Hurricane Damage Assessment:
Lessons Learned from Hurricane Katrina

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Abstract: Hurricane Katrina has been estimated to be the costliest storm in U.S. history, with total losses exceeding $100 billion. Hurricane Katrina was at Category 5 strength while in the Gulf of Mexico, and reportedly diminished to a strong Category 3 when it struck the Louisiana and Mississippi coast on August 29, 2005. The hurricane surge forces breached protective levees in New Orleans, and resulted in catastrophic flooding in the City. Although the flooding catastrophe in New Orleans drew world-wide attention and the media's focus during the reporting of the hurricane aftermath, the strongest winds and highest storm surge from Hurricane Katrina ravaged Mississippi coastal communities. The Mississippi coast was vulnerable to the destructive forces developed on the "right side" of the hurricane, and had little or no protection from levees, barrier reefs, or breakwater structures. Given the severity of this storm and resultant damages to the Mississippi coastal communities, the structural engineering profession has a unique opportunity to evaluate our approaches to hurricane damage assessment.

The purpose of this paper is to provide structural engineers with lessons learned from building damages that occurred along the Mississippi coastline during Hurricane Katrina. The authors personally inspected and/or supervised the damage assessment of over 300 buildings and structures in Mississippi as a result of Hurricane Katrina. This paper presents an approach to assessing hurricane damages from this storm in order to provide answers to society so as to rebuild from this catastrophe. The insurance industry requires that specific questions be answered by structural engineers who assess hurricane damages, and we will address those issues in this paper.

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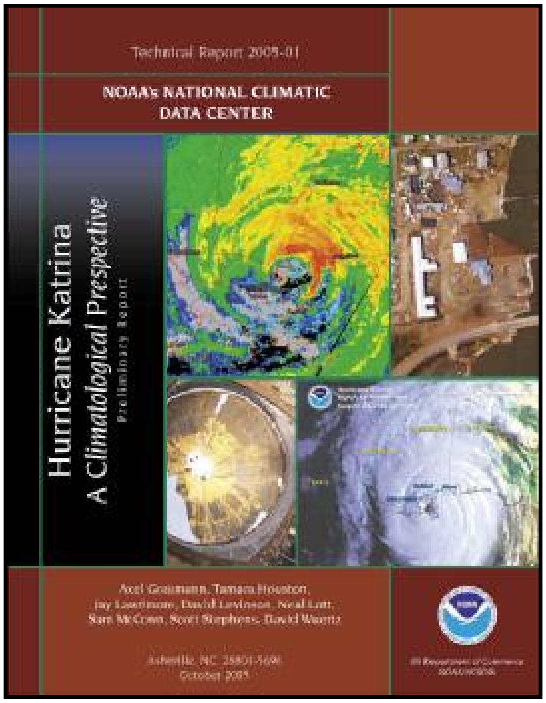
Introduction

Hurricane Katrina was a very powerful storm that struck the Mississippi coastline on August 29, 2005. As reported by the National Oceanographic Atmospheric Administration (NOAA), many of the key weather stations failed during the hurricane making it difficult to quantify information on the storm. NOAA and other forensic meteorologists published their findings and analyses several weeks after the hurricane event [see Figure 1]. In some cases, computer modeling was performed to estimate the hurricane characteristics as it struck the coastline.



Technical Report 2005-01

NOAA's NATIONAL CLIMATIC DATA CENTER

Hurricane Katrina
A *Climatological* Prespective
Preliminary Report

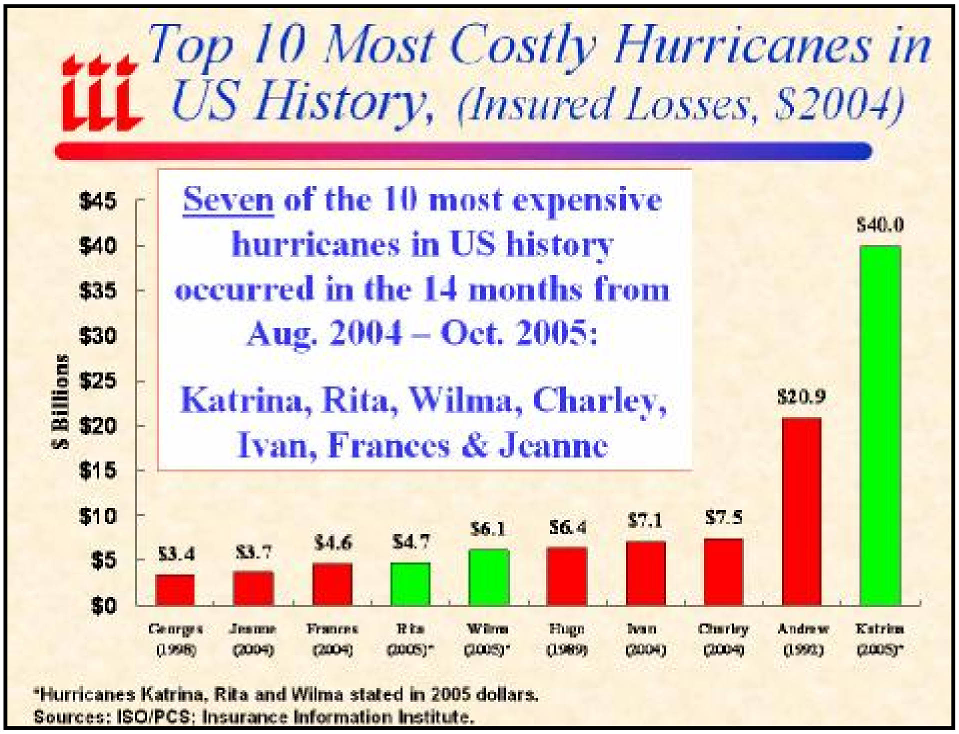
Axel Graumann, Tamara Houston,
Jay Lawrimore, David Levinson, Neal Lott,
Sam McCown, Scott Stephens, David Wuertz

