most of the guests were tourists who were not able to get out prior to the storm. As in the Hyatt Hotel, everyone stayed in the ballrooms throughout the storm. Prior to the visits, an interview was conducted by the research team with a faculty member from Notre Dame who was stranded at the Sheraton Hotel during the hurricane. Concerning refuge in a high-rise building, the faculty member felt safe under the supervision of the management at the hotel. The key factors that ensured a sense of security included the management informing the guests how to prepare and maintaining communication with the guests during and after the hurricane. Overall the hotels that provided shelter were able to keep occupants safe, although the degree of comfort varied.

In urban zones, interior regions of high-rise buildings can serve as a storm refuge to escape from storm surge and wind effects. Therefore, cities with limited escape routes and lack of transportation may consider vertically evacuating some residents provided selection of buildings, their availability, and the integrity of their structural systems and cladding have been pre-evaluated.

Concluding Remarks

In an effort to understand and improve the performance of glass and cladding on tall buildings subjected to extreme winds associated with hurricanes, the research team conducted a field reconnaissance study to assess the damage to the glass and cladding of a number of tall buildings in New Orleans in the wake of Hurricane Katrina. The team found considerable evidence that wind-borne debris from rooftops attributed to the glass and cladding damage of buildings. In several cases, vertical evacuation was effective in providing a safe refuge from hurricane flood waters despite the significant glass and cladding damage sustained. A detailed report is forthcoming.

Commonly, in extreme wind events, an overall lack of wind resistant provisions is responsible for most structural damage, including glass and cladding, rather than simply the severity of the storm. This conclusion was previously noted during Hurricane Celia in Corpus Christi, Texas, Hurricane Alicia in Houston, Texas, Hurricane Andrew in South Florida, and Typhoon York in Hong Kong. Cladding damage as experienced during Hurricane Katrina is not only costly but also threatens lives, exposes building interiors to costly damage, and puts buildings out of service for extended periods of time thus seriously impacting the community’s day-to-day infrastructure and economy. As long as the availability of wind-borne debris exists in urban areas, it will continue to threaten the integrity of fragile building envelopes even in storms that experience winds under design level. Current levels of cladding damage and associated losses are unacceptable. In order to alleviate this situation, effort must be made to limit the roof top gravel, secure appurtenances and appendages, and ensure the integrity of penthouses and railings.

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