MCEER SPECIAL REPORT SERIES

Engineering and Organizational Issues Before, During and After Hurricane Katrina

HURRICANE KATRINA

Volume Five

BRIDGES

Damage to Bridges from Wind, Storm Surge and Debris in the Wake of Hurricane Katrina

Jerome S. O'Connor and Paul E. McAnany

MCEER is a national center of excellence dedicated to establishing disaster-resilient communities through the application of multidisciplinary, multi-hazard research. Headquartered at the University at Buffalo, State University of New York, the Center was originally established by the National Science Foundation (NSF) in 1986, as the National Center for Earthquake Engineering Research (NCEER).

Comprising a consortium of researchers from numerous disciplines and institutions throughout the United States, the Center's mission has expanded from its original focus on earthquake engineering to address a variety of other hazards, both natural and man-made, and their impact on critical infrastructure and facilities. The Center's goal is to reduce losses through research and the application of advanced technologies that improve engineering, pre-event planning and post-event recovery strategies. Toward this end, the Center coordinates a nationwide program of multidisciplinary team research, education and outreach activities.

Funded principally by NSF, the State of New York and the Federal Highway Administration (FHWA), the Center derives additional support from the Department of Homeland Security (DHS)/Federal Emergency Management Agency (FEMA), other state governments, academic institutions, foreign governments and private industry.

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Volume 5

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Foreword

On August 29, 2005, Hurricane Katrina made landfall with sustained winds estimated at 125 mph, storm surges as high as 25 feet and winds extending 125 miles from its center. It resulted in over 1,800 lives lost, and caused major flooding and damage that spanned more than 200 miles along the Gulf Coast of the United States.

The extensive damage to the built environment far exceeded the expected damage for a storm of this intensity. Based on measured wind speeds and the Saffir-Simpson scale, Hurricane Katrina reached Category 5 strength while in the Gulf of Mexico, but quickly dissipated to a Category 3 storm before landfall. Although the wind speeds were substantially reduced before striking land, the storm surge apparently maintained the heights associated with a Category 5 storm and appears to have been responsible for most of the damage along the Mississippi coast and in the Mississippi Delta below New Orleans. Levee failure in New Orleans, associated with storm surge, is responsible for most of the property loss in New Orleans. Note that early estimates ranked Hurricane Katrina as a Category 4 storm at landfall; the National Hurricane Center downgraded this ranking after revising wind speeds in December 2005.

Hurricane Katrina caused significant damage to engineered infrastructure including levees, commercial and public buildings, roads and bridges, utility distribution systems for electric power and water, wastewater collection facilities, and vital communication networks. Damage to critical infrastructure such as hospitals and communication systems crippled the affected communities, and more importantly, the response and recovery efforts following the hurricane. In the aftermath of Hurricane Katrina, the important question is now: How can we better prepare ourselves to prevent or minimize the level of damage and the subsequent catastrophe in the next extreme event?

Funded by the National Science Foundation, a multidisciplinary team of investigators from the Multidisciplinary Center for Earthquake Engineering Research (MCEER), headquartered at the University at Buffalo, conducted post-disaster field reconnaissance to examine the impact of Hurricane Katrina on physical engineered systems and the response and recovery efforts that followed. Their objectives were to examine wind, storm surge and debris damage from a multi-hazard perspective. Implications of lessons learned from this reconnaissance effort are being examined to mitigate damage and improve response and recovery efforts not only from future hurricanes, but also from other extreme events such as earthquakes or terrorist attacks. By collecting this multi-hazard information, MCEER is seeking to develop engineering design strategies and organizational strategies that will make communities more resilient against any extreme event.

The MCEER special report series “Engineering and Organizational Issues Before, During and After Hurricane Katrina” was initiated to present the findings from the field reconnaissance mission. The topics addressed include advanced damage detection using remote sensing, damage to engineered structures, organizational decision making primarily in hospitals, and environmental and public health issues. The reports will contribute to the development of a better understanding of how to cost effectively enhance the resilience of the nation’s infrastructure against future extreme events.

Acknowledgements

In spite of the hardship caused by the storm, Gulf Coast residents were gracious and hospitable. The authors appreciate the willingness of many people to share information and their experiences.

The authors would like to recognize the contributions of state and local transportation officials who provided photographs and offered suggestions. A few of these individuals are: George Conner, Alabama Department of Transportation (DOT); Keith Carr and Mitchell Carr, Mississippi DOT; and Ray Mumphrey and Arturo Aguirre, Federal Highway Administration (FHWA). The authors also wish to acknowledge the efforts and help from other members of the MCEER and NIST reconnaissance teams. Special thanks go to Mal Woodcock, Chief Flight Instructor and Pilot, Gulf Coast Flight Training Center for a safe and productive fly-over of the region. Thanks to all.

Numerous members of MCEER staff provided the authors support before, during, and after the time in the field. Drs. Michel Bruneau and Andre Filiatrault planned and managed the effort; Pat Kraemer provided logistical support; Jane Stoyle and Michelle Zuppa organized the findings and worked long hours to keep the MCEER web site current as new information came in; Don Goralski contributed communication and coordination. Joy James provided administrative support and prepared subsequent papers and presentations, including this document. Thanks to all.

Funding for this reconnaissance mission was provided by the National Science Foundation (NSF) and the Federal Highway Administration (FHWA); acknowledgment is given to Contract Officer - Technical Representative Dr. Phil Yen, FHWA and Project Director Dr. George Lee, University at Buffalo.

The support of the U.S. Department of Commerce, National Institute of Standards and Technology (NIST) is also recognized. The information in this report is supplemented with photos and data collected by the author during a "lifelines" reconnaissance mission conducted October 15-21, 2005. Thanks go to ImageCat, Inc. and Applied Technology Council (ATC) for the invitation to join the team and to Tom Rodino, Senior Maritime Consultant, U.S. Coast Guard (retired), Sub-team Coordinator.

Contents

1.0 Introduction

Since there is an abundance of detailed information about Hurricane Katrina available in other sources (Mosqueda and Porter, 2007; NIST, 2006), this report does not describe the storm itself. This report focuses on the structural performance of bridges. As an "extreme event" research center, MCEER was interested in capturing photographs of the raw damage caused by Katrina and collecting perishable data that would be lost during repair and reconstruction. The purpose of documenting the damage is to allow others to explore some of the reasons why certain structures survived and others did not. Investigations such as this can lead to improvements to bridge design standards for coastal design, similar to the way post-earthquake investigations led to a better understanding of seismic loadings and an improved performance-based seismic design specification. Results of actual events can provide invaluable data that is difficult if not impossible to collect in a laboratory setting. Figure 1-1 shows the geographic area covered by investigators and the extent of the bridge damage encountered.

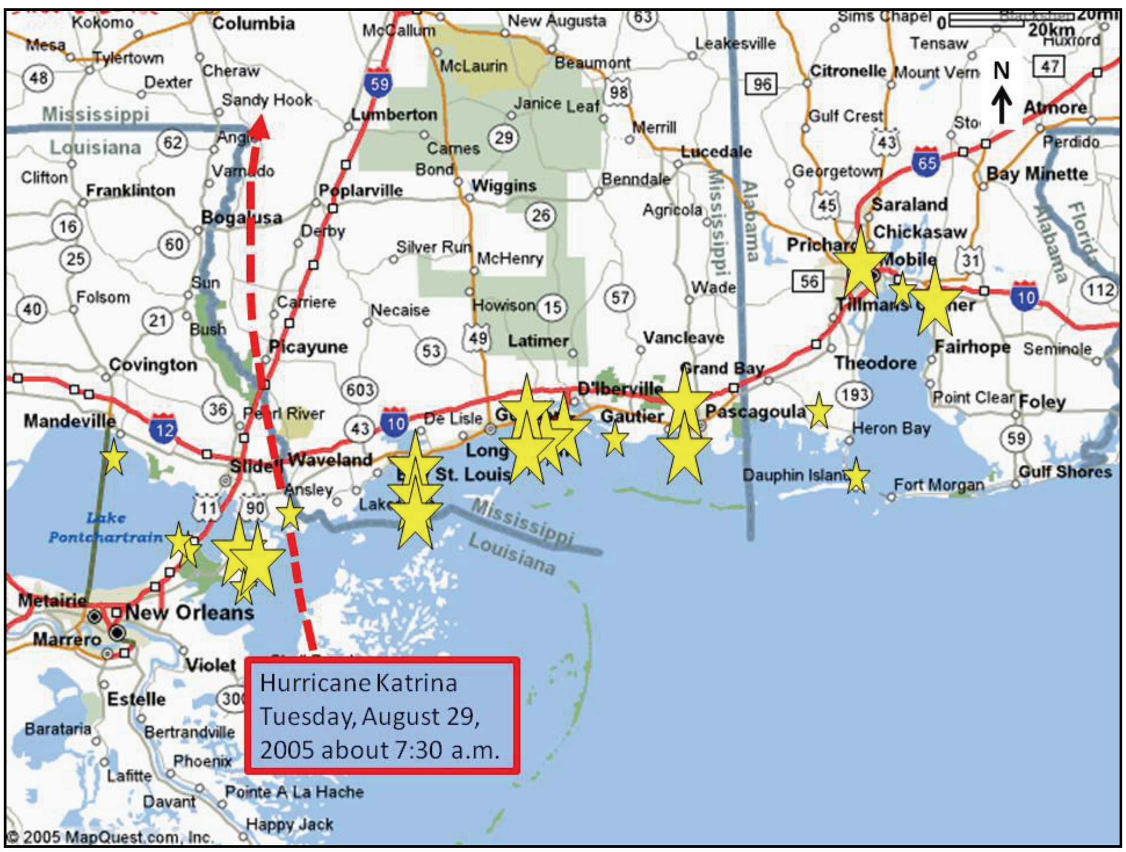


Figure 1-1. The stars on this map of the U.S. Gulf Coast provide an indication of the scope and location of bridge damage.

Most of the information presented in this report was collected from first hand observations in the affected areas. Photos provided courtesy of others are noted with a reference. The report is primarily based on a reconnaissance trip conducted about a week after the event (Sept. 6-11, 2005), but is supplemented by information acquired during a second trip a month later (October 16-21, 2005) (NIST, 2006).

The eye of Katrina hit the U.S. mainland at the state line between Louisiana and Mississippi. It had a wide swath that had a severe impact in these states and as far away as Alabama. The information collected is presented in the order it was collected, generally from east to west. It starts with an overview based on an aerial reconnaissance flight over the Mississippi coast. This provides a broad understanding of the scope of the disaster before going into detailed accounts of the ground survey.

A photographic essay documents the site by site account of the ground reconnaissance. Photos are grouped by areas that were subjected to similar conditions, beginning with aerial photos of the area and progressing to more detailed ones. Bridges over Biloxi Bay and the vicinity for example are presented together. Bridge sites that were inspected are tabulated and identified with a site number based on the date that the site was first visited. Information from the second reconnaissance trip is inserted into the report according to how it fits geographically with site reports from the first trip.

The report contains much information about the bridges along the coast of Mississippi and the adjoining parts of Louisiana and Alabama. However, since this report only describes findings of two reconnaissance missions, it does not include all bridge damage resulting from Katrina. Table 1-1 provides an indication of the types of damage found by the authors and its cause. Additional information may be available from the local state transportation departments, or other sources.

It is worth noting that the most severe damage was found at bodies of water such as Biloxi Bay, St. Louis Bay, and Lake Pontchartrain. Katrina's intensity lifted water levels in the ocean to unprecedented elevations. As the storm approached the bay areas, the tidal surge grew even higher as it was funneled in a horizontal plane by the natural shape of the coastline and in a vertical plane as the bay bottom became shallower and shallower near the shore. The combination of these factors created a scenario that was not envisioned when the bridges were designed and built. Structural failures resulted primarily from wave forces and debris hitting bridges and inducing loading situations that they were not designed to handle.

Table 1-1. Types of Bridge Damage

Impact:	
	Vessel (Barges, Shrimp Boats, Yachts)
	Misc. (Oil Platform, Oil Tanks, Appliances, Logs & Other Debris)
Storm Surge, Wave Action & Wind:	
	Displaced Spans or Total Collapse of Spans
	Destruction of Concrete Decks and Prestressed (P/S) Beams Due to Uplift & Other Forces
	Railroad Tracks & Ties Stripped Off
	Flooding of Moveable Bridge Electrical & Mechanical Systems
Scour & Erosion:	
	Pier Settlement or Loss of Pier
	Undermined Approach Slabs; Washed Out Approaches
	Erosion and Loss of Abutment Armoring (even at road crossings)

Though this report emphasizes bridges, Figure 1-2 is provided to put this report in context with other consequences of the storm. A detailed description of each photograph is as follows:

a. Large steel tanks (about 8 feet in diameter) such as these broke loose and were swept away in flood waters. Items like this caused damage to bridges, homes, and other buildings.
b. Note the steel shipping container lodged under the bridge. It's dimensions are about 8 feet x 8 feet x 20 feet. This may have caused the damage to the bridge railing on Rigolets Bridge.
c. On US-90 in Gautier, MS, numerous fiberglass light poles broke off near the base due to wind and surge waters. Missing street signs and traffic signals complicated travel after the storm.
d. Hundreds of boats was swept up in the storm. This one came down in the median of US-90 in Gautier, MS.
e. Waves peeled up entire courses of asphalt pavement. This made sections of road very difficult to traverse during the reconnaissance. This view is on US-90 in Louisiana.
f. Layers of asphalt pavement on US-90 were peeled up and transported 50-100 feet away.
g. Debris fields were left behind after the storm. This material was hazardous because of nails and glass but also because it could contain hazardous chemical waste. This scene was at Rigolets.
h. After the water receded this boat landed on the I-10 WB interstate highway, just east of Lake Pontchartrain.

i. In Biloxi, MS, surge washed away entire neighborhoods. It was difficult to determine where houses had once stood. This photo was taken about a half mile north of the beach.
j. Neighborhoods near Slidell, LA were littered with debris from the storm.
k. Local streets in a neighborhood near Slidell, LA needed to be cleared of debris left behind by surge waters.
l. Most highways needed clearing after the storm in order to become passable. This view is in Louisiana near the west end of I-10 bridges.
m. Broken tanks and pipelines polluted water resources and caused environmental damage.
n. This is one of many buildings that were destroyed by wind and surge.
o. The concrete floor of a warehouse at the State Port Authority in Gulfport, MS was destroyed when it was flooded by surge water. The floor was supported by a network of concrete piles and beams; the air cavity under the floor may have worsened the damage.
p. This exterior storage area at the State Port Authority in Gulfport, MS was supported by a network of concrete piles and beams. If air could not escape from the cavity underneath, the weight of 24 feet of water above may have caused the slabs to fail.
q. A wastewater treatment plant in Gulfport was taken out of service when it became flooded.
r. An accurate elevation for surge level could be taken from waterlines left behind after the water receded such as this distinct line on the side of a filing cabinet. This is 21 feet above mean sea level. GPS coordinates: N 30° 24' 21.4", W 88° 53' 48.6."
s. New Orleans was under control of the military during the September reconnaissance. A thorough investigation of bridge damage was not possible.
t. The military were still protecting the City of Orleans during the September reconnaissance.
u. This 28-inch pine tree near Slidell was sheared off during the storm. GPS coordinates: N 30° 14' 19.8", W 89° 45' 06.4."
v. High water was often marked by debris left in trees. This tree was on the east side of Biloxi Bay. High water was approximately 21 feet. At another site on the west side of Biloxi Bay (GPS coordinates N 30° 23' 34.9", W 88° 51' 28.9"), debris was measured to be 24 feet above water level.
w. Looking north from the Gulf shore, one can see that there was widespread destruction of anything within a half mile of the beach.
x. Most houses in this beach zone near Gulfport were leveled down to the foundation slab.

(a) Tanks carried by the surge caused damage.

(b) Shipping containers hit bridges.

(c) Light poles were downed.

(d) Boats were caught up in the surge.

(e) Courses of asphalt pavement peeled up.

(f) Layers of pavement moved 50-100 feet.

Figure 1-2. Storm Damage (see page 3 for a detailed description of each photograph).

(g) Debris fields made walking hazardous.

(h) Hundreds of boats were lost, then found.

(i) A neighborhood in Biloxi, MS.

(j) Debris near Slidell, LA.

(k) A neighborhood near Slidell, LA.

(l) Debris covered highways.

Figure 1-2. Storm Damage (Continued)
(see pages 3-4 for a detailed description of each photograph).

(m) Oil spill in a pond.

(n) Destroyed buildings.

(o) Warehouse slab at the Port Authority.

(p) Exterior concrete slab at the Port Authority.

(q) A wastewater treatment plant.

(r) Watermarks helped mark surge levels.

Figure 1-2. Storm Damage (Continued)
(see page 4 for a detailed description of each photograph).

(s) New Orleans was guarded by the military.

(t) The military patrolling New Orleans.

(u) This 28″ pine tree was snapped off by the storm.

(v) High water was marked by debris in trees.

(w) Surge destroyed most things near the beach.