Asheville, NC 28801-5696
October 2005

US Department of Commerce
NOAA/NESDIS

Figure 1: NOAA preliminary report[4] issued 10/05

The insurance industry also found Hurricane Katrina to be very destructive. In fact, the Insurance Information Institute estimated Hurricane Katrina to be the costliest hurricane in U.S. history, with claims expected to approach $40 billion [see Figure 2].



Top 10 Most Costly Hurricanes in US History, (Insured Losses, $2004)

Seven of the 10 most expensive hurricanes in US history occurred in the 14 months from Aug. 2004 – Oct. 2005:

Katrina, Rita, Wilma, Charley, Ivan, Frances & Jeanne

*Hurricanes Katrina, Rita and Wilma stated in 2005 dollars.
Sources: ISO/PCS; Insurance Information Institute.

Figure 2: Hurricane Katrina was the costliest hurricane in U.S. history

The Structural Engineer's Role in Assessing Hurricane Damage

Due to the extensive nature of damages to buildings along the Mississippi coastline from Hurricane Katrina, structural engineers played a pivotal role in assessing the extent of damages and reparability of the damaged structures. The insurance industry responded almost immediately to the damages incurred, and sent hundreds (if not thousands) of adjusters to Mississippi coastal communities after the hurricane struck. Most of these adjusters required the services of structural engineers so as to produce accurate assessments of the monetary cost of damages to insured buildings and structures.

First and foremost, structural engineers were charged with determining the extent of damages to buildings and structures ravaged by the hurricane. Armed with the understanding of load paths of various structural systems, behaviors of building materials, and general construction of residential and commercial buildings, structural engineers offered valuable insights into the evaluation of buildings exposed to the hurricane. In many instances, apparent damages to buildings pre-existed Hurricane Katrina. The structural engineer determined which damages were caused by the hurricane, and which pre-existed the storm or were caused by other means.

Secondly, structural engineers were typically asked to determine which of the hurricane damages were caused by high winds versus damages caused by the associated storm surge and waves. This was of particular interest to the insurance industry, as certain policies were triggered by wind damage versus other policies that covered only flood damage. Generally, the insurance industry considered wind damages to result from direct air movement against a building or structure, or from wind-blown materials that impacted the building or structure. Damages that resulted from water (other than wind-driven rain), including tidal or wave forces, and fast or slow moving water were typically covered by flood policies.

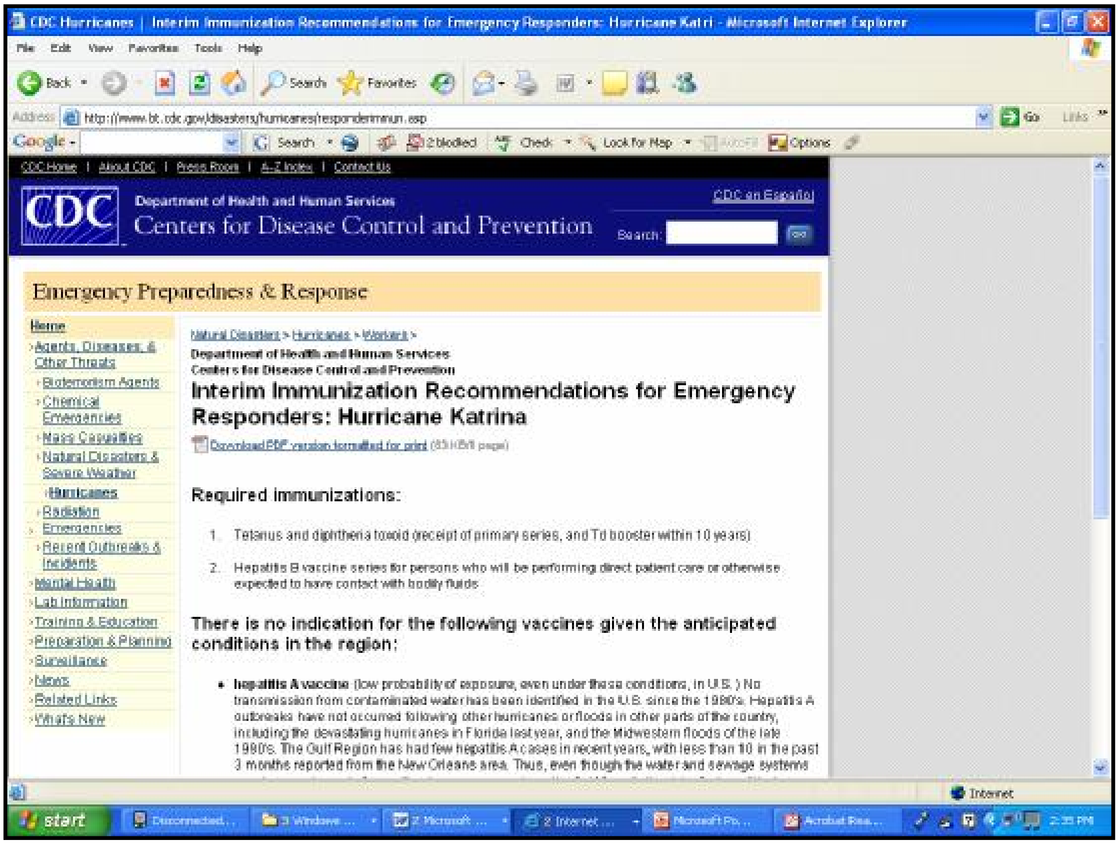
Finally, structural engineers were asked to determine if a building or structure could be feasibly repaired. During the initial damage assessments, this determination was typically limited to an opinion based upon the structural engineer's visual observations at the site.

Initially, the quantity of licensed engineers in Mississippi qualified to evaluate structural damage was limited. As such, many structural engineers supervised field technicians who gathered data on damaged buildings for them. These technicians required instruction on recording the damages, and communicating this information to the structural engineers.

Challenges for the Structural Engineer Inspecting Katrina Damage

The first step for supervising structural engineers headed to Mississippi to inspect building damage was to get properly licensed. Mississippi required structural engineers in responsible charge to be licensed as professional engineers in the State of Mississippi. It was unlawful for out-of-state engineers to offer their services as structural engineers without first obtaining licensure in Mississippi. Inspectors not licensed as engineers in Mississippi required supervision from Mississippi professional engineers. State government officials recognized the need for out-of-state help, and expedited the licensure process by reviewing applications weekly (rather than monthly). These officials helped in-state engineers displaced by the hurricane by temporarily postponing their continuing education requirements.

The next challenge for structural engineers headed to the hurricane ravaged areas was to acquire appropriate protection for their health and safety. The Center for Disease Control provided a listing of required immunizations and other recommendations for those entering the hurricane-damaged areas [see Figure 3]. Furthermore, on-site security was of concern to structural engineers inspecting properties where reports of looting occurred. Hard hats, protective gloves, boots and appropriate clothing were a necessity, and highly visible vests were recommended to properly identify inspectors from trespassers. Many neighborhoods within a few blocks of the beach were under martial law after the hurricane, and only those who obtained special authorization from the local municipality officials were permitted to access these areas.



Department of Health and Human Services
Centers for Disease Control and Prevention

Interim Immunization Recommendations for Emergency Responders: Hurricane Katrina

Required immunizations:

1. Tetanus and diphtheria toxoid (receipt of primary series, and Td booster within 10 years)
2. Hepatitis B vaccine series for persons who will be performing direct patient care or otherwise expected to have contact with bodily fluids

There is no indication for the following vaccines given the anticipated conditions in the region:

- **hepatitis A vaccine** (low probability of exposure, even under these conditions, in U.S.) No transmission from contaminated water has been identified in the U.S. since the 1980's. Hepatitis A outbreaks have not occured following other hurricanes or floods in other parts of the country, including the devastating hurricanes in Florida last year, and the Midwestern floods of the late 1980's. The Gulf Region has had few hepatitis A cases in recent years, with less than 10 in the past 3 months reported from the New Orleans area. Thus, even though the water and sewage systems

Figure 3: Immunization requirements from the CDC[2]

Assessing Damage to Structures – Wind Versus Surge

A tremendous amount of information became available for those assessing Hurricane Katrina damage. Of particular value were aerial photographs of the hurricane damaged areas published by NOAA[3] [see Figure 4]. Other valuable resources included weather data from a variety of sources, United States Geological Survey (USGS) topographic maps[5], and aerial photographs taken prior to the hurricane. The use of these resources to supplement on-site observations provided structural engineers with the means to determine damages caused by high winds versus the storm surge. These resources were available free of charge on the internet. Forensic meteorologists were also available to provide weather information and opinions on the chronology of the wind and surge components of the hurricane.

Figure 4: Aerial photographs of damages near Gulfport, Mississippi after Hurricane Katrina [provided by NOAA]. Note the difference in damages in buildings on either side of the debris field. The debris field was created by the storm surge, and those structures impacted by the storm surge were essentially destroyed, whereas buildings inland from the storm surge remained intact.

In most areas along the Mississippi coast line, a distinct debris field was evident near the beachfront. By comparing the outer edges of the debris field with topographic maps, one could estimate the storm surge height – or at least provide an approximate confirmation of reported surge estimates [see Figure 5]. In addition, a Federal Emergency Management Agency (FEMA) website[8] provided reference maps that showed the estimated inland extent of the storm surge.

The debris wash-line followed the 20-foot contour from the USGS map. This was consistent with a reported storm surge of approximately 20 feet.

Image courtesy of the U.S. Geological Survey

Figure 5: By orienting the NOAA aerial damage photograph from Figure 5 and comparing to a USGS topographic map of the area, the storm surge height may be estimated by examining the location of the debris wash-line.

In some coastal neighborhoods, all of the visible building superstructures were destroyed. A structural engineer assessing a distinction of damages caused by high winds before the storm surge swept through the site had a very daunting task. Without the aid of the aforementioned resources, an opinion regarding the extent of the likely wind damages was difficult (if not impossible) to substantiate. Figure 6 shows some of the typical views along the areas with the most severe damage.

Figure 6: Typical views of devastation along the Mississippi coast caused by Hurricane Katrina. Determining the extent of wind damages prior to the storm surge sweeping through these sites was a daunting task for the structural engineer.

In some instances, there was enough of the superstructure left on-site for a structural engineer to determine the distinction between wind and surge damages. It is vital that structural engineers understand that the forces from surge water current typically exceed wind forces. For example, a 1-foot tall seawater current moving at 10 mph will produce a total lateral force equivalent to a 310 mph wind force acting over a 1-foot height (including dynamic and hydrostatic conditions):

$$\text{Force} = \underset{\underset{\text{Dynamic Force Component}}{\uparrow}}{\frac{mv^2}{2}} + \underset{\underset{\text{Hydrostatic Force Component*}}{\uparrow}}{\frac{Ph^2}{2}}$$

$$\text{Force of 1' water @ 10 mph} = \frac{64.0\ \text{pcf}}{2 \times 32.2\ \text{ft/sec}^2} \times (10\ \text{mph})^2 \times \left(\frac{5280\ \text{ft/mile}}{3600\ \text{sec/hr}}\right)^2 + 64.0\ \text{pcf} \times (1\ \text{ft})^2 / 2$$

= 245.8 lbs-force

Wind Pressure[1] $= 0.00256 \times V^2$

$245.8\ \text{lbs} = 0.00256 \times V^2$

* We included the effects of hydrostatic force in this calculation, since video documentation taken during Hurricane Katrina showed a flood height outside a building to be 2 to 4 feet above the water depth inside the building as the surge rose.

Solve for Equivalent Wind Speed, V = 310 mph

Maximum wind gusts reported along the Mississippi coast was 140 to 150 mph, much less than in our example calculation shown above. The purpose of this exercise is to show that surge forces were more likely to cause destructive forces than wind forces during the hurricane. This example is very conservative. In reality, it is likely that water current during the surge exceeded 10 mph. Furthermore, it is likely that the water had a greater density than clean seawater, since sand and debris was churned up into the flood waters. With this in mind, damages due to the storm surge will be greater at lower elevations on a structure, while wind forces are greater at higher elevations on a structure. Typical damages due to high winds include torn and missing roofing and siding, and localized removal of wall and roof sheathing. Typical damages due to storm surge (other than water damages due to flooding) include displaced walls, columns, and piers; and scouring/undermining of foundations. The demolition of superstructures was consistent with the powerful forces of Katrina's storm surge, while localized damages to roof coverings was consistent with damages from the hurricane winds.

We will now examine several case examples to show the distinction between damages caused by high wind forces versus damages caused by the storm surge from Hurricane Katrina.

Case Study 1: Wood-Framed Church in Pascagoula

Slow-rising flood waters from the storm surge reached a height of 30-inches above the first floor, causing extensive water damage to interior floor and wall coverings. High winds damaged the roof covering, caused wind-blown debris to penetrate the roof sheathing, and removed roof and wall sheathing panels from the windward gable end. Wind-driven rain entered breaches in the roof covering and gable wall openings causing water damages to the ceilings and partial second story.

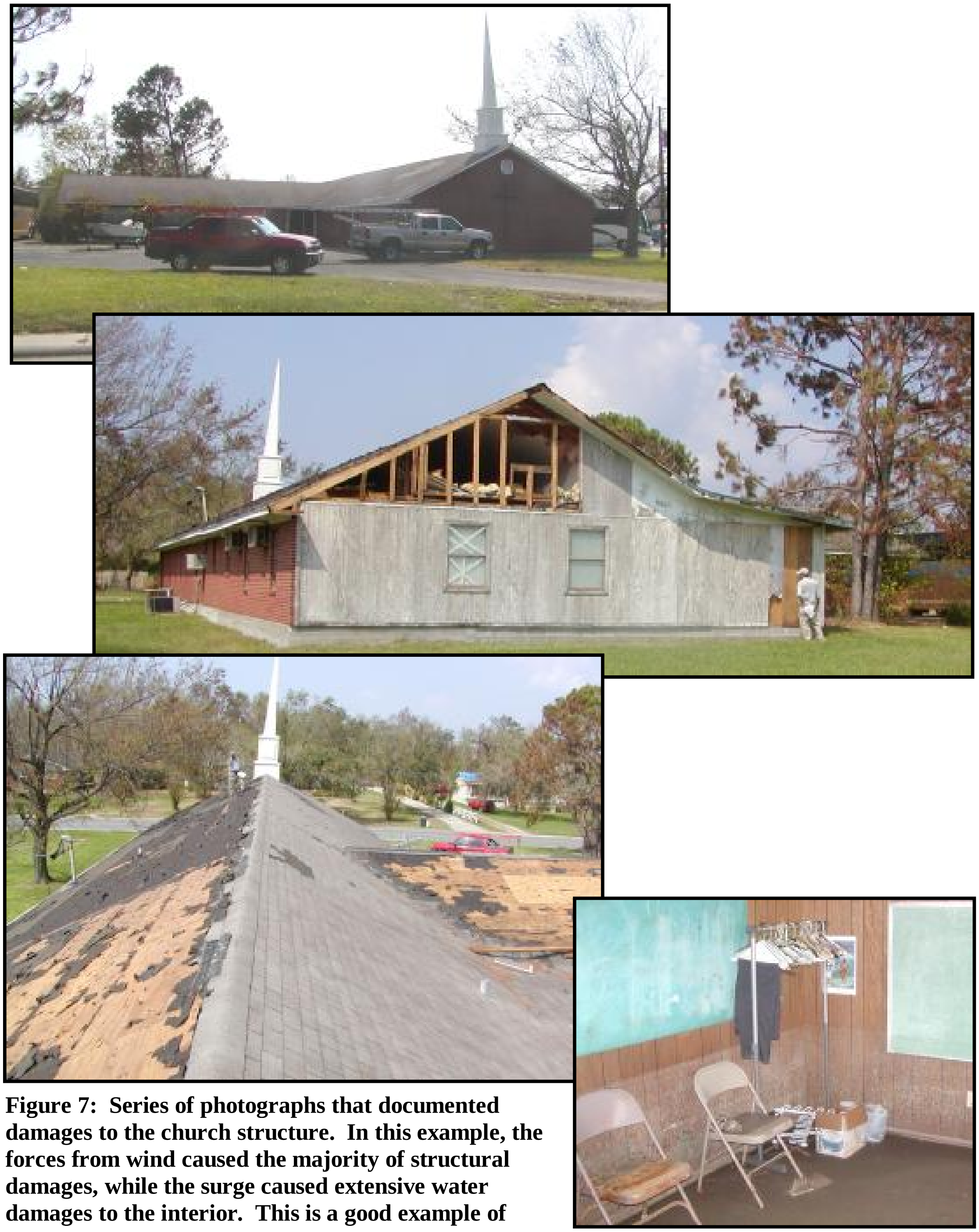


Figure 7: Series of photographs that documented damages to the church structure. In this example, the forces from wind caused the majority of structural damages, while the surge caused extensive water damages to the interior. This is a good example of typical wind damages caused by Hurricane Katrina.

Case Study 2: Wood-Framed, Single-Family House in Long Beach

The storm surge reached a height of about 10-feet at this site, and caused the destruction of the south exterior wall (facing the beach). The severity of damage was greatest at the first story, consistent with the destructive forces of the storm surge. Relatively minor damage to the roof covering was the extent of wind damages found at this structure.

Figure 8: Series of photographs that documented damages to the house. Note that minimal damage was present to the roof covering, while severe damages were on the lower part of the structure. This was a good example of typical damages caused by the storm surge from Hurricane Katrina.

Case Study 3: Wood-and-Steel-Framed, Two-Story Restaurant in Diamondhead

The storm surge reached a height of about 20-feet at this site (near the roof eave), and caused extensive damage to the first two stories. High wind forces caused localized damages to the roof structure. All surrounding wood-framed residences were demolished by the hurricane such that only some of the piers and beams remained.

Figure 9: Series of photographs that documented damages to the restaurant building and surrounding residences. In this example, the extent of wind damages was evident by the remaining roof structure, while the devastation caused by the storm surge was readily apparent. The remaining portions of the restaurant structure supported the likelihood that the destruction of surrounding wood-framed houses was caused by the storm surge, and that probable damages from high winds would have been relatively localized.

Case Study 4: Steel and Precast Concrete Shopping Mall in Gulfport

The storm surge did not reach this site, thus the storm damage was caused by high winds. Wind gusts of 132 mph were estimated in Gulfport. Damages to these buildings included localized portions of missing metal roof deck, removal of about half of the membrane roof covering, and the collapse of an elevated roof structure.

Figure 10: Series of photographs that documented damages to the shopping mall. The partial collapse of the elevated roof structure was attributed to construction defects (inadequate bracing / unstable construction) whereas the removal of localized portions of roof deck occurred at the perimeter due to the failure of puddle welds.

Case Study 5: Steel and Concrete Casino in Biloxi

The storm surge reached a height of about 25-feet at the site, and caused severe damages to all of the first and second story walls and finishes. Waves from the storm surge caused a floating casino structure to break from its moorings and batter the building as it drifted ashore. There was finish damage caused by the wind to the portions of the structure above the second floor.

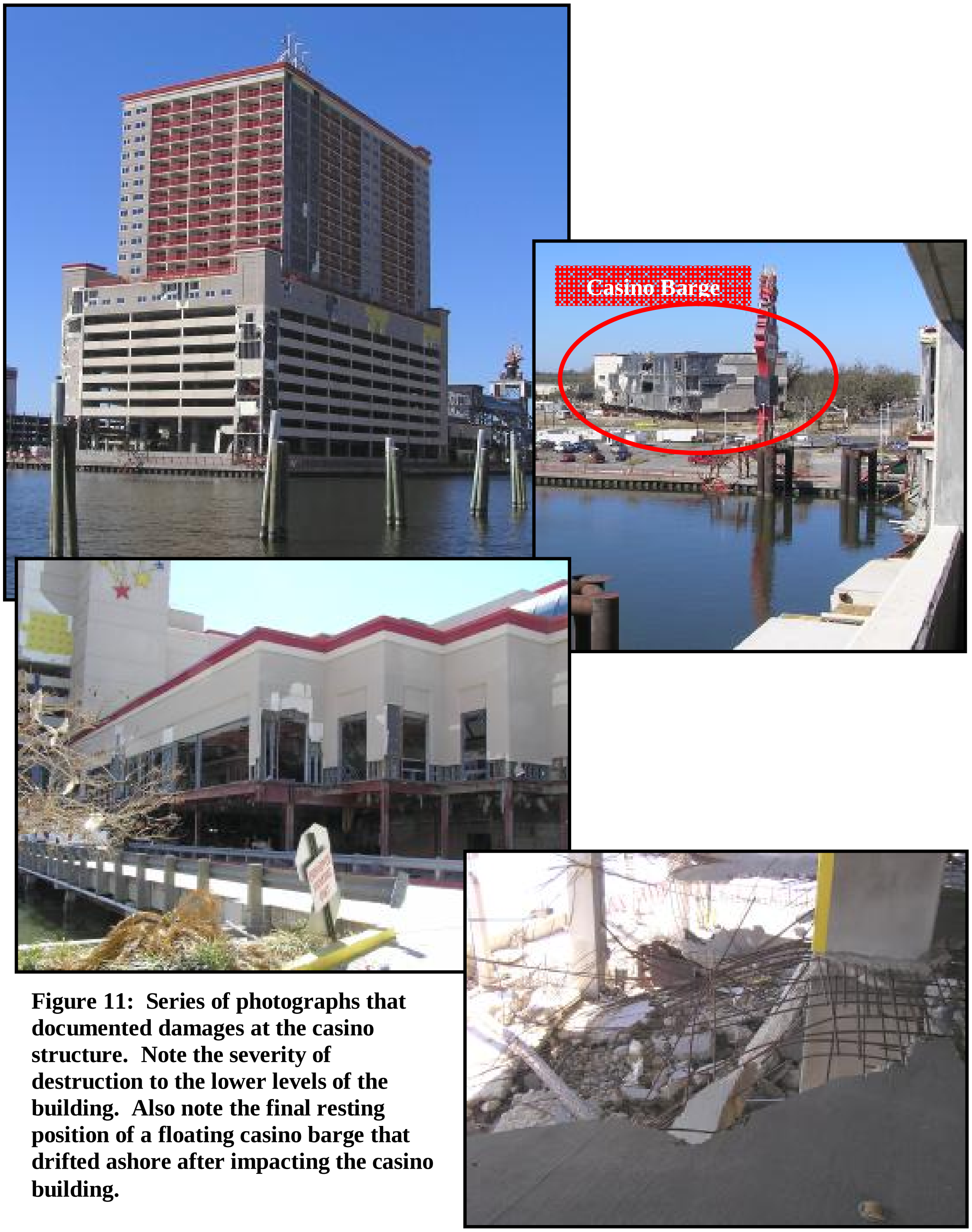


Figure 11: Series of photographs that documented damages at the casino structure. Note the severity of destruction to the lower levels of the building. Also note the final resting position of a floating casino barge that drifted ashore after impacting the casino building.

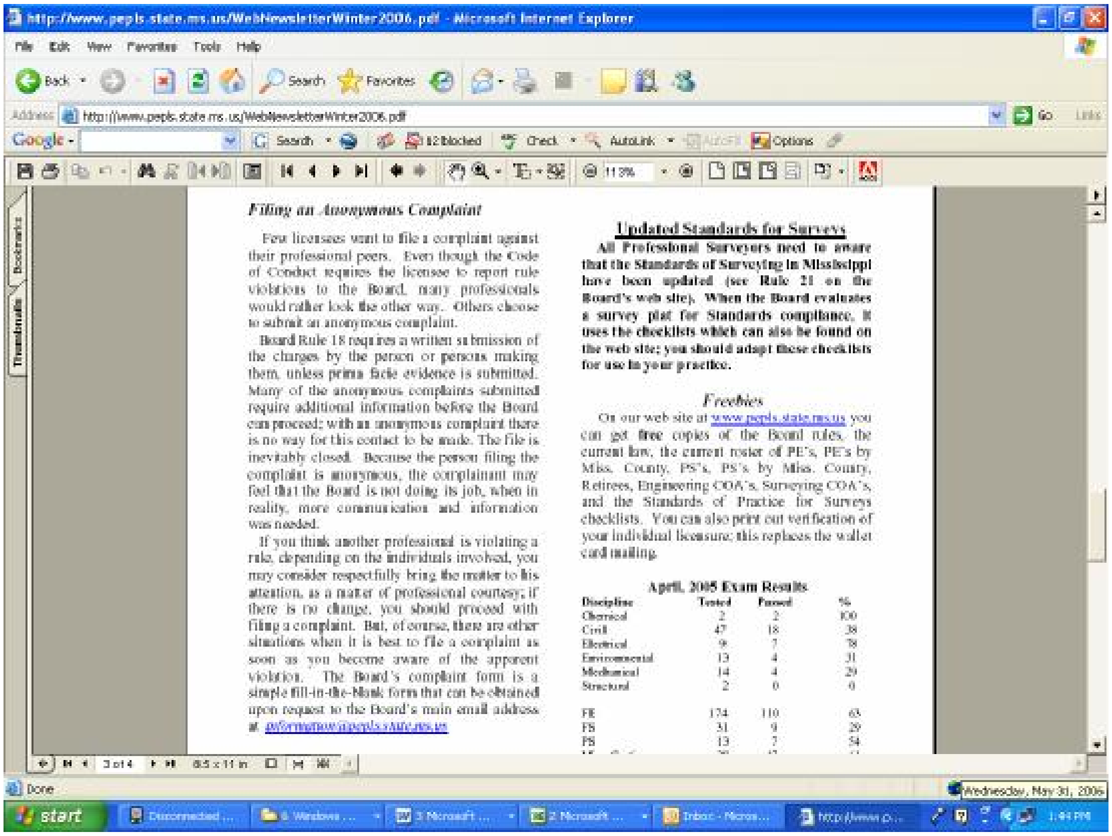
Regarding Ethics Issues

The extent of damages along the Mississippi coast exceeded practically everyone's worst predictions. In particular, flooding from the storm surge reached areas that were thought to be relatively risk-free (above the floodplain) causing damages further inland than anticipated. Since many property owners had no flood insurance on their buildings damaged by the hurricane, the determination of wind versus water damages by structural engineers could bring financial ruin to individuals or families. How do structural engineers deal with the pressures created by this unfortunate circumstance? Ethics! Ethic standards, in particular – the ASCE *Code of Ethics*[6], provide help to structural engineers in this situation.

The key factors in dealing with ethical pressures placed upon the inspecting structural engineers are honesty, integrity, and objectivity. The inspecting structural engineer must uncover the facts so as to form substantiated opinions. If opinions cannot be substantiated based upon available resources, then the structural engineer must explain that specific answers to their client's questions cannot be determined.

Another problem that many structural engineers faced was the tremendous volume of buildings to inspect. Over 250,000 people were displaced by Hurricane Katrina – their homes damaged or destroyed during the storm. Rebuilding efforts were not likely to start until insurance issues were resolved regarding these damaged buildings. These insurance issues more than likely hinged on the conclusions needed from an inspecting structural engineer. In this situation, structural engineers must give due consideration to each building they inspect. Practically every building is unique in its ability to resist lateral forces from a hurricane. Factors that differ among buildings include age/deterioration, building materials, over/under-designed structural systems, construction defects, over/under-loaded conditions, and surrounding terrain features. Thus, we cannot simply assume that conclusions reached for a particular building will also apply to all of the surrounding buildings.

Considering the huge number of damaged buildings to inspect and the finite number of licensed structural engineers to examine them, it should come as no surprise that there have been reports of individuals not properly qualified as structural engineers performing or supervising damage assessments of buildings. For guidance on this issue, consider Cannon 2 of the ASCE *Code of Ethics*[6], "Engineers shall perform services only in areas of their competence." Should you come across someone known to be misrepresenting themselves as structural engineers, consider Cannon 1: "Engineers shall hold paramount the safety, health and welfare of the public and shall strive to comply with the principles of sustainable development in the performance of their professional duties"; and subpart d: "Engineers who have knowledge or reason to believe that another person or firm may be in violation of any of the provisions of Canon 1 shall present such information to the proper authority in writing and shall cooperate with the proper authority in furnishing such further information or assistance as may be required.") The Mississippi Board of Licensure for Professional Engineers and Surveyors requires that complaints be submitted in writing by the person or persons making them. A recent newsletter from the Board explained that they typically cannot pursue anonymous complaints[7].



Filing an Anonymous Complaint

Few licensees want to file a complaint against their professional peers. Even though the Code of Conduct requires the licensee to report rule violations to the Board, many professionals would rather look the other way. Others choose to submit an anonymous complaint.

Board Rule 18 requires a written submission of the charges by the person or persons making them, unless prima facie evidence is submitted. Many of the anonymous complaints submitted require additional information before the Board can proceed; with an anonymous complaint there is no way for this contact to be made. The file is inevitably closed. Because the person filing the complaint is anonymous, the complainant may feel that the Board is not doing its job, when in reality, more communication and information was needed.

If you think another professional is violating a rule, depending on the individuals involved, you may consider respectfully bring the matter to his attention, as a matter of professional courtesy; if there is no change, you should proceed with filing a complaint. But, of course, there are other situations when it is best to file a complaint as soon as you become aware of the apparent violation. The Board's complaint form is a simple fill-in-the-blank form that can be obtained upon request to the Board's main email address at information@pepls.state.ms.us

Updated Standards for Surveys

All Professional Surveyors need to aware that the Standards of Surveying in Mississippi have been updated (see Rule 21 on the Board's web site). When the Board evaluates a survey plat for Standards compliance, it uses the checklists which can also be found on the web site; you should adapt these checklists for use in your practice.

Freebies

On our web site at www.pepls.state.ms.us you can get **free** copies of the Board rules, the current law, the current roster of PE's, PE's by Miss. County, PS's, PS's by Miss. County, Retirees, Engineering COA's, Surveying COA's, and the Standards of Practice for Surveys checklists. You can also print out verification of your individual licensure; this replaces the wallet card mailing.

April, 2005 Exam Results

Discipline	**Tested**	**Passed**	**%**
Chemical	2	2	100
Civil	47	18	38
Electrical	9	7	78
Environmental	13	4	31
Mechanical	14	4	29
Structural	2	0	0
FE	174	110	63
FS	31	9	29
PS	13	7	54

Figure 12: Article from Mississippi Board newsletter

Conclusions

Hurricane Katrina imposed unique challenges to structural engineers charged with the task of assessing damages to buildings and structures. Although most of the attention for the aftermath of the hurricane was focused on the levee failures and resultant flooding in New Orleans, the strongest wind and surge forces that made landfall from the hurricane were imposed on the Mississippi coastal communities. The resultant damages to the Mississippi coastline from Hurricane Katrina were the most expensive from any storm in U.S. history. As the insurance industry mobilized to help property owners recover during the aftermath of the hurricane, the services of structural engineers were needed to uncover facts for adjusters so that they could determine which insurance policies applied. Specifically, structural engineers had the challenge of determining a distinction between damages caused by high winds versus damages caused by the associated storm surge and waves. In this paper, we reviewed techniques and discussed available resources for structural engineers to formulate substantiated opinions regarding Hurricane Katrina damage. We also discussed unique challenges for structural engineers involved in assessing damage to the Mississippi coast, including health and safety issues, licensure / legal aspects, and ethical issues.

A note regarding SI units:

Data from the referenced publications and weather sources were provided in English units. In order to maintain continuity and to minimize confusion for the reader, who may wish to review these references, the sample calculations provided in this paper are also provided in English units. We offer the following basic conversions for those who wish to consider SI units:

$1\ \text{kg/m}^3 = 0.0624\ \text{pcf}$

$1\ \text{m} = 3.281\ \text{ft}$

$1\ \text{m}^3 = 35.3147\ \text{ft}^3\ \text{(cf)}$

$1\ \text{cm} = 2.54\ \text{in}$

$1\ \text{km} = 0.621\ \text{miles}$

$1\ \text{m}^2 = 10.764\ \text{ft}^2\ \text{(sf)}$

References

[1] American Society of Civil Engineers (ASCE). 1995. *Minimum Design Loads for Buildings and Other Structures.*

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[6] American Society of Civil Engineers (ASCE). 1914 (Amended 1996). *Code of Ethics, http://www.asce.org/inside/codeofethics.cfm#note3*

[7] Mississippi Board of Licensure for Professional Engineers and Surveyors. 2005. *Winter, 2006 Newsletter,* http://www.pepls.state.ms.us/WebNewsletterWinter2006.pdf

[8] Federal Emergency Management Agency (FEMA). 2006. *Hurricane Katrina Flood Recover Maps,* http://www.fema.gov/hazard/flood/recoverydata/katrina/katrina_ms_maps.shtm