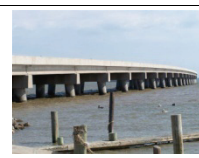
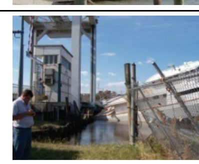
(x) Most houses near the beach were leveled.

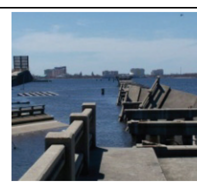
Figure 1-2. Storm Damage (Continued)
(see page 4 for a detailed description of each photograph).

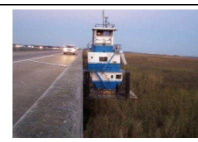
2.0 Assessment of Damage

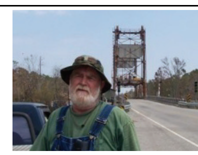
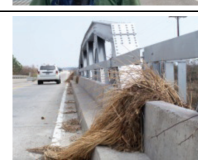
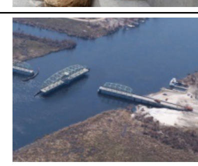
Table 2-1 provides a listing of sites inspected. The list is by no means a comprehensive list of all bridges damaged by Hurricane Katrina and does not include every site visited by the reconnaissance teams. It includes the sites of major damage and enough sites with minor damage to give an idea of the extent of damage caused by Katrina. The sites are listed in the order that they were first inspected. A site number is assigned based on the day of the month followed by a number corresponding to the sequence of bridges inspected that day. Because the inspections were conducted from east to west across the Gulf Coast, the bridges appear on the list generally from east to west.

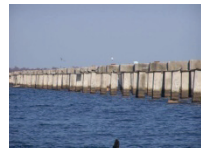
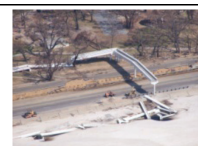
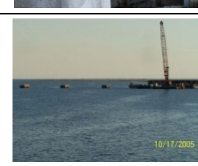
Table 2-1. Bridge Sites Inspected

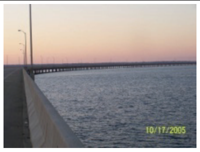
Site#	St	County/ Parish	Bridge Name/ Features Carried & Crossed	Description	ID Photo	Damage	Page
Tuesday September 6, 2005							
6-0	AL	Mobile	Rte 193 over Middle Fork Deer	Newer high-rise steel superstructure		No apparent damage.	-
6-1	AL	Mobile	Rte 193 over Grants Pass to Dauphin Island	P/S concrete, oriented N-S, built in 1982, 6' above sea level		Approach had been partially washed out. Repaired.	21
6-2	AL	Mobile	Rte 188 over inlet at Bayou La Batre	Moveable lift bridge		Vessel impact & flooding of control room. Inoperable.	23
6-3	AL	Mobile	Conchrane-Africatown USA Bridge (US-90/ Mobile River)	New cable stayed bridge		Hit by errant oil platform.	24
6-4	AL	Mobile	Rte 90 over Polecat Bay	Long interstate bridge with steel superstructure		Erosion had accurred at approach. Repaired.	27

Site#	St	County/ Parish	Bridge Name/ Features Carried & Crossed	Description	ID Photo	Damage	Page
6-5	AL	Baldwin	Ramp US-90 to I-10 EB over Mobile Bay	Low interstate ramp bridge		Approximately four spans displaced 4 ft. Road closed.	29
Wednesday September 7, 2005							
7A	MS	Jackson	Rte 613 over Escatawpa River	Segmental concrete construction		No apparent damage.	-
7B	MS	Jackson	Rte 63 over Escatawpa River	Multiple span steel bridge.		No apparent damage.	-
7C	MS	Jackson	Magnolia St. over Trib. W. Pascagoula River	Low, 3-span P/S concrete, built in 2004		No apparent damage.	-
7D	MS	Jackson	US-90 over W. Pascagoula River	New P/S construction		Excellent condition.	-
7-1A	MS	Harrison	US-90 over Biloxi Bay	1.6 mile long bridge w/ P/S simple spans; built about 1961; 6.5" CIP deck with 42' spans		All but highest spans near moveable span at center of channel were destroyed	48
7-1B	MS	Harrison	Pedestrian Bridge (Old 90/Biloxi Bay)	Retired bridge used for fishing pier, built in the 1930's		All spans lost.	54
7-2	MS	Harrison	CSX RR over Biloxi Bay	Railroad bridge with 60' P/S simple spans		Bridge survived. Tracks had been washed off.	56
7-3	MS	Harrison	Pedestrian Bridge (Old 110 over Back Bay of Biloxi)	Retired bridge used for fishing pier		Several spans and piers lost. SE sidewalk broke off.	68

Site#	St	County/ Parish	Bridge Name/ Features Carried & Crossed	Description	ID Photo	Damage	Page
7-4	MS	Harrison	I-110 over Back Bay of Biloxi	New interstate bridge, 60' above normal high tide		Functional. Impact damage to one pier & SE fascia.	69
7-5A	MS	Jackson	I-10 EB over Pascagoula River at Moss Point	Long, low interstate over bayou with P/S simple spans		Closed due to barge impact. Six spans displaced.	38
7-5B	MS	Jackson	I-10 EB over Pascagoula River at Moss Point	Long, low interstate over bayou w P/S simple spans		Several vessel impacts. Minor damage.	41
7-5C	MS	Jackson	I-10 EB over Pascagoula River at west abutment	Long, low interstate bridge over bayou.		Boat lodged under WB lanes, far west span.	42
Thursday September 8, 2005							
8-1 & 8-6	LA	Orleans & St. Tammany	I-10 WB over Lake Pontchartrain	5.4 mile long bridge built modularly in '63		Most spans displaced or dropped into water.	97
8-2	LA	Orleans & St. Tammany	I-10 EB over Lake Pontchartrain	5.4 mile long bridge built modularly in 1963		Most spans displaced or dropped into water.	97
8-3	LA	St. Tammany	Small bridge in Slidell	Short bridge built in 1990		Passable but plugged with debris.	-
8-3B	LA	St. Tammany	Rte 433 over Bayou Liberty, West of Slidell	Floating bridge	No photo	Not visible; covered by boats.	-
8-4	LA	Orleans & St. Tammany	US-11 over Lake Pontchartrain	CIP concrete bridge built 1927. New deck in 2001.		Functional but moveable span was without electricity.	106
8-5	LA	St. Tammany & Orleans	Norfolk Southern RR over Lake Pontchartrain	Railroad bridge with P/S concrete simple spans, 5.8 miles long		Bridge survived. Tracks washed off.	109

Site#	St	County/ Parish	Bridge Name/ Features Carried & Crossed	Description	ID Photo	Damage	Page
8-7 & 10-3	LA	Orleans	US-90 over Chef Menteur Pass	Multiple span with swing span; built in 1929		Closed to road traffic.	116
8-8	LA	Orleans	I-10 in City of New Orleans	1970 era interstate bridges		Widespread flooding, esp. ramps.	110
8-9	LA	Jefferson & St. Tammany	Causeway over Lake Pontchartrain	~24 mile long, bridge; built '56 & '69; deck is 20' above water		N. approach washed out. Some ramps spans lost.	113
Saturday September 10, 2005							
10-1	LA	St. Tammany	Highway 433 over Salt Bayou	Low five span concrete bridge built in 1955.		Functional. Minor pier settlement.	91
10-2	LA	St. Tammany & Orleans	Rigolets Bridge: US-90 over Lake Pontchartrain	50 P/S spans + 3 truss spans over Rigolets Strait		Moveable span not functional. SW approach undermined.	115
10-4	LA	St. Tammany	US-90 over West Pearl River	Vertical lift bridge		Closed to boat traffic but road is passable.	92
10-5 thru 10-7	LA	St. Tammany	US-90	Series of pony truss bridges		Overtopped but no apparent damage.	93
10-8	MS - LA state line	Hancock Co. & St. Tammany	US-90 over East Pearl River	Multiple span bridge with swing span		Inoperable; open to boat traffic. Damage to approach.	94
10-8B	MS	Hancock	I-10 over local Road, north of Bay St. Louis	Typical interstate crossing local road		Severe abutment erosion at road crossing.	78

Site#	St	County/ Parish	Bridge Name/ Features Carried & Crossed	Description	ID Photo	Damage	Page
10-9	MS	Hancock - Harrison	US-90 over St. Louis Bay	1.9 mile long P/S bridge built in 1953.		All spans lost & numerous piers scoured out.	81
10-10	MS	Hancock – Harrison	CSX Railroad over St. Louis Bay	P/S simple spans		Entire super-structure lost	87
10-11[1]	MS	Harrison	US-90 at Henderson Point	East of US-90 bridge over St. Louis Bay near Pass Christian		Spans displaced at east abutment.	89
18-1	MS	Harrison	Pedestrian bridge over US-90	Precast concrete construction		Collapsed spans	77
Sunday September 11, 2005							
Aerial survey of Mississippi and Lake Pontchartrain bridges taken from 1000 feet. Video taken on September 11, 2005; see *http://mceer.buffalo.edu/research/Reconnaissance/Katrina8-28-05/videos.asp*.							
Monday October 17, 2005							
17-1	MS	Jackson	Hwy 609 over Fort Bayou	Moveable bridge built in 1985		Inoperable. Control room flooded.	64
17-2	MS	Jackson	Shearwater Bridge in Ocean Springs	Precast construction completed in 2003		Minor approach damage.	62
17-3A	MS	Jackson	US-90 over W. Pascagoula River	Multiple P/S concrete spans		Minor approach damage.	34
17-3B	MS	Jackson	CSX RR over W. Pascagoula River	Low lying railroad bridge with steel superstructure		Superstructure lost on at least 15 spans. Piers remain.	35

Site#	St	County/ Parish	Bridge Name/ Features Carried & Crossed	Description	ID Photo	Damage	Page
17-4	MS	Jackson	Naval Station bridge over Pascagoula Bay	Low lying superstructure		No apparent damage.	36
Thursday October 20, 2005							
20-1	MS	Harrison	Southern Terminus of I-110 in Biloxi	CIP concrete box ramp bridges		No apparent damage.	76
20-2	MS	Harrison	Popps Ferry over Back Bay of Biloxi	P/S concrete, simply supported spans		Closed; inoperable bascule span, spans displaced, fascia battered.	71

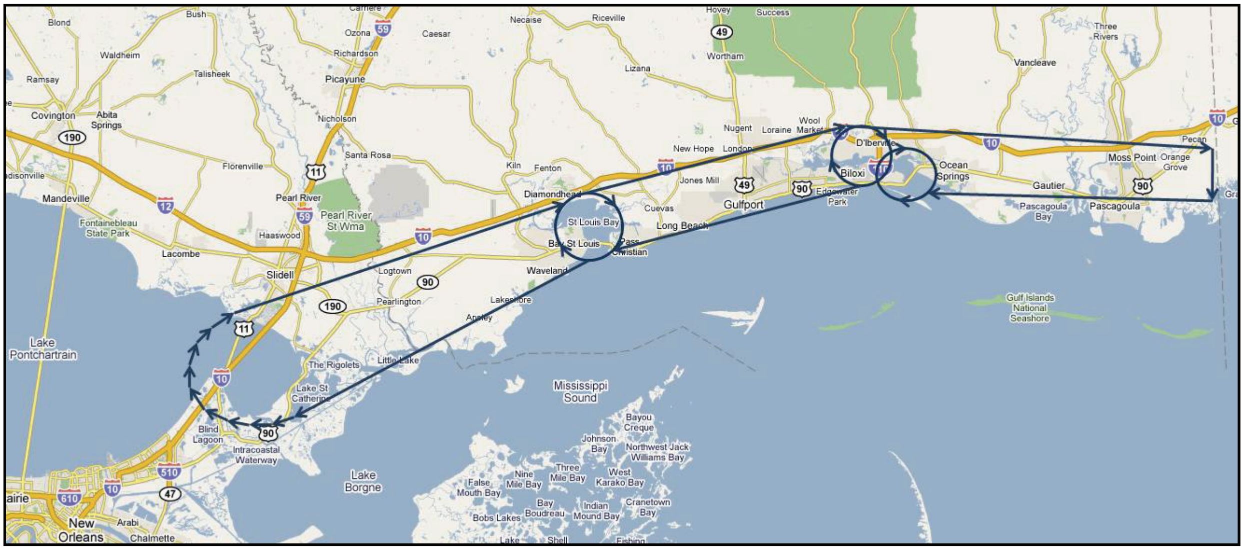
Note: "P/S" = prestressed concrete beams; "CIP"= cast-in-place

[1] This site was not inspected from the ground. An aerial photo was taken 9/11/05.

2.1 Aerial Survey

The aerial survey was actually conducted at the conclusion of the driving tour but is presented here to provide an overview of the damage in the region. Figure 2-1 is a map of the flight route. The Inspector's Daily Journal in Appendix A gives a more detailed description of the ground survey. Section 2.2 provides a short description of the site, the damage found and photographs of the damage.

The conclusion that an aerial view was necessary came after a week of on-the-ground inspections. Being on the ground gave access to detailed information but did not allow an assessment of macro patterns of the bridge failure such as a count of the spans in the bridge, direction of span displacements, etc. Any future reconnaissance surveys should, if at all possible, start with an aerial view of the entire region to detect the most important damage on major routes and on routes inaccessible from the ground. It also would have been useful to look at the bridges from the water, though that was not as critical. To provide a flavor of the flying experience, only minor modifications have been made to the original narrative.



2008 Google - Map

Figure 2-1. Flight Path of the Aerial Reconnaissance

Sunday 9/11/05, 10:00 a.m.

Jerry O'Connor and Paul McAnany started an aerial reconnaissance in a Cessena Skyhawk 172 airplane, chartered out of the Pascagoula, MS airport. The pilot was Mal Woodcock. We were able to fly as slow as 90 knots at 1,100 feet, which was excellent for viewing and photographing. The pilot did a great job of providing a good view, orbiting the bridge sites several times to allow various shots of still photos, zoomed photos, and video. It was not possible to record GPS coordinates and was difficult to record the location and direction of the photos. With technological advances, these problems can be eliminated on future reconnaissance trips.

Upon leaving the Trent Lott International Airport, located just north of Moss Point, we flew south toward the shore, crossing I-10 and looking west, seeing the site where the eastbound (EB) bridge had been hit by at least one tug boat and several barges that had cranes mounted on them. These were photographed again at the end of the 2.5-hour flight.

South of Pascagoula we saw, for the first time, the long railroad bridge that runs E-W parallel to Highway US-90 over the Pascagoula Bay near the Naval Station. Its superstructure had been damaged. After this, we turned west and saw extensive damage on the same railroad line across most of the state of Mississippi (roughly 75 miles). Damage included collapsed bridge superstructures, tracks displaced from these bridges and the ballast on the ground, and derailed railcars in a disheveled position along the tracks. Although the railroad lines are a critical part of our transportation infrastructure, these bridges are privately owned by the railroads, and not a target of our reconnaissance. Information about the railroads was recorded when easily obtainable.

The pilot flew in a westward direction, following US-90 and the rail line along the coast. In the description that follows, large bodies of water are designated in italics; they were the sites of major bridge failures. From east to west, the Mississippi communities and features observed from the plane were Pascagoula, Gautier, Ocean Springs, *Biloxi Bay*, *Back Bay*, D'Iberville (a little further to the north), Biloxi, Gulfport, Long Beach, Pass Christian, *St. Louis Bay*, and Bay St. Louis. Continuing into the state of Louisiana, we observed Slidell, *Lake Pontchartrain*, and the City of New Orleans. Because New Orleans was still under the control of the military, air space was controlled and we were only able to approach the east edge of the city. This was sufficient for viewing the bridges over Lake Pontchartrain that suffered damage. We did not fly over the 24 mile long toll Causeway that leads into the city from the north. This is an important structure that survived the hurricane and was opened to emergency vehicles after repairs were made to the approach at the north end of the SB bridge. There was apparently loss of some low lying turnaround ramp spans.

The sites that were the focus of this flyover were the major structures that spanned Biloxi Bay, Back Bay, St. Louis Bay, and Lake Pontchartrain. Additionally, the flight enabled us to discover several significantly damaged bridges that went undetected during the ground inspection. These included the large railroad bridge near the Naval Station, a pedestrian structure near the Grand Casino in Gulfport, a collapsed bridge span on the US-90 approach to the east end of the St. Louis Bay bridge, and an inoperable moveable bridge. It also allowed us to see how several smaller structures that had been inspected from the ground fit into the overall landscape. Another bridge that would have been good to see but we did not was near Gulfport. When we approached it from the ground, access and view was blocked by a huge pile of pleasure and fishing boat wreckage.

When we flew over the bays, the pilot circled the bridges several times to allow adequate time for observation and photography. If viewed from above, our orbit was in a clockwise direction. This is noted to help determine the direction that a photo was taken from. As noted, there was not time to take notes or record position. For each of the bays, a video was taken along the entire length of the longest bridge. This gives an overall view of the damage that will help us determine macro trends such as which direction the spans moved. Since we didn't have access to inventory data and could not walk the bridge, it was also useful for counting the number of spans and estimating overall bridge length. It will also help piece together a puzzle of still photos. At Biloxi Bay, video was taken facing north. For St. Louis Bay, video of the entire length was taken looking south. For Lake Pontchartrain, the view was facing SE, perpendicular to the parallel I-10 structures, with the WB lanes closest to the plane.

At Biloxi Bay, we saw extensive damage to three bridges. On the north side, there is a newer concrete railroad bridge that was still standing. From our ground inspection, we knew that the tracks had been stripped from the bridge and this was verified from the air. We saw a bare concrete surface the entire length of the bridge. South of the railroad bridge was an old, narrow bridge that paralleled new US-90. Farthest to the south was the four lane US-90 bridge, which is 1.6 miles long. All spans of the E-W oriented bridge have been displaced from their original position, with most submerged. The bridge as a whole exhibited a repeated pattern that is reminiscent of earthquake damage, i.e. a saw tooth effect, created by concrete slab and girders laying at rest with one end of a slab in the water and the other leaning against the top of a pier. From the ground inspection, we knew that the bridge had been a series of simply supported prestressed (P/S) concrete girders with a cast in place concrete deck. The spans were not designed to be continuous and did not hold together in the storm. They were also not sufficiently restrained to the pier cap by anchor bolts. Spans that moved laterally went in a northerly direction. From the air, we saw nothing to contradict our observation from the ground that all the piers were generally intact and standing plumb.

The pilot then took us over Back Bay which was not far away to the west. We saw the newer I-110 bridge which runs in a N-S direction. This is operational but the number of lanes has been restricted because of an impact to the moveable span. From the top of the bridge, we saw slight damage to the railing on the east side. (Later we discovered that one of the piers had also been damaged by impact.)

Just to the east of I-110 is an old bridge with many collapsed spans. It is referred to here as old 110 over Back Bay. It apparently has been closed to vehicular traffic and used as a fishing pier. On the east side, many sections of the cantilevered concrete sidewalk had broken off and were dangling from the side of the bridge. Further to the north, complete spans were missing. A local resident said that he used to be able to walk all the way out to the navigation channel but now entire spans of the bridge, including substructure units, were gone.

From Biloxi, we flew west to St. Louis Bay and circled the bay in a clockwise orbit. Furthest to the south was the railway bridge. It had extensive damage. Piers were visible but no spans were in place. All had collapsed into the water.

Parallel to the north was Highway US-90 over St. Louis Bay. This long bridge also had extensive damage with most all spans in the water. We took video of the entire length, then took still photos of specific sections of the bridge.

We progressed west again and saw the moveable bridge that carries US-90 over the East Pearl River. This is the bridge that we were told malfunctioned during the storm. Bob is the captain of a shrimp boat who said that on August 28, he was trying to move his boat upstream to seek refuge from the hurricane. He said the bridge was stuck half closed for navigation so he could not pass the bridge. He also said that vehicular traffic was unable to use the bridge and that the route was still being promoted on the radio as an evacuation route out of New Orleans. He shared a harrowing story of how he rode out the storm in his boat and eventually came down on dry land several miles (approximately 5 miles) from where he started. He was very fortunate to have survived the ordeal.

Following US-90 westward, we came to a long bridge oriented N-S over the channel that connects Lake Pontchartrain on the west with Lake Borgne to the east (Rigolets Bridge). On the date of our ground inspection, state bridge maintenance crews were on site trying to clean it up and get the moveable span working again. Other spans were in good condition. The south end of the bridge had a severe undermining of the approach slab with a void large enough to walk into. The structural slab seemed to be bridging the gap without distress. Vegetation hanging from the bridge was evidence that high water had exceeded the elevation of the roadway.

Southwest of there was US-90 over Chef Menteur Pass. This bridge is an older bridge (1930's) that had been inspected from the ground a few days earlier. The moveable span was open for navigation as it had been left prior to the hurricane.

On the way back east we tracked I-10. We took photos of oil contaminated wetlands, fallen trees, the site where the barges and tug boat collided into the south side of I-10 EB north of Pascagoula, and patterns of salt-burned trees near the airport.

The pilot pointed out several moveable bridges near Diamond Head that were not working yet.

Video clips taken from the air are available from *http://mceer.buffalo.edu/research/Reconnaissance/Katrina8-28-05/videos.asp.*

2.2 Site Reports

Inspections were conducted from east to west across the Gulf Coast so the following reports appear generally from east to west, starting in Alabama. As the inspections progressed from Alabama across Mississippi and into Louisiana, it became obvious that damage was concentrated at the bay crossings. For this reason, the site reports are grouped together and presented according to the body of water that the bridge spans. Groupings include the vicinity of Mobile Bay, Pascagoula Bay, Biloxi Bay, Back Bay of Biloxi, St. Louis Bay, and Lake Pontchartrain. Moveable bridges and tunnels are discussed as special cases.

2.2.1 ALABAMA

Mobile Bay & Vicinity

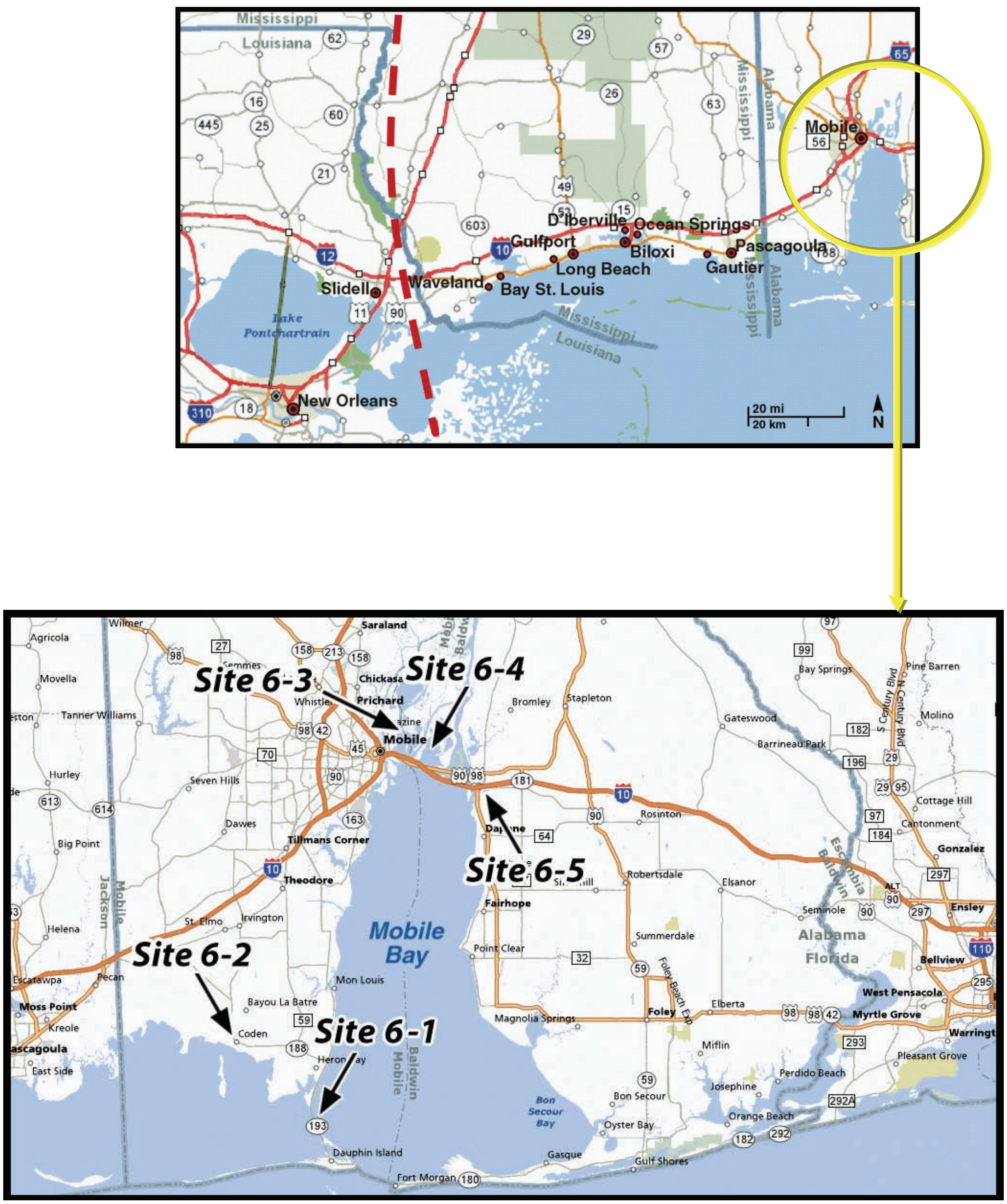


Figure 2-2. Sites in Alabama near Mobile Bay saw a surge of 10-12 feet.

SITE 6-1

Route 193 over Grants Pass
Dauphin Island, Alabama

GPS Coordinates: N 30° 18' 15.1", W 88° 08' 11.2"

About 40 miles south of the City of Mobile is Dauphin Island. It is joined to the mainland by a concrete multi-girder bridge built in 1982 identified as Route 193 over Grant's Pass. The bridge remains in excellent condition but was partially closed to traffic after the Hurricane due to a washout of the north approach. The bridge is in good structural condition but access to the island is restricted for security reasons (to prevent looting). The checkpoint guard said that there was always one lane of traffic open, though it was necessary to escort vehicles through the washed out areas. The approach and nearby roadway had already been repaired (Figure 2-4). Alabama Department of Transportation (ALDOT) said that this area repeatedly washes out though, recently repaired stretches where geotextile reinforcement were used are holding up well. The elevation is less than six feet above sea level.

The design of the superstructure to pier cap connection does not seem to account for much lateral loading from wave action. Steel clip angles securing the P/S beams to the pier cap seem to be common detail in the region (Figure 2-5). The fact that the bridge is protected by the island and oriented in a N-S direction seems to have helped it weather the storm.

Figure 2-3. The Route 193 bridge to Dauphin Island, facing south.

Figure 2-4. Approaches had been partially washed out.

Figure 2-5. Tie down detail between the P/S beams and pier cap.

SITE 6-2

J. A. Wintzell Memorial Bridge
Route 188 over Little River
Bayou La Batre, Alabama

GPS Coordinates: N 30° 24' 18.4", W 88° 14' 51.6"

The J. A. Wintzell Memorial Bridge is a vertical lift bridge. According to an ALDOT maintenance person on site, water came several feet above the roadway, into the office and was half way up the adjacent fence. This flooding caused the bridge to be inoperable. It was open for motor vehicle traffic.

A large boat had been moored nearby and hit the bridge tender's office when it was tossed about in the storm. It apparently caused no major damage, just scrapes along the side of the building.

Figure 2-6. The boat on the right hit this lift bridge. The control room was also flooded.

SITE 6-3

Conchrane-Africatown USA Bridge
US-90 over Mobile River
Mobile, Alabama

GPS Coordinates: N 30° 44' 02.3", W 88° 02' 52.3"

The Conchrane-Africatown USA Bridge is a newer cable-stayed structure that crosses the Mobile River at the north end of Mobile Bay. It was built in 1991 to carry four lanes of traffic. It is 7,291 feet long and 80 feet wide and normally has 140′ of clearance underneath. As a result of Katrina, a 13,000-ton oil drilling platform (PSS Chemul) broke loose from dry-dock and was carried 1.5 miles north until it hit the center span and became lodged under it (see Figure 2-7 provided by the Federal Highway Administration). ALDOT immediately restricted traffic so damage could be assessed. In order to reduce live loading, a weight restriction was imposed and the number of traffic lanes on the bridge was reduced to one in each direction. Although not visible at the time of inspection, it was later reported that the bridge superstructure was pushed four inches into the bridge pier. Figure 2-9 shows the platform a week later, secured about a half mile south of the bridge.

Photo courtesy of the Federal Highway Administration

Figure 2-7. An oil platform lodged up against the Conchrane-Africatown USA Bridge.

Figure 2-8. Conchrane-Africatown USA Bridge

Figure 2-9. 13,000 Ton oil platform PSS Chemul

Figure 2-10. From the topside, damage to the railing and concrete barrier can be seen. A cable is wrapped to prevent moisture ingress, suggesting that it also was struck by the part of the oil platform. Note the silver damping devices on the other cables. These are commonly used on this type of structure to control wind vibration.

Figure 2-11. Lane and weight restrictions were necessary after the impact.

SITE 6-4

Route 90 over Polecat Bay
Mobile, Alabama

GPS Coordinates: N 30° 41' 05.7", W 88° 00' 38.3"

US-90 is a heavily traveled four lane road running E-W just south of Mobile. There was debris caught in the superstructure of the bridge (e.g., 12 inch log) but no damage was evident. There had been severe erosion at the west spill-through abutment but ALDOT had already made repairs. Failure to address this situation quickly could result in settlement of the approach pavement that would have presented a hazard to traffic and a repair that would have necessitated disruption to traffic.

Figure 2-12. Erosion at the west abutment.

Figure 2-13. Concrete was used to fill erosion at the NW wingwall.

SITE 6-5

US-90 to I-10EB Ramp Bridge over Mobile Bay, Baldwin County, Alabama

GPS Coordinates: N 30° 40' 40.2", W 87° 59' 20.0"

Although Mobile is almost a hundred miles from the path of Katrina's eye, the storm was so powerful that it caused the tide to surge 11-12 feet in Mobile Bay. This had a devastating impact on the low lying structure where US-90 joins I-10 EB, just east of Mobile. The structure, identified as 011926, was built as a series of simply supported prestressed (P/S) concrete spans and is very close to the water near the approach. Tie-down clips either broke or ripped out of the concrete pier cap and five spans were displaced laterally to the north as much as six feet. Figures 2-14 and 2-15 (provided by ALDOT) show the ramp bridge under water, the afternoon of August 29.

Figure 2-14. Several spans washed out the day of the storm. This photo faces east.

Figure 2-15. The ramp bridge is inundated. The picture was taken facing south.

Figure 2-16. Facing east toward spans that were pushed to the north.

Figure 2-17. Looking east at the displaced spans.

Figure 2-18. Tie down clips ripped out of the concrete pier cap.

2.2.2 MISSISSIPPI

- **Pascagoula Bay**
- **Biloxi Bay**
- **Back Bay of Biloxi**
- **St. Louis Bay**

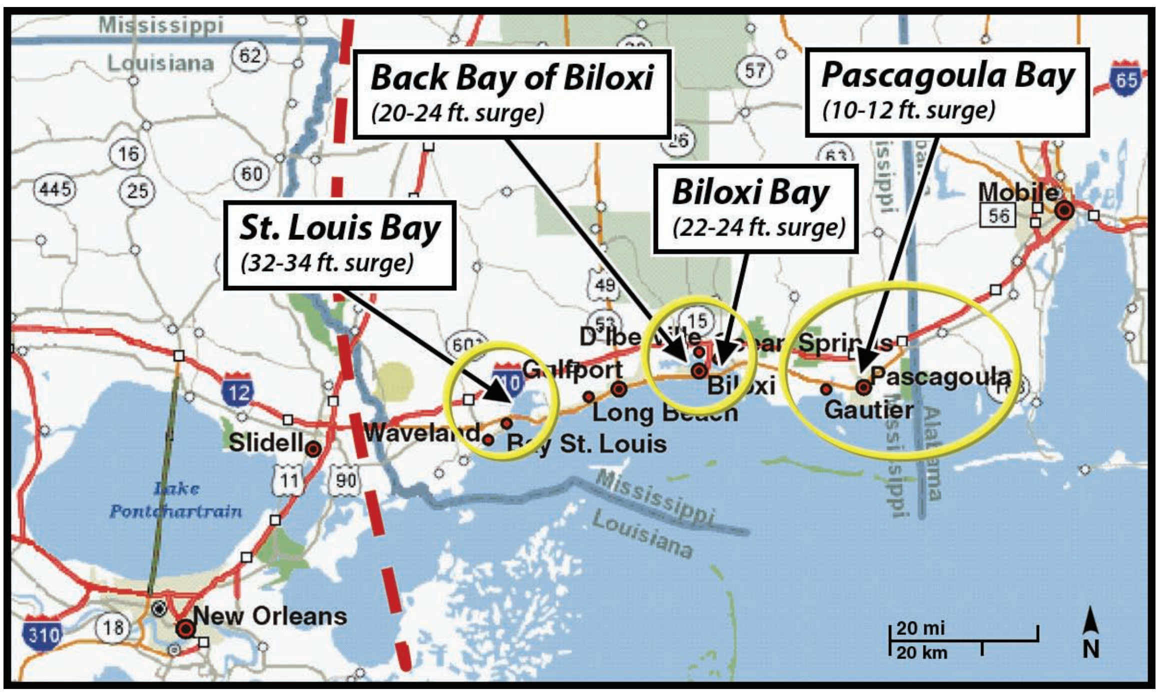
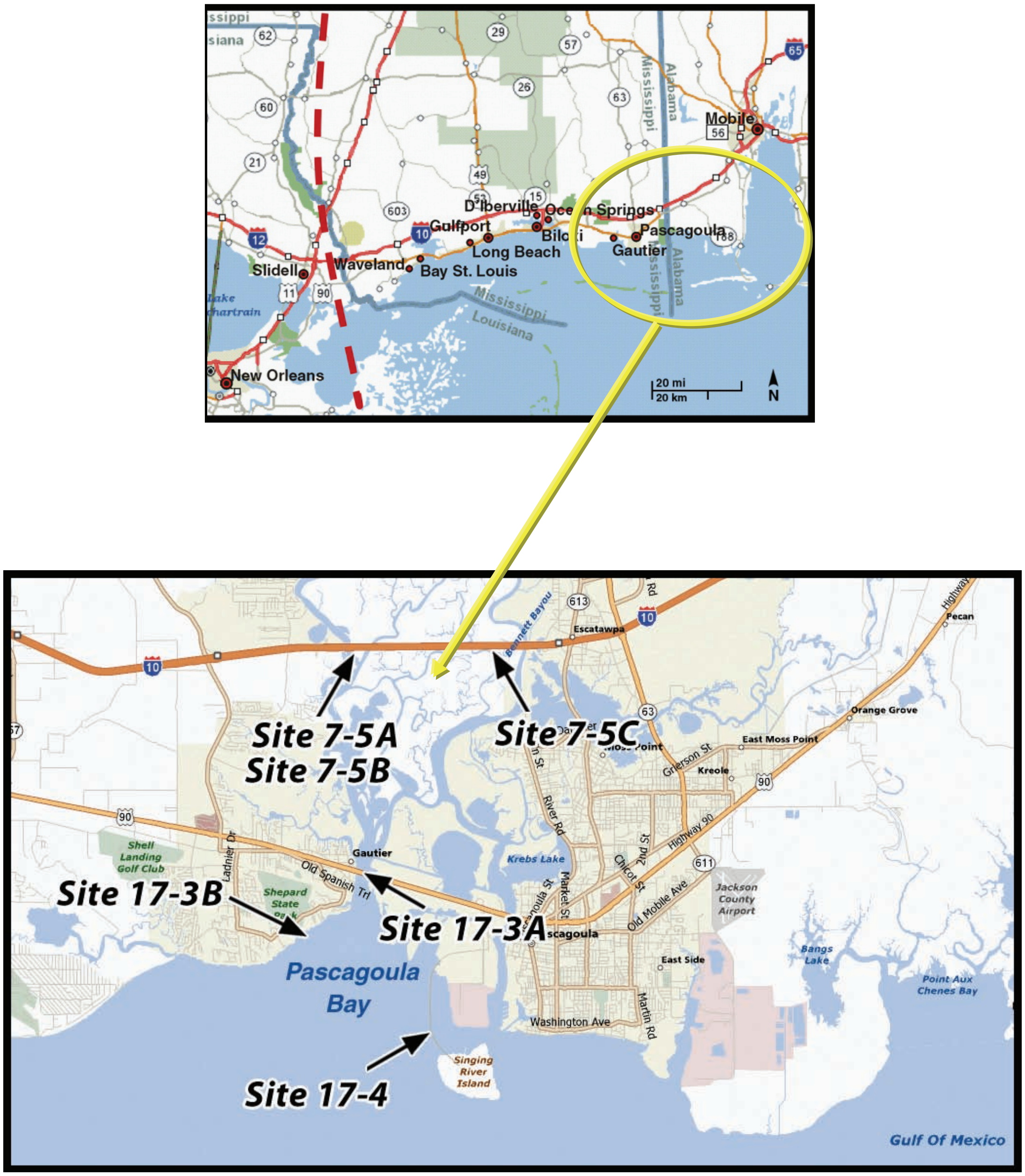


Figure 2-19. Bay areas in Mississippi that suffered from record surge levels.

Pascagoula Bay, Mississippi



Mapquest 2008

Figure 2-20. Sites in Mississippi near Pascagoula Bay

SITE 17-3A

US-90 over West Pascagoula River
Jackson County, Mississippi

GPS Coordinates: N 30° 22' 57.6", W 88° 36' 29.7"

The bridge carrying US-90 over the west branch of the Pascagoula River is a multiple span bridge built with simply supported P/S concrete beams. Although the CSX railroad bridge just to the south was destroyed when its superstructure was washed off the piers, this bridge survived well. It may have benefited from a deck made continuous for live load. This would serve to join spans together for more mass to resist lateral loads.

Figure 2-21. P/S concrete beams on concrete piers.

SITE 17-3B

CSX Railroad Bridge over West Pascagoula River Jackson County, Mississippi

GPS Coordinates: N 30° 22' 57.6", W 88° 36' 29.7"

Fifteen steel girders spans of the CSX railroad bridge were taken off the piers by surge. The bridge seat is less than 10′ above the water.

Figure 2-22. CSX railroad bridge lost the tracks and superstructure. US-90 is in the background.

SITE 17-4

US Naval Station Bridge over Pascagoula Bay
Jackson County, Mississippi

GPS Coordinates: N 30° 20' 13.5", W 88° 34' 48.0"

The 3.2 mile long bridge near the Pascagoula Naval Station performed well, despite its precast construction. The deck is 17 feet above mean sea level. This is probably due to better detailing at the joints and a deck that tied then spans together.

Figure 2-23. This bridge, connecting the Pascagoula Naval Station to the mainland performed well.

Figure 2-24. Typical connection between spans and pier configuration over a pier.

SITE 7-5A

I-10 EB over Pascagoula River at Moss Point, Jackson County, Mississippi

GPS Coordinates: N 30° 26' 15.9", W 88° 35' 54.2"

Although the I-10 bridges near Moss Point are several miles inland, they are relatively low and long over a large salt bayou. The high water caused by Katrina swept several boats and barges north until they crashed into the eastbound bridge. Six spans were pushed out of place by a barge with a crane mounted on it. The barge displaced the bridge superstructure about four feet to the north and tipped piers, causing a vertical drop of four to six inches at the deck joint.

Figure 2-25. I-10 traverses a large salt bayou near Moss Point. It was hit and damaged by a stray barge.

Impacts to bridges caused substantial damage and interruption of service. The damage at the Moss Point site necessitated closure of the EB bridge and a 50% loss of capacity. EB traffic was diverted onto the WB bridge and contraflow was maintained (one lane of traffic in each direction) until repairs could be completed. Important relief traffic was delayed for over one hour each direction due to the subsequent congestion. MSDOT used an emergency repair contract with financial incentives ($100,000 per day) to rebuild the bridge by October 1, 2005. It was completed in 20 days at a cost of $5.2 million.

Figure 2-26 The concrete deck was being removed from the I-10 EB bridge on September 11, 2005.

Figure 2-27. A vessel impact displaced six spans of I-10 EB.

Figure 2-28. I-10 EB was hit by this barge and pushed four feet to the north.

SITE 7-5B

US-10 EB over Pascagoula Bay
Jackson County, Mississippi

GPS Coordinates: N 30° 26' 16.3", W 88° 34' 42.7"

Figure 2-29. I-10 EB suffered multiple hits.

SITE 7-5C

I-10 EB over Pascagoula Bay
Jackson County, Mississippi

GPS Coordinates: N 30 26′ 15.6″ W 88 36′ 59.0″

Figure 2-30. Large debris was lodged under the WB lanes of I-10 (a boat, tank, and a log).

Biloxi Bay, Mississippi

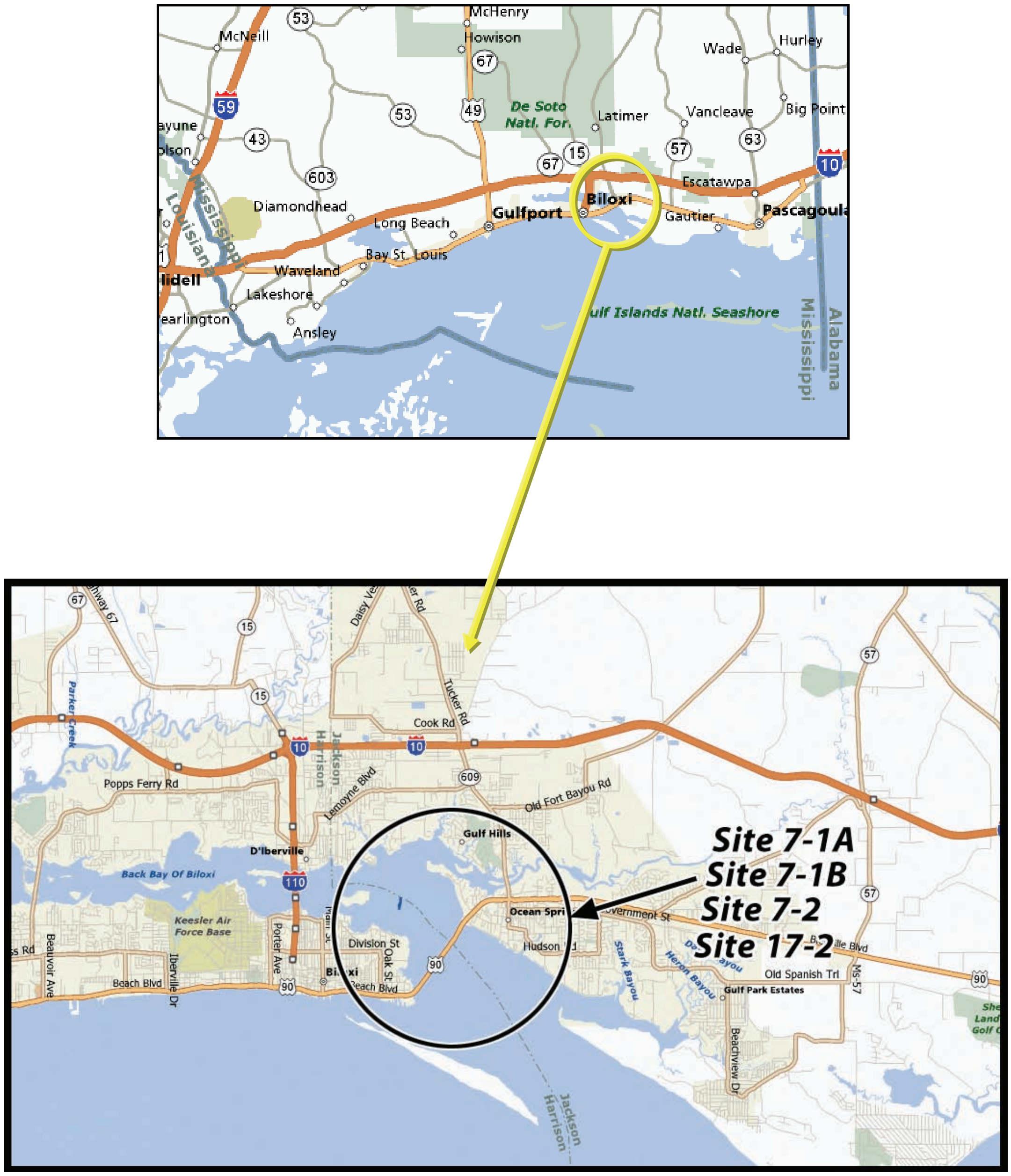


Figure 2-31. The Biloxi Bay bridges join Biloxi on the west and Ocean Springs on the east.

Figure 2-32. This pre-Katrina photograph (taken 8/28/05) shows the three bay crossings from Biloxi facing east toward Ocean Springs.
Accessed 11/14/08 from http://biloxi.ms.us/photogallery

Figure 2-33. This Post-Katrina photograph (taken 9/11/05) shows the three bay crossings from Biloxi facing east toward Ocean Springs. Many spans are missing.

Biloxi Bay separates the City of Biloxi on the west and Ocean Springs to the east. Three long bridges traverse the bay. From south to north, they are:

- Site 7-1A: US-90, 1.6 miles long
- Site 7-1B: An older highway bridge (referred to in this report as old route 90), that has been used recently for a pedestrian bridge and fishing wharf
- Site 7-2: CSX railroad bridge
- Site 17-2: Shearwater Bridge

Figures 2-32 and 2-33 show a before and after picture, respectively, of the three bridges from the west shore of the bay. Note that only the US-90 spans at the highest elevation survived the 22-foot surge. Other spans were destroyed by the wave action or thrown into the water. The old highway bridge met the same fate. An aerial view in Figure 2-34 shows the east side of Biloxi Bay, facing SE. In the foreground is the CSX railroad bridge, the middle bridge is the old highway crossing, most recently used as a fishing pier, and farthest south is US-90. Figure 2-35(a) also shows the east side of Biloxi Bay, but faces north. In the foreground are the ruins of the US-90 bridge, in the middle is the old highway crossing, and on the far side is the CSX railroad bridge.

Figure 2-34. Biloxi Bay, facing SE.

(a) Eastern shore of Biloxi Bay, looking North.

(b) Biloxi Bay, facing south toward the City of Biloxi. From top to bottom, the bridges are US-90, old route 90, and the CSX railroad.

Figure 2-35. Biloxi Bay

There was evidence of surge levels of 22-24 feet in this area. Most of US-90 and old route 90 were destroyed when the entire superstructures washed off the piers or were broken up. The CSX railroad bridge withstood the storm with minor structural damage, although it tracks were washed off the bridge.

Figure 2-35(b) provides a good perspective facing south toward the City of Biloxi. From top to bottom, the bridges are US-90, old route 90, and the CSX railroad bridge. Despite the loss of tracks, the CSX bridge was considered a success. All spans survived with relatively little displacement. The concrete deck is seen in the picture.

Figure 2-36 is a photograph taken at deck level facing north. In the foreground is an inclined span of the US-90 bridge. Just behind it are the remains of the old highway bridge. In the background is the CSX railroad bridge, structurally intact except for the swing span, which was impaired when it was flooded. As can be seen in the accompanying photos, the railroad tracks were swept off the concrete deck.

Figure 2-36. Although both were subjected to essentially the same conditions, there was a remarkable difference in performance between the US-90 (foreground) and CSX bridges (background).

SITE 7-1A

US-90 over Biloxi Bay
Harrison County, Mississippi

GPS Coordinates:
East end: N 30° 24' 39.0", W 88° 50' 27.4"
West end: N 30° 23' 34.9", W 88° 51' 28.9"

The US-90 bridge was built in 1961 to carry four lanes of traffic. It is a 1.6-mile long bridge constructed with a series of 42-foot long simply supported concrete spans, with a 7-inch cast in place (CIP) compositely acting concrete deck. The girders were 36-inch deep prestressed (P/S) girders, spaced at 6 feet. The deck to beam shear connection is provided by #5 bars spaced every at 12 inches. The bridge measured 66 feet wide curb-to-curb, with a longitudinal joint at the centerline. Each half section carries a six-foot shoulder on the right, two 12-foot lanes, and a 3-foot shoulder on the left. In the center, over the navigation channel, there is a lift span. Piers are 20-inch square concrete piles, spaced at 7 feet, with a 3-foot wide x 4-foot high concrete cap (see Figure 2-36).

The west end of US-90, near the west abutment was severely battered. The authors interviewed a policeman and viewed a video that recorded turbulent wave action on the bridge. Video was taken until about 4:00 am August 29, 2005 before they left to find cover; the worst of the storm hit about 7:30 am. Upon their return, the bridge was in the condition shown in Figures 2-39 and 2-40. Large debris such as vehicles and shipping containers accentuated the problems (Figure 2-40).

Many P/S girders were wrecked before they were tossed off the piers. The remains of spans looked like they were hit repeatedly by waves during the storm. Some appear to have broken up when buoyant uplift forces relieved the dead weight, allowing the prestressing forces to crack the beam (Figure 2-43). The twisting of beams also contributed to destruction of the seven inch concrete deck (Figures 2-44 to 2-47).

The bearings for the US-90 bridge were simple steel bearing plates as shown in Figures 2-48 and 2-49. The weight of the superstructure and friction provided the resistance to forces that the bridge was designed to withstand. There was no positive connection to attempt to prevent uplift and only small steel angles to resist horizontal forces. When the bridge was hit with wave forces from the surging tide, the beams pushed to north. Figure 2-48 shows the plate under the end of the beam at the east abutment and Figure 2-49 shows where it was before the storm. Note the small steel angle on the left side that was bent over when the beam slid to the left.

Figure 2-37. US-90 (and old route 90 on the right) at the east abutment, looking NW.

Figure 2-38. US-90 over Biloxi Bay at the west abutment, facing east.

Figure 2-39. A close-up view of the west end of US-90.

Figure 2-40. Floating debris such as vehicles and shipping containers also caused damage to bridges. This photo was taken at the west end of the US-90 bridge.

Figure 2-41. The center spans survived because they were at an elevation above that of the surge level.

Figure 2-42. Looking toward the City of Biloxi from the east abutment.

Figure 2-43. Uplift forces probably helped destroy this beam.

Figure 2-44. The beam, deck and diaphragm failed under surge loading.

Figure 2-45. A view of the deck underside.

It is estimated that the surge in this area was over 22 feet. It caused complete devastation of the US-90 highway bridge and the pedestrian bridge. The fact that the spans were simply supported (i.e. not continuous) was probably the most significant contributor to collapse of the bridges. Almost all spans were thrown from the piers to the north into the water. Higher spans near the navigation channel did not see the same destruction.

Figure 2-46. The 7 inch CIP composite deck has been peeled away from the P/S concrete beam and has broken transversely, exposing its steel reinforcement. This photo was taken at the east end of the US-90 bridge.

Figure 2-47. Steel reinforcing bars is all that remains of the concrete deck above the concrete girder. This photo was taken at the west end of the US-90 bridge.

Figure 2-48. Note the bearing plate under the end of the P/S concrete beam. This beam slide to the north (left), bending down the retainer angle and anchor bolt seen in Figure 2-49.

Figure 2-49. This bearing plate on the east abutment of US-90 over Biloxi Bay is typical of all bearings

SITE 7-1B

Old Route 90 over Biloxi Bay
Harrison County, Mississippi

GPS Coordinates: East End: N 30° 24' 39.5", W 88° 50' 28.6"

Generally parallel to the US-90 bridge, and just to the north, is an older highway bridge, referred to here as old route 90 (see Figures 2-35(a) and 2-37). When the US-90 bridge was constructed in 1961, the old bridge was relegated to pedestrians and fishing enthusiasts. The roadway was 20 feet curb-to-curb with a 16-inch curb on the north fascia and a 4'8" sidewalk on the south side, for a total out-to-out width of 26 feet. The span of each simply supported concrete tee-beam was 36 feet. The east approach is almost contiguous with the US-90 bridge but the alignment of the two bridges diverges as one stands at the east end and looks in a westerly direction. The piers are concrete and remained standing after the storm.

Figure 2-50. Looking west from the east abutment. US-90 is on the left.

Figure 2-51. Looking east from the west end of old route 90.

Figure 2-52. Facing south at old route 90 with the higher spans of US-90 near the navigation channel behind it.

SITE 7-2

CSX Railroad over Biloxi Bay
Harrison County, Mississippi

GPS Coordinates:
East end: N 30° 24' 44.9", W 88° 50' 31.2"
West end: N 30° 24' 16.4", W 88° 51' 37.3"

North of the highway bridges is a CSX railroad bridge (see Figures 2-32 to 2-35). The CSX bridge was overtopped by the storm and all of the tracks were swept off and dropped on the north side but the structure itself endured the surge with relatively minor structural damage. Mechanisms of the truss swing span needed repair.

Figure 2-53. CSX railroad bridge, looking east from the west abutment.

The bridge is constructed of prestressed concrete girders and a concrete deck. The girders are 54 inch deep I- sections, with a length of 60 feet. The bridge was designed to carry one set of tracks on a concrete deck that is 16 feet wide. The piers are 2 foot x 2 foot driven prestressed concrete piles with a concrete cap beam. Mean sea level is approximately 16 feet below deck elevation (field measured 10/17/06).

Even with the loss of the rail and wood ties, the CSX bridge can be considered a success because the damage was repairable. Apparently, the tracks are routinely placed without positive attachment to the bridge so the two can act independently. This practice proved fortuitous since the tracks being ripped off the structure by the surge did not cause any damage to the structure. Repair consisted primarily of replacing the track.

According to repair crews, 15 spans were knocked out of alignment. At the Ocean Springs end, the maximum displacement was 6 inches; at the Biloxi end, it was as much as 15 inches. The concrete shear blocks on the north side of the cap beams at these locations needed to be rebuilt. This work was almost entirely accomplished by the time the author made a second inspection in October (seven weeks after the storm).

Several design details contributed to the survival of the bridge. These include:

- Concrete shear blocks restricted lateral movement on each pier and at the abutments (Figures 2-58, 2-60 and 2-61).
- Since the shear blocks were tight against the beams (Figure 2-60), any uplift component of force would be met by frictional resistance from the vertical face of the block.
- The P/S beams were tightly spaced to accommodate live loads. This minimized the amount of air that could be trapped and contribute to buoyancy (Figure 2-59).
- Transverse tie rods bound the precast beams together and forced them to act as a unit (see Figures 2-53 to 2-55). The mass of the assembly made it more resistant to uplift than individual beams would have been.
- Concrete diaphragms kept the structural system geometrically stable. Having the beams fixed relative to one another also provided a direct load path for lateral forces from the south side to the north. Wave forces applied to the south face could be transmitted efficiently to the shear blocks on the north side. The diaphragms can be seen between the beams in Figure 2-59.
- Steel shear keys in the deck joints locked the sections together and prevented rotation in a horizontal plane (see Figures 2-62 and 2-63).

Figure 2-54. Pier and superstructure configuration of the CSX railroad bridge.

Figure 2-55. The tracks near the east end are upside down on the north side.

Figure 2-56. Tracks were completely stripped from the deck but the bridge survived.

Figure 2-57. Modular sections of track were used to restore the line to service.

Figure 2-58. Lateral restraint blocks at the west abutment.
Note the scars from debris.

Figure 2-59. Tightly spaced prestressed beams with concrete diaphragms.

Figure 2-60. Massive shear blocks on each side of the superstructure successfully restricted horizontal forces imposed by wind and waves.

Figure 2-61. A simple concept, like permanently inscribing the pier number in the concrete, makes for positive identification and clear communication. This undoubtedly served the owner well when during repair operations as well as being useful during reconnaissance surveys.

Figure 2-62. This steel plate prevents debris from falling through the joints between spans but also tightens up the superstructure assembly to restrict movement.

Figure 2-63. Though not anchored into the concrete, the tight-fitting steel joint plate probably acted as a shear key to resist relative horizontal displacement and restrain rotation between spans.

SITE 17-2

Shearwater Bridge
Biloxi Bay Inlet
Harrison County, Mississippi

GPS Coordinates: N 30° 24' 20.3", W 88° 49' 16.4"

The Shearwater Bridge in Ocean Springs, MS was built in 2003. It is very close to Biloxi Bay and had evidence of being overtopped. Inspectors discovered the broken railing visible in Figure 2-64 and saw that washouts at the approaches had been repaired (Figure 2-65) but there was no apparent damage to the superstructure. Shear blocks (Figure 2-66) helped secure the superstructure from lateral movement, preventing significant damage.

Figure 2-64. The Shearwater bridge is very close to Biloxi Bay and was submerged under water.

Figure 2-65. Approach erosion was easily repaired.

Figure 2-66. The shear block at the end of the pier cap restrained the precast superstructure units.

SITE 17-1

Fort Bayou Bridge in Ocean Springs, Jackson County, Mississippi

GPS Coordinates: N 30° 25' 24.3", W 88° 49' 44.7"

The Fort Bayou Bridge in Ocean Springs, Jackson County was built in 1985. It carries Highway 609 with a north-south orientation and typically has a clearance of 25 feet. The reported surge height at this location was 21 feet. The operators house suffered wind damage, (e.g., broken windows), but the mechanical room was flooded. It submerged generators and motors and electrical switch boxes.

Figure 2-67. The mechanical room of this moveable bridge flooded, making the bridge inoperable.

Back Bay of Biloxi, Mississippi

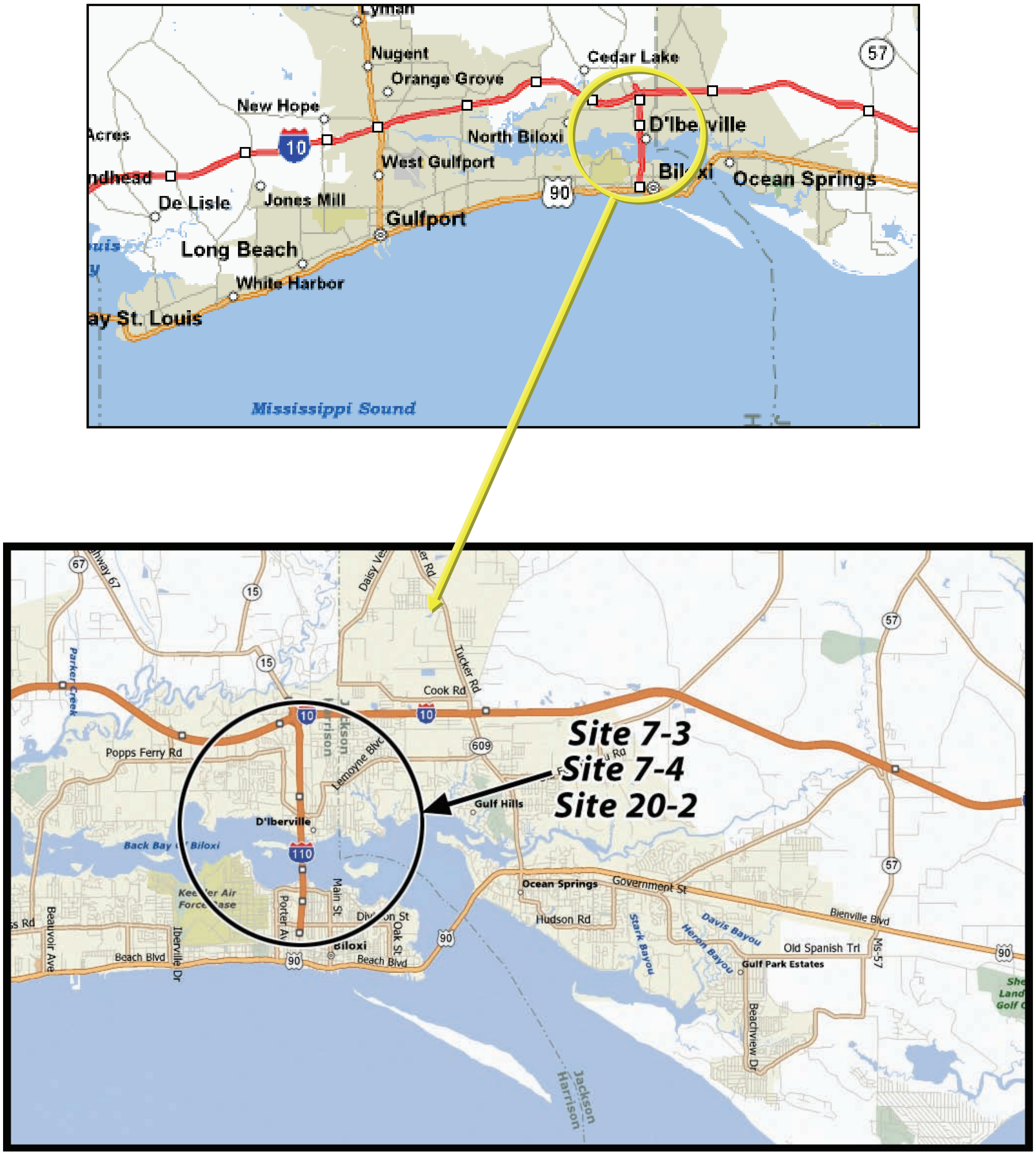


Figure 2-68. Back Bay of Biloxi

Biloxi's Back Bay is north of the city, running generally east-west. On the north side of the bay is the village of D'Iberville. Bridges investigated over Back Bay include:

- Site 7-3: referred to by the author's as old 110
- Site 7-4: I-110 over Back Bay of Biloxi
- Site 20-2: Popps Ferry

The original N-S crossing has been relegated to pedestrian traffic and is used as a fishing wharf. It runs north-south. It is concrete tee-beam construction with a curb-to-curb width of 30'. The old bridge lost several spans, most likely from scour, since the piers are also missing. According to a resident, an entire section of the bridge, including the substructure, disappeared into the water. He had been able to walk from the south end of the bridge to the navigation channel but now could not. Sections of railing broke off many spans that remained standing (see Figures 2-69 and 2-70). Figure 2-71 shows the topside of the bridge, facing north. Figure 2-72 is an elevation view looking NE.

Figure 2-69. This photograph was taken facing NW. A hotel and floating casino are shown in the foreground. Near it is the bridge referred to as old route 110, with several sections missing. I-110 at the top of the picture was hit by a barge and debris but remained functional.

Figure 2-70. Facing south over Back Bay toward Biloxi and the Gulf.

SITE 7-3

Old 110 over Back Bay of Biloxi
Biloxi, Mississippi

GPS Coordinates: N 30° 24' 49.4", W 88° 53' 32.1"

Figure 2-71. Looking north onto old 110 over Back Bay. Note the missing sidewalk and railing on the east side.

Figure 2-72. Elevation view looking NE at the old 110 over Back Bay which had been used for a fishing pier. Note the dangling concrete railing on the far (east) side.

SITE 7-4

I-110 over Back Bay of Biloxi
Biloxi, Mississippi

GPS Coordinates: N 30° 25' 19.9", W 88° 53' 39.5"

Figure 2-73. Repairs were made within a few weeks, allowing the bridge to be returned to full service.

The primary route heading north out of Biloxi is I-110. It is a high-rise interstate bridge with a lift span over the navigation channel that normally provides 60 feet of clearance. It is designed to current highway standards and carries four lanes of traffic.

When the bridge was inspected on September 7, northbound traffic was restricted to one lane. Piers on the east side were hit by a barge or other items carried by the surge. When the site was visited a second time on October 17, MSDOT had already shored up the damaged area by driving additional piles adjacent to the damaged ones (Figure 2-73) and had reopened all lanes. The railing and sidewalk on the east side were also damaged from debris (Figure 2-74).

Figure 2-74. The metal railing on the east fascia of the span that carries I-110 over the navigation channel of Back Bay of Biloxi was damaged by boats or debris carried by the surge.

SITE 20-2

Popps Ferry over Back Bay of Biloxi, Harrison County, Mississippi

GPS Coordinates: N 30° 24' 49.4", W 88° 53' 32.1"

Figure 2-75. Numerous prefabricated spans were shifted to the west. None tipped over into the water. Note the black joint strip seal on top of the deck.

About a mile west of I-110 is another long bridge (approximately 3,500 feet) crossing Back Bay. The bridge carries Popps Ferry Road. It is constructed of prestressed concrete spans simply supported on concrete piers that have driven prestressed concrete piling. The spans are 50 feet long and 35 feet wide. The prestressed girders are 42 inches deep with a 11.5-inch deck that includes 2.25 inches of overlay. The parapet is a Jersey type concrete barrier. There is a double bascule lift span over the navigation channel, visible in Figure 2-76.

Mean sea level is 15 feet below the elevation of the deck (field measured on Oct 20, 2005). Surge in this area exceeded 20 feet, putting the bridge under water. In addition to the bascule span becoming inoperable, the P/S concrete spans were pushed laterally (west) off their bearings by a blockage of surge borne debris. Though the spans did not drop, the bridge became unusable (see Figures 2-75 and 2-77). The moveable span remained stuck in the open for several months, until it could be repaired (Figure 2-76).

It is interesting to see the damage caused to the east fascia (Figures 2-79 and 2-80). The concrete barrier was destroyed by debris engulfed in the surge as well as the wave action. On the outside of the fascia, one can see the remains of the metal railing and utility poles stuck in the structure (Figure 2-80). The outside face of the concrete battered concrete barrier is also visible in this picture. Figure 2-78 shows a section of barrier that survived but that evidently had extreme pressure behind it. Concrete at its toe seems to have failed in compression and spalled.

Inspectors were at first puzzled by the rubber joint seal that popped out of several joints (Figure 2-81). However, this could be explained by the buildup of pressure underneath the slab. Entrapped air under a head of several feet of surge water was apparently enough to force the seal out.

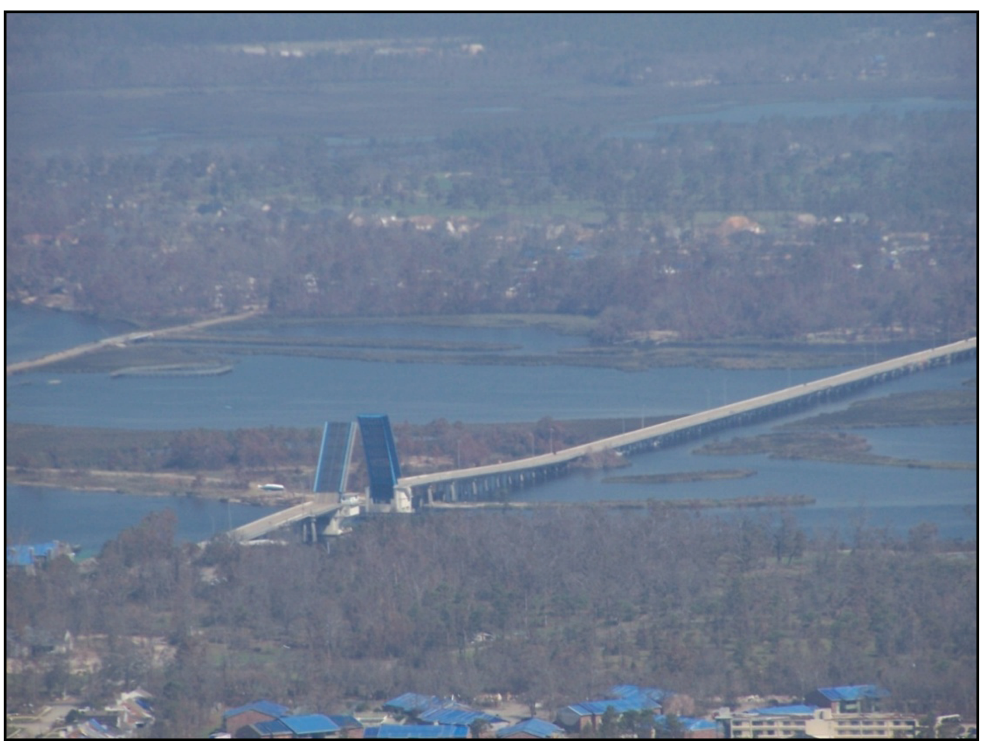


Figure 2-76. Popps Ferry over Back Bay, upstream of I-110.
The photograph was taken facing NW.

Figure 2-77. Spans shifted horizontally on the pier caps as much as three feet. This photo was taken looking south at the west fascia.

Figure 2-78. Hydraulic pressure on the backside of this barrier probably caused the spalling found at its toe. This photo is along the east fascia of the bridge.

Figure 2-79. A debris dam pounding on the east fascia probably caused this damage to the concrete parapet.

Figure 2-80. The east fascia was destroyed by debris engulfed in the surge.

Figure 2-81. Several bridge joints had the seal blown out, indicating the possibility of pressure from entrapped air below the deck.

Figure 2-82. A look down at the top of a pier cap shows that the span on the left moved to the west by as much as four feet.

SITE 20-1

Southern Terminus of I-110
Biloxi, Harrison County, Mississippi

GPS Coordinates: N 30° 25' 08.4", W 88° 49' 42.9"

Figure 2-83. Southern terminus of I-110, with the Gulf in the background.

Note the proximity of these ramp bridges to the Gulf of Mexico in the background. This southern terminus of I-110 in Biloxi was built in 1975. It was subjected to extreme surge but survived intact due to the fact that it was cast-in-place construction, rather than precast. Its mass, integral construction and continuity were characteristics that played a role in its survival, despite the perilous location.

Site 18-1

Pedestrian Bridge,
Harrison County, Mississippi

GPS Coordinates: N 30° 23' 04.7", W 88° 00' 59.5"

This pedestrian bridge crossed over US-90 near Gulfport, MS. It was assembled from precast concrete components but the connections were not sufficient to utilize the full strength of the components in resisting the wave forces that accompanied the surge. Eight of the eleven spans collapsed.

Figure 2-84. This pedestrian bridge utilized precast construction shown in the inset.

SITE 10-8B

I-10 EB over Local Road

GPS Coordinates: none obtained.

This bridge carries I-10 over a service road just north of Bay St. Louis. Even though it is several miles from the Gulf, its embankment was damaged by scour.

Figure 2-85. Scour is usually associated with water crossings, but this bridge over a road saw scour.

St. Louis Bay, Mississippi

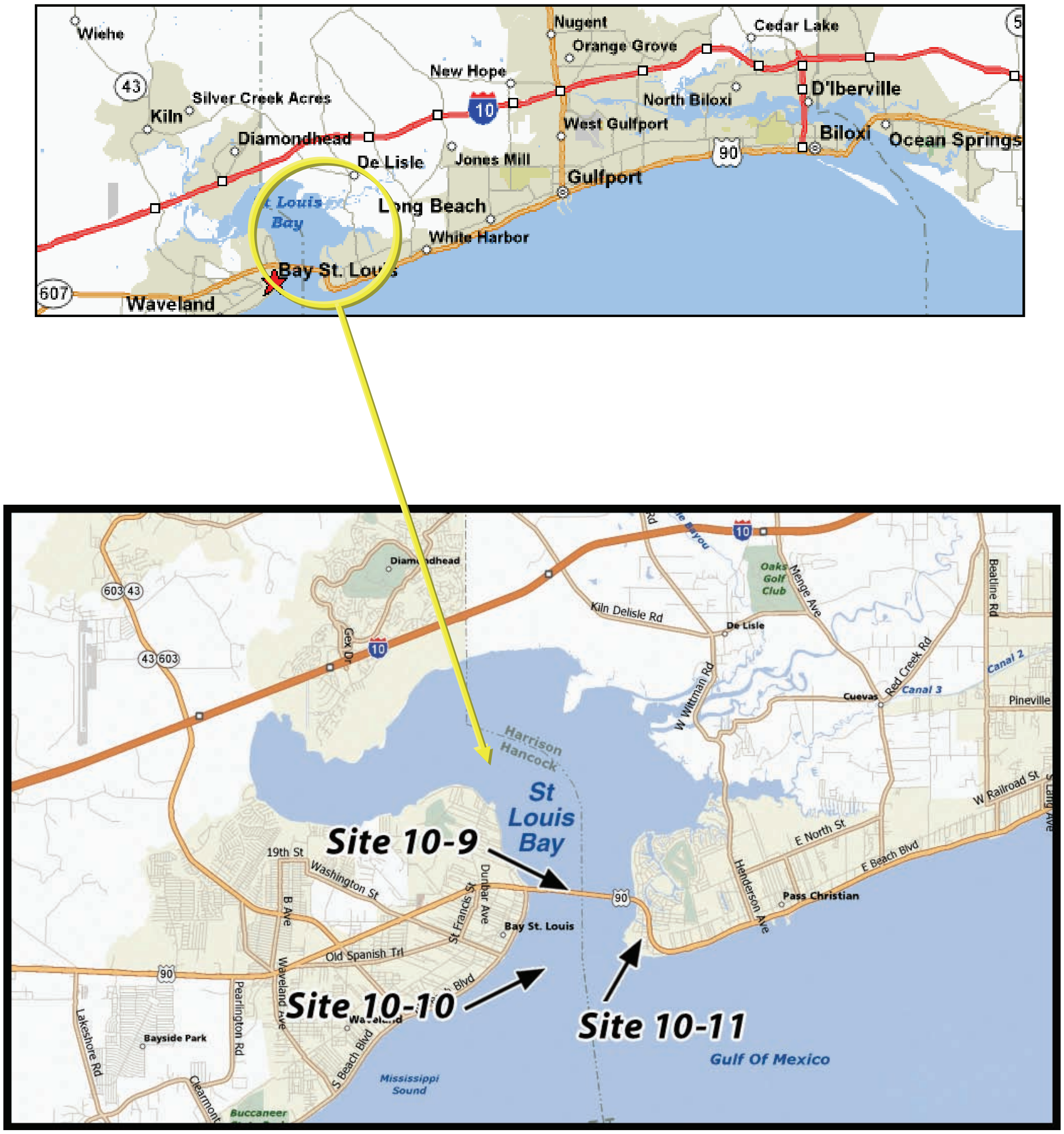


Figure 2-86. Surge at St. Louis Bay exceeded 30 feet.

Figure 2-87. US-90 over St. Louis Bay, facing SE.
The CSX railroad bridge is on the right.

SITE 10-9

US-90 over St. Louis Bay
Hancock-Harrison Counties, Mississippi

GPS Coordinates: West end: N 30° 19' 09.6", W 89° 19' 21.2"

US-90 was constructed in 1953 as a 1.9-mile long series of simply supported P/S spans. The span units are tee-girders with a composite concrete deck.

Bay St. Louis is very close to where the eye of Hurricane Katrina hit land, and the site of the greatest surge. Surge height depth exceeded 30 feet in St. Louis Bay, much greater than had ever been experienced at this location. The photograph in Figure 2-87, taken facing SE toward Pass Christian, shows the remains of US-90 over St. Louis Bay. All spans were tossed from their supports except the moveable span over the navigation channel. Several piers in the middle of the bay were scoured out completely. Figure 2-88 shows the destruction to the west abutment and approach, even though there was a break wall built to protect it.

Figure 2-88. Western terminus of US-90 over St. Louis Bay, facing east.

Figure 2-89. Many US-90 piers scoured out. The photo was taken facing SW.

Figure 2-90. All superstructure spans were stripped from the piers.

Figure 2-91. Eastern terminus of US-90 over St. Louis Bay, facing north. Lack of structural continuity contributed to the collapse of many spans in a failure pattern that is almost identical to that witnessed after earthquakes.

Figure 2-92. West abutment, looking SE, with an overturned span in the foreground.

Figure 2-93. Facing east. Piers standing after their superstructure spans were washed off.

Figure 2-94. Extreme scour at the west abutment and undermining of the approach.

The photograph in Figure 2-95 shows the right half (south side) of the westernmost span. It was tossed off the pier and rotated 90 degrees so the railing visible in the photo is pointing north. Note the yellow centerline stripe. Aside from being in the wrong place, the unit appeared to be structurally intact. Figure 2-96 shows the left half (north side) of the westernmost span. It flipped over and was thrown to the north of the bridge a distance of 100 feet. Note the bearing plates attached to the bottom of the prefabricated unit and the concrete diaphragms that would have been at the abutment.

Figure 2-95. This precast span unit was tossed off the pier and rotated 90 degrees.

Figure 2-96. The north side of the westernmost span was flipped over and thrown 100 feet.

Figure 2-97. This photograph was taken facing NE at the east end of the US-90 bridge.

SITE 10-10

CSX Railroad over St. Louis Bay
Hancock-Harrison Counties, Mississippi

GPS Coordinates: West end: N 30° 18' 35.3", W 89° 19' 34.6"

Figure 2-98. CSX railroad over St. Louis Bay, facing NW.
US-90 over St. Louis Bay is on the right.

The CSX railroad bridge is south of US-90. It was constructed of simply supported prestressed concrete spans on concrete piers. Almost all of these spans were lost in the storm. The swing span was also taken out of service.

Figure 2-99. By October 20, repairs the CSX bridge had already begun. In the foreground, on the north side of the bridge, the tracks that had been washed off can be found.

Figure 2-100. Piers from the CSX railroad bridge remain but the superstructure has been lost.

SITE 10-11

US-90 at Henderson Point
Harrison County, Mississppi

GPS Coordinates: none obtained.

On the east side of St. Louis Bay, US-90 turns south, then east again as it enters Pass Christian at Henderson Point. The eastern-most span the WB bridge was lifted out of place by the surge, rotated and dropped to the north. The eastern-most span the EB bridge rotated slightly but was not lifted out of place.

Figure 2-101. Henderson Point, east of St. Louis Bay at Pass Christian. The photo was taken facing NW.

2.2.3 LOUISIANA

St. Tammany Parish

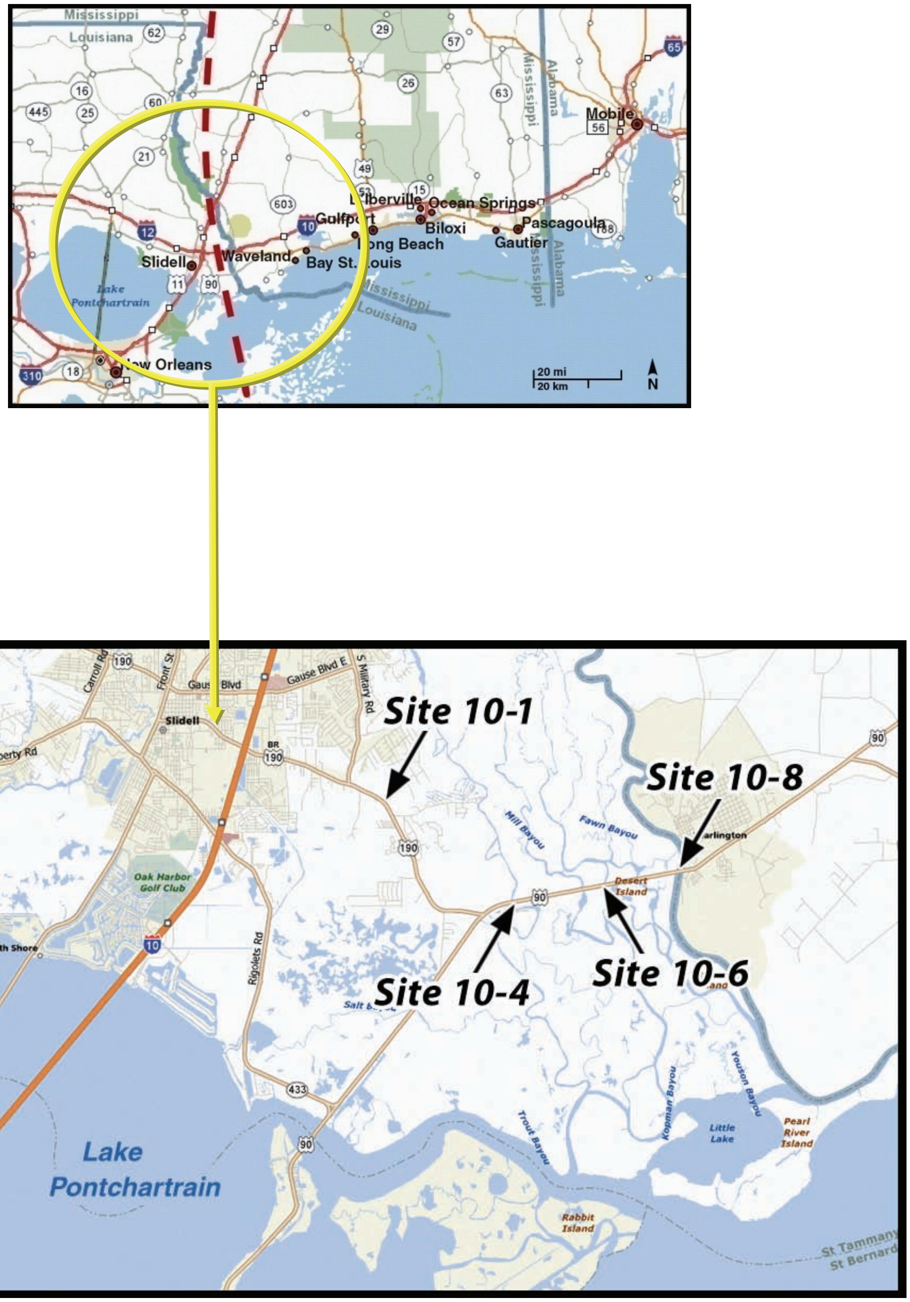


Figure 2-102. Louisiana sites.

SITE 10-1

Highway 433 over Salt Bayou
Tammany Parish, Louisiana

GPS Coordinates: N 30° 11' 46.5", W 89° 45' 17.5"

The bridge over Salt Bayou was built in 1955 as a five span bridge with simply supported spans. There is evidence of pier settlement but it was still functional. Notice the kinks in the vertical alignment in Figure 2-103. A local business owner said that some of the settlement had occurred during a previous hurricane (Camille in 1969). Note the shear blocks at the end of the pier caps. This detail probably helped retain the superstructure.

Figure 2-103. Rte 433 over Salt Bayou was inundated but survived with little damage.

SITE 10-4

US-90 over West Pearl River
St. Tammany Parish, Louisiana

GPS Coordinates: none obtained.

Figure 2-104. US-90 at West Pearl River.

On US-90 there is a stretch of road called five bridges. The first bridge (farthest west) is US-90 over West Pearl River, a vertical lift bridge pictured in Figure 2-104. To the east are three multiple span pony truss bridges identified by the authors as Sites 10-5 through 10-7. Farthest east, on the Louisiana-Mississippi state line, is US-90 over East Pearl River, which has a truss swing span for navigation traffic (Figure 2-106). It is at East Pearl River where the eye of Katrina passed.

The three truss bridges were no doubt inundated but seemed to survive quite well. The two moveable bridges were damaged by the storm. According to some locals, the lift span in the background of Figure 2-104 was not working properly, even before Katrina.

Site 10-6

US-90 between West and East Pearl River
St. Tammany Parish, Louisiana

GPS Coordinates: none obtained.

Figure 2-105. This is one of three similar bridges on US-90 between West Pearl River and East Pearl River.

Debris left behind is evidence that the bridges were overtopped but survived well. Surge in this area exceeded 30 feet.

SITE 10-8

US-90 over East Pearl River
St. Tammany Parish, Louisiana at MS State Line

GPS Coordinates: N 30° 14' 19.9", W 89° 36' 58.7"

Figure 2-106. US-90 at East Pearl River; facing west.

East Pearl River forms the state line between Louisiana and Mississippi and is very close to where the eye of the storm struck landed. The swing bridge in Figure 2-106 became stuck in the open position, preventing its use for motor vehicles. On September 10, 2005, DOT crews were repairing the west approach pavement that had washed out.

Figure 2-107. US-90 over East Pearl River

Figure 2-108. There was minor misalignment of the curb on the east side of the bridge.

Figure 2-109. A boat captain who rode out the storm said water levels were near this top of this tree.

Lake Pontchartrain and Vicinity

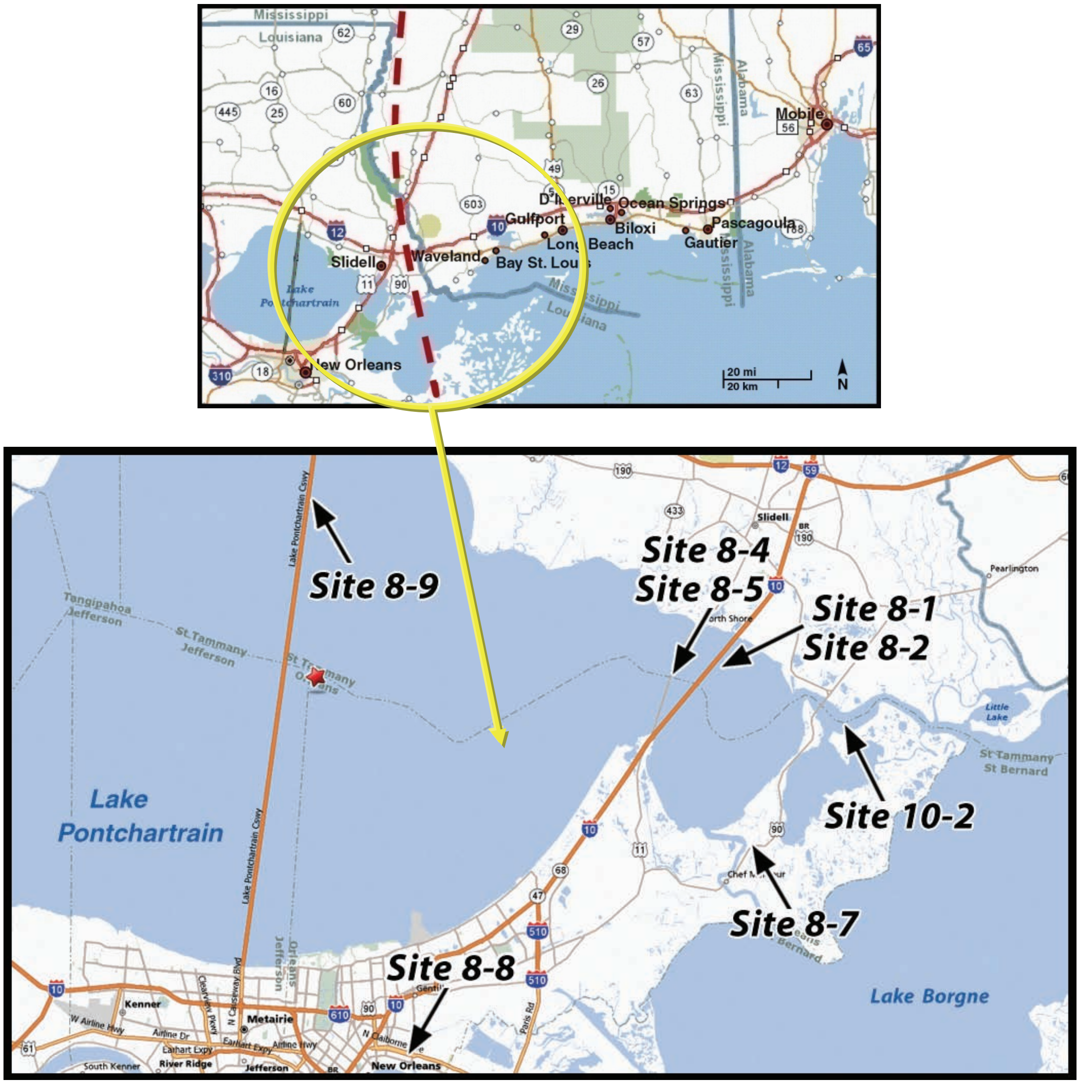


Figure 2-110. Lake Pontchartrain and vicinity.

Bridges over Lake Pontchartrain and the vicinity were all seriously impacted by Katrina's storm surge. The locations of sites investigated are shown above in Figure 2-110. Sites in the Lake Pontchartrain vicinity are:

- Site 8-1: I-10 Westbound (WB) over Lake Pontchartrain,
- Site 8-2: I-10 Eastbound (EB) over Lake Pontchartrain
- Site 8-4: US-11 over Lake Pontchartrain
- Site 8-5: Norfolk Southern Railroad over Lake Pontchartrain
- Site 8-8: City of New Orleans
- Site 8-9: Lake Pontchartrain Causeway
- Site 10-2: Rigolets Bridge
- Site 8-7: Chef Menteur Pass

SITE 8-1
I-10 Westbound (WB) over Lake Pontchartrain

SITE 8-2
I-10 Eastbound (EB) over Lake Pontchartrain
Orleans - St. Tammany Parishes, Louisiana

GPS Coordinates: NE end: N 30° 12' 43.4", W 89° 47' 36.9"

The fury of Katrina is exemplified in Louisiana where she destroyed the twin I-10 bridges over Lake Pontchartrain. Surge elevations exceeded the deck elevation of 14 feet. Though the storm came from the south, these low lying bridges bore the brunt of the storm from their north side. With the eye of the storm passing to the east, the counterclockwise winds of the hurricane blew in from the north and stirred up waves that battered the bridges and toppled many spans. Many spans of both bridges were displaced laterally or fell off their pedestals completely and dropped into the water. The substructures survived without extensive damage. Table 2-2 provides LADOTD's account of the status of the spans after the storm.

Table 2-2. Disposition of I-10 bridge spans after Katrina

I-10 Bridge Spans	Dropped	Displaced Laterally
West Bound (WB)	26	303
East Bound (EB)	38	178

The I-10 bridges were built in 1963 to carry two lanes of traffic in each direction NE out of New Orleans toward Slidell to connect it to the east. They are 5.4 miles long. For ease of construction, it was prefabricated, with monolithic spans cast off-site, barged into place and set on the concrete piers. The 50-inch deep AASHTO Type 5 prestressed concrete sections are each 65 feet long, 40 feet wide curb-to-curb, 45 feet out-to-out, and simply supported. The 45-foot wide superstructure sections weigh approximately 285 tons each and were designed to have friction plate bearings without positive tie-down. The deck elevation is 14 feet above mean sea level, with a short high-rise section over the navigation channel. Piers consist of 54-inch precast, prestressed cylindrical piles with a concrete cap.

An inspection after the storm revealed evidence that violent wave action repeatedly slammed the prefabricated spans into each other, up and down onto the pier caps, and snapped off cantilevered sidewalk sections of the westbound bridge. Higher spans near the navigation channel suffered less damage. Photographs do the best job of showing the extent and type of damage.

Figure 2-111. I-10EB & WB, facing west toward New Orleans. US-11 is on the right.

Figure 2-112. I-10EB & WB, facing east away from New Orleans. US-11 is on the left.

Figure 2-113. I-10 WB & EB over Lake Pontchartrain near the center of the navigation channel, facing east.

Figure 2-114. I-10 EB & WB over Lake Pontchartrain at East terminus, facing south.

Figure 2-115. I-10 WB & EB at east terminus, facing north toward Slidell.

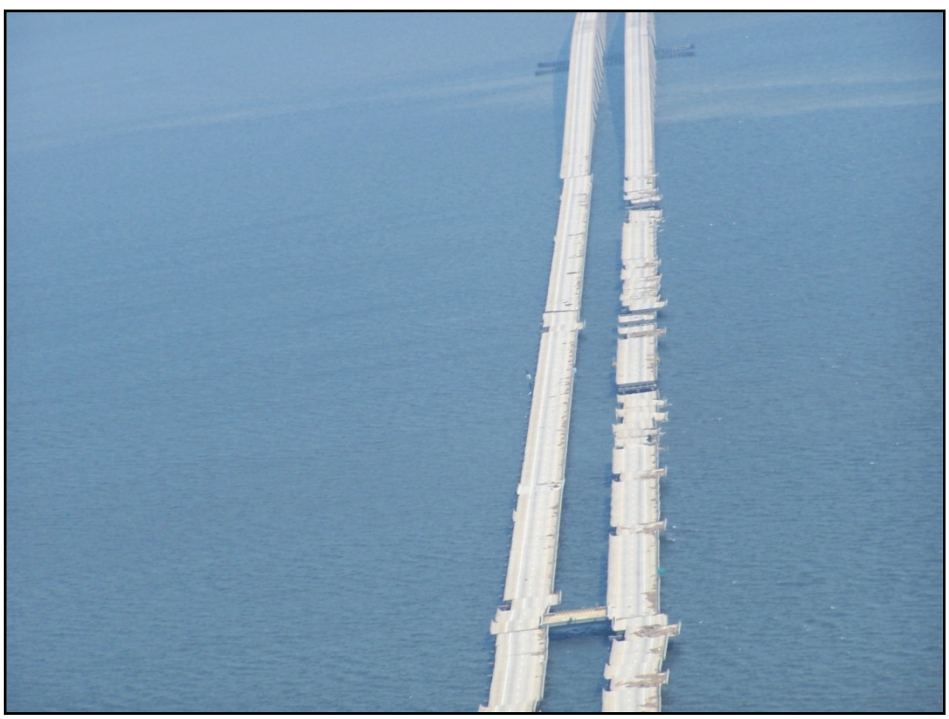


Figure 2-116. I-10 WB & EB, showing numerous displaced spans.

Figure 2-117. I-10, showing spans missing after lateral displacement, facing North.

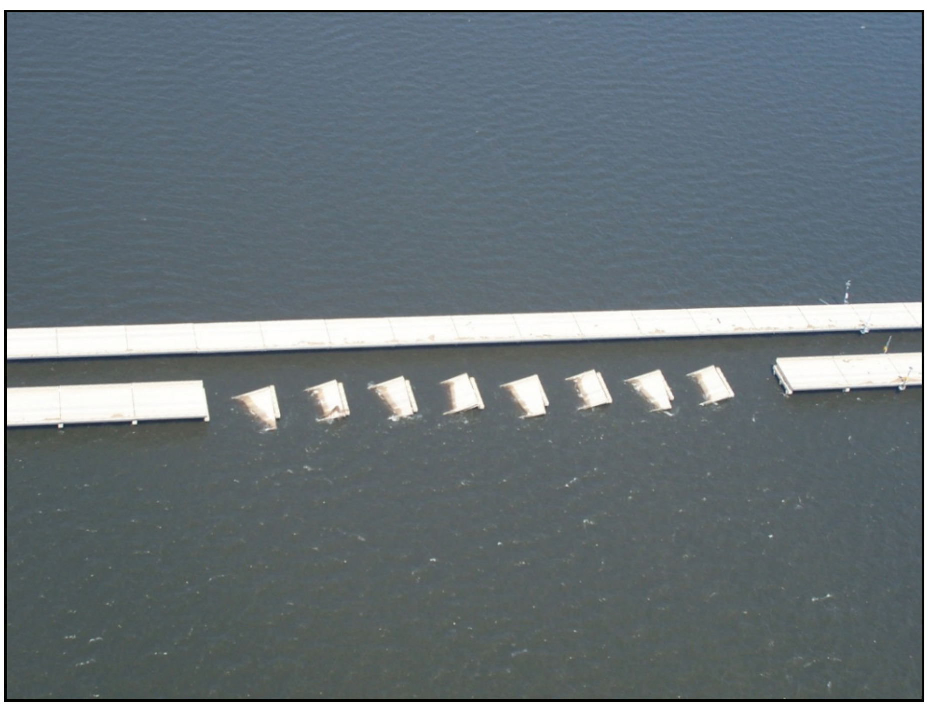


Figure 2-118. The missing span on the far right seems to have slid out, causing the others to topple.

Figure 2-119. I-10 WB, facing west to the high-rise spans over the navigation channel. Note the scrape marks on the pier caps, caused by the falling spans.

Figure 2-120. I-10 EB facing west.

Figure 2-121. Bearings were not designed to provide resistance to uplift or lateral loads.

Figure 2-122. The north parapet broke off and is dangling down in the picture. Note uniform shift to the south.

Figure 2-123. Relative displacement between spans.

Figure 2-124. The wave action exerted on the spans must have been violent as evidenced by the spalled concrete resulting from longitudinal pounding between spans.

Figure 2-125. WB bridge is on the left.

Figure 2-126. Span units of the EB bridge dropped.

Figure 2-127. Lateral movement may have been restricted by the short pedestal (riser).

Figure 2-128. This EB span worked its way out laterally even as the adjacent spans stayed on the pier cap.

Figure 2-129. This view is looking SE so the EB bridge is on the far side. On this section of the bridge, the EB side lost many more spans.

Figure 2-130. This view is looking SW from the deck of the WB bridge. Spans not dropped into the water completely were displaced to the south.

Figure 2-131. Seat length has been an important consideration in earthquake designs.

Figure 2-132. Span units are relatively intact.

Figure 2-133. The highest spans of the I-10 bridges survived.

Figure 2-134. Some spans dropped in an inclined manner, and some moved sideways.

SITE 8-4

US-11 over Lake Pontchartrain
Orleans - St. Tammany Parishes, Louisiana

GPS Coordinates: N 30° 12' 12.0", W 89° 50' 07.0"

Figure 2-135. Though older and lower, US-11 performed better than I-10.

US-11 was built about 1927 as the main route north out of New Orleans. It served for many years before the I-10 interstate was built as an alternative route. It was built with a cast-in-place concrete construction. It is “T” beam construction supported by concrete piles and piers. It is 30 feet curb-to-curb and approximately 35 feet out-to-out.

The deck on US-11 is just 11 feet above mean sea level. According to a LADOTD employee familiar with the bridge, it received a new concrete deck in 2001. By inspection, it appears that the intent was to make the spans continuous for live load. This tied adjacent spans together, thereby making it more resistant to surge-induced forces.

Traffic on US-11 was restricted for security reasons, even though the bridge was passable. On the day of inspection, the moveable span needed to be operated with diesel power because electricity was not available.

It is interesting to note that there are several subsurface geologic faults in Lake Pontchartrain (*http://www.usgs.gov*). When driving the bridge, the authors experienced a noticeable dip over one part. When asked, the operator of the lift bridge replied that it had always been there. On-line research revealed that this was the location of one of the faults.

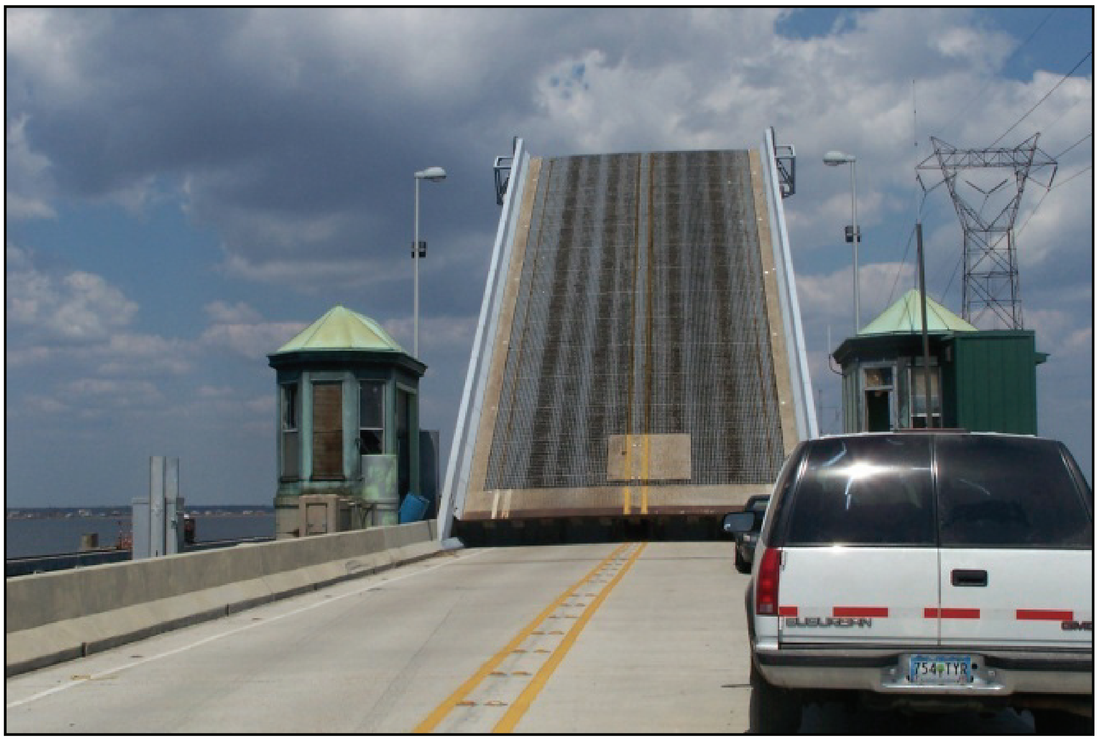


Figure 2-136. The bridge was functional, even though some repairs were necessary.

Figure 2-137. This section of concrete parapet on US-11 failed from wave force but was already in a weakened state from corrosion prior to the storm. Corrosion in the concrete barrier contributed to its failure from wave action. A subsequent investigation by LADOTD led to plans for replacement of all of this barrier.

SITE 8-5

Norfolk Southern Railroad over Lake Pontchartrain
Orleans - St. Tammany Parishes, Louisiana

GPS Coordinates: N 30° 13' 00", W 89° 49' 40" (East End)

Figure 2-138. Norfolk-Southern had a crew relaying track about a week after the storm.

To the west of US-11 is a Norfolk-Southern railroad bridge, built in 1987. The railroad bridge is parallel to US-11 at its northern terminus but diverges away from US-11, as it gets closer to New Orleans. The 5.8-mile-long structure is a series of simply supported P/S spans with a concrete deck. The ties and tracks are designed to float on ballast on top of the deck. The railroad bridge survived well. The tracks, ties, and ballast were washed off the bridge but all piers and spans remained in place. Norfolk-Southern was able to replace the track and restore service within a few weeks of the storm. The shear blocks at the end of the pier caps contributed to the survival of the bridge. Because of live load requirements, railroad bridges are always more robust than a highway bridge. The extra mass would also help secure the superstructure.

SITE 8-8

City of New Orleans
Orleans Parish, Louisiana

GPS Coordinates: None obtained

Because of the extreme difficulties experienced by the city, reconnaissance was not conducted there. Flooding of some neighborhoods had occurred and the military was restricting access. A few photos are provided to give an understanding of the situation. Except for Figure 2-139, these photographs were provided courtesy of LADOTD.

Figure 2-139. On the date of this photo (September 8, 2005), many ramps in the city of New Orleans were flooded and not useable except as a boat launch.

Photo provided by LADOTD

Figure 2-140. I-10- and I-610 in New Orleans

Photo provided by LADOTD

Figure 2-141. I-510 near Six Flags Amusement Park

Photo provided by LADOTD

Figure 2-142. Almonaster – Inner Harbor

Photo provided by LADOTD

Figure 2-143. Boats grounded on the Empire Bridge.

SITE 8-9

Lake Pontchartrain Causeway
Jefferson – St. Tammany Parishes, Louisiana

GPS Coordinates: N 30° 21' 56.6", W 90° 05' 38.0"

Photo courtesy of LADOTD

Figure 2-144. The north approach to the Lake Pontchartrain Causeway.

The longest structure over Lake Pontchartrain is the toll Causeway, which runs north-south across the center of the lake. This 24-mile long bridge, renowned as the longest bridge over water in the world, connects the City of New Orleans to the north. The deck elevation is typically 20 feet above mean sea level. However, there are some sections built as turn-around spans that are closer to the water. The newer NB bridge was built in 1969.

Although the Causeway survived pretty well, it was not immediately useable because the north approach had washed out. It was already repaired when the reconnaissance team visited on September 8, 2005. In addition, some of the low lying turnaround spans were lost.

Photo provided by LADOTD

Figure 2-145. Some low-lying sections of the Causeway were lost due to the storm surge.

SITE 10-2

Rigolets Bridge
Orleans - St. Tammany Parishes, Louisiana

GPS Coordinates: N 30° 10' 12.5", W 8°9 44' 03.8"

Figure 2-146. Rigolets Bridge carries US-90 This photograph was taken facing west.

Rigolets Bridge carries US-90 over a strait of the same name. The strait connects Lake Pontchartrain and Lake St. Catherine to Lake Borgne and forms the boundary between St. Tammany Parish and Orleans Parish. There are 50 multi-girder spans that are each 42 feet long plus three truss spans. It is 20 feet wide curb-to-curb. The Rigolets deck elevation is 17 feet above mean sea level and there was evidence of overtopping. This resulted in damage to the moveable span because the electro-mechanical systems were flooded, some damage to the railings, and undermining of the approach slab, but generally the bridge fared well.

SITE 8-7

Chef Menteur Pass
Orleans Parish, Louisiana

GPS Coordinates: N 30° 03' 59", 7 W 89° 48' 20.0"

West of Rigolets on US-90 is the bridge over Chef Menteur Pass. The waterway connects Lake Pontchartrain to Lake Borgne (see Figure 2-147). Note the CSX railroad line on the right side of the picture.

U.S. 90 at Chef Menteur Pass is an old cast in place concrete bridge with three truss spans, the center one being on a turntable to allow boats through. The bridge was posted with a 25-ton weight restriction before the storm but was closed entirely at the time of inspection. The roadway is two lanes wide, 20 feet curb-to-curb.

There was damage to the moveable span so that it remained in the open position (available for use by marine traffic). The concrete barrier on the northwest corner was impacted by some sort of floating debris (Figure 2-149). Scour damage had occurred in the past because it was obvious that there had been various attempts to stabilize the approach spans. A pier was tipped (Figure 2-151). There was also evidence of new settlement, indicating that there was additional scour action from Katrina.

Figure 2-147. US-90 over Chef Menteur Pass, facing east.

Figure 2-148. Facing NW. The swing span became inoperable.

Figure 2-149. The north side of the approach barrier was hit.

Figure 2-150. US-90 remained closed months after the storm.

Figure 2-151. A tipped pier indicates that scour has occurred.

2.2.4 MOVEABLE BRIDGES

Various Locations

Highways and roads in the affected region have a variety of moveable bridges, including lift spans, swing bridges, and bascule bridges (drawbridges). The state of Mississippi owns five moveable bridges: US-90 over Biloxi Bay, I-110 over Back Bay, US-90 over St. Louis Bay, Fort Bayou Bridge, and Lorraine Cowan. All of these suffered damage. LADOTD reported that of their 152 moveable bridges, 142 were affected by the storm and 52 bridges were damaged.

Structurally, most of these bridges survived the forces of Hurricane Katrina. Most however, were rendered inoperable because of flood damage to electro-mechanical motors and controllers. Flooding of control rooms and/or mechanical rooms caused damage to the gear mechanisms and electrical systems. Vegetation and other debris was jammed in lift mechanisms and had to be cleared (see Figures 2-152 and 2-153). Even when repairs were made quickly, commercial power was typically unavailable for several weeks after the storm. In some cases, auxiliary diesel generators were available to operate the bridges; however, such operations are time-consuming and are undertaken only in emergency situations. At St. Louis Bay, a span became inoperable in the down position and had to be removed under emergency contract to clear the navigation channel for vessel traffic (Figure 2-154).

Photo courtesy of LADOTD

Figure 2-152. Typical debris buildup in the gear mechanism of a moveable bridge.

Figure 2-153. Equipment failed after being submerged in salt water.

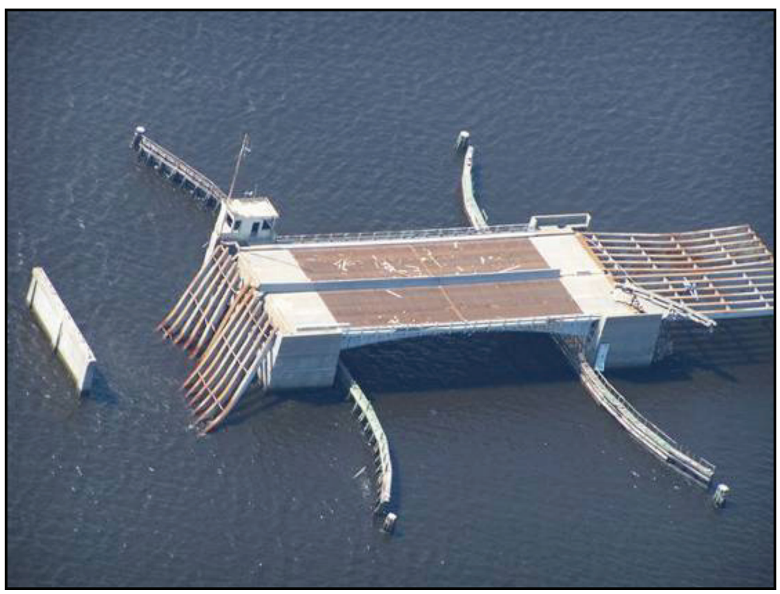


Figure 2-154. Inoperable draw spans prevented use of the channel by vessels.

There is a county owned lift bridge in Pass Christian called Portage Bridge [N 30° 20' 31.7", W 89° 15' 51.8"]. Clearance under the bridge is normally 28 feet but surge inundated the mechanical room. It was raised for the first time after the storm about October 12. On October 19, the electrical wiring needed to be replaced. Emergency generators were still needed to operate it.

2.2.5 TUNNELS

Mobile River

Even though the focus of this report is on bridges, this section is included because tunnels are such an important part of the transportation network. The information was provided by Alabama DOT, courtesy of Nick Amberger, former Division 9 Maintenance Engineer and Lee Reach, Division 9 Maintenance Engineer, and Gerald Criswell, Tunnel Manager.

The city of Mobile, Alabama is located northwest of Mobile Bay and west of the Mobile River and its associated bayous. The following structures span the Mobile River, linking Mobile with Pensacola, Florida and points east. While there is some system redundancy, each facility is critical to the smooth flow of traffic through the metropolitan area.

- The Cochrane-Africatown Bridge, as discussed earlier in this report
- Bankhead Tunnel, a 21 foot wide tube with two-lanes, carrying two-way traffic on US-98 in downtown Mobile.
- George Wallace Tunnel, a two tube tunnel carrying four lanes of traffic on I-10

Photo courtesy of ALDOT

Figure 2-155. Bankhead Tunnel, US-98 in Mobile, AL

Late on August 28, 2005, Alabama DOT officials closed the flood doors on the Bankhead tunnel as a precaution against anticipated flooding. At midday on August 29, 2005, the Cochrane-Africatown Bridge was also closed because of damage resulting from being struck by an oil platform[1]. This left the I-10 George Wallace Tunnel as the only access across the Mobile River remaining open during and immediately following the hurricane.

When the George Wallace Tunnel was built in the early 1970's, it was constructed with provisions to counteract flooding. Unfortunately, the tunnel was not immune to the rising waters of Hurricane Katrina. During the event, a valve broke and backflow from the storm surge in the bay filled up the sump pumps and pump room at the east end of the tunnel. The pumps were original and not the submersible type so they quickly shorted out.

Photo Courtesy of SouthEastRoads.com

Figure 2-156. George Wallace Tunnel, I-10 in Mobile, AL.

With no pumps to handle the inflow, water began to fill up the air ventilation shaft beneath the roadway. There was a sump pump at the low point of the ventilation shaft but it was very small and only intended to handle wash water during tunnel cleaning. The airshaft filled with seawater to within a few inches of producing a ventilation system to shut down. Since the tunnel would have had to be closed if there was no ventilation, fire trucks were used to pump out

[1] The Disaster Center's Tropical Storm - Hurricane Katrina Page at the University of Delaware

the floodwaters. The I-10 tunnel traffic remained open, although traffic was reduced to a single lane in each direction in the tunnel.

Damage to the Wallace Tunnel cost Alabama DOT $1,117,048 in repairs and upgrades to the tunnel pumping system. The work included cleaning, tile repair, valve and pump repair, new electric power control circuits, paint, insulation, and video monitoring equipment. In the event of a reoccurrence, ADOT will connect temporary power to submersible pumps and keep the tunnels open.

3.0 Lessons Learned

The authors offer the following observations:

Lateral loads, along with uplift from buoyancy, caused most of the damage, but it is not always intuitive which direction the most extreme loads will be applied from. In almost all cases, these loads were not accounted for when the bridges were designed. A screening procedure might be able to identify which existing bridges are most vulnerable to lateral and vertical loads. Displacements need to be controlled. Principles such as span continuity and designed-in restraint mechanisms could result in fewer losses.

Prestressed concrete beams can fail due to buoyant forces negating the dead load.

Prefabricated components such as prestressed concrete beams have been used across the country to save time and money during construction. Although they have served for years in the Gulf Coast, many bridges failed when their components came apart.

Connections are critical to successful use of shop made parts that are to be assembled in the field. Additional research is needed for its safe use in areas of moderate to high seismicity and in areas where other dynamic loads might be present such as in a coastal environment.

Continuity can help spans of a multiple span superstructure act as a unit and resist loadings that could topple individual spans. (The deck replacement on US-11 in 2001 apparently made the bridge continuous for live load and tied the spans together (see Figures 2-135 and 2-136).

Earthquakes have given bridge engineers many lessons that may be transferrable to coastal situations. The failure mode of some bridges from Katrina was virtually identical to that found after past seismic events. Although there are definite differences in the loadings that result, the parallels should be investigated. Over the past few decades, there have been great strides made in the advancement of nonlinear analysis and performance-based design strategies and some of this would be applicable to coastal engineering for bridges. At the very least, the rigorous process used to gather information needed to modify the *AASHTO Bridge Design Specification* has been established and can be followed.

Wave and buoyancy forces were applied to bridges as a result of Katrina's unprecedented surge level. These loadings were probably not considered during the design stage when these bridges were built, but as the ocean level rises each year due to **global warming**, current design specifications need to consider the possibility that bridges designed today will see these extreme conditions at some time over their service life.

Floating debris caused substantial damage. Items that struck bridges include an oil platform, shipping containers, buildings, appliances, logs, and jams made up of entwined smaller debris. This material caught up in waves produced very large loads applied laterally to bridges that were designed for wind loading at best.

Seismic detailing can be used to reduce the number of catastrophic failures due to hurricanes. It was evident that some simple, inexpensive details could have made a difference in some of the bridges inspected. Concrete **shear blocks** can be employed to resist lateral forces induced by wind and waves as well as to protect from earthquakes (see Figures 2-58, 2-60 and 2-66). Even in cases where lateral loading cannot be envisioned, it may be wise to incorporate it into the design. Hits from vessels, debris or motor vehicles are never planned, but on occasion, they do occur. If protection can be added for little additional cost, it would be worthwhile. It may be analogous to a dovetail joint used in quality furniture making. It may not be necessary, but it provides a belt and suspenders approach that will serve the owner long after the glue joint dries out. Likewise, providing extra seat width (or **seat length**) on a pier cap might prevent the loss of a span that has been displaced due to dynamic loading (see Figure 2-131).

Retrofitting existing structures may be prudent. Resources such as FHWA's *Seismic Retrofitting Manual for Highway Structures* (Buckle et al., 2006) would be a valuable resource. **Tie down clips** seen on most structures offer little resistance to lateral loading. Providing **restrainers** similar to those used in earthquake prone areas should also be considered. Although some advanced **analysis** would be advised to be sure that one understands the expected load path, there may be measure such as this that would reduce a bridge's risk. Other regions, not just the Gulf Coast, should give serious thought to taking proactive action.

Condition played a role in the ability of a bridge or bridge component to resist forces generated by Katrina. For instance, concrete bridge railing on US-11 over Lake Pontchartrain broke off from wave forces and/or debris impacts, but upon closer inspection, it could be seen that the section was in a weakened state because of corrosion (see Figure 2-137). The authors interviewed a boat captain who said that an old lift bridge had problems because of age and was not operating even before the storm hit.

Multiple hazard design is necessary for future designs and code development. As was demonstrated by this event, structures need to be able to resist all hazards, whether they be coincidental, cascading, striking while the bridge is in a deteriorated condition, or just because we never know which hazard will be the next one to strike. A methodology for balancing the sometimes-competing needs of each hazard is necessary.

Scour damage was not as great as might have been expected, but still, many piers were washed out in St. Louis Bay. Attention to new hazards is needed but remembering the importance of scour protection is important.

Network redundancy assured I-10 was passable at Moss Point where a barge hit the EB Bridge, even if with reduced capacity (see Figure 2-25). When planned, I-10 could have been designed and built as a single structure that accommodated four lanes of traffic. By building two separate structures, damage to one bridge restricted the use of two lanes but two lanes remained available for traffic. Although this may not have been consciously considered during planning, it was a real benefit. The reduced capacity of I-10 caused traffic delays that hindered response efforts, but the situation would have been much worse had all four lanes been part of one structure.

Global warming may be leading to more intense and more frequent storms as well as higher ocean levels. Weather patterns and resultant storms cannot not be considered as a static set of conditions, so research should be conducted on how to address an *increasingly* adverse set of conditions. Since the anticipated service life of a new bridge is at least 75 years, codes should reflect and give guidance on the resistance levels needed for continued operation of 75 years or more.

Lifeline routes can be designated and designed to a higher standard than typical to ensure that vital services can be maintained. These routes may or may not be interstate highways, but they would be roads that have the greatest probability of being functional after a disaster.

Moveable bridges proved to be particularly vulnerable to failure. They were subjected to the same wind, hydraulic, and debris loading as fixed bridges, thus were faced with the same risk of scour, uplift, overturning, damage from impacts, etc. In addition, these bridges have electrical-mechanical systems that need to be clean and dry to operate. Most lift mechanisms failed when the storm surge submerged their control rooms. According to representatives of Mississippi Power, it is not just a matter of cleaning and drying the equipment out again; exposure to salt water can result in permanent damage to motors and wiring. If the mechanisms could be protected, the bridges would still be dependent upon availability of power, and this is all but assured in a situation like Katrina. In the experience of the authors, almost all moveable bridges were still not functional six weeks after the storm. There seems to be a trend that newer bridges in coastal areas are built as high-rise structures with, at most, one moveable span. This is prudent practice and should be encouraged despite any extra costs. If the bridge can be built without any moveable parts, it will more likely be available when it is needed, either as an evacuation route or for response after the event.

Trusses endured quite well. This may be attributable to the mass associated with an entire span that provided enough inertia to resist the surge forces, or the fact that wind and water could pass through the superstructure instead of catching it like a sail (see Figure 2-146).

Design criteria need to be revisited. Most bridge damage resulted from the storm surge (dynamic wave forces, inundation, buoyancy, scour). Designers need guidance on how to account for these loadings. There was ample evidence that newer bridges performed better, so this is an indication that improvements to the AASHTO bridge design specification over the years have in fact made bridges safer.

Armoring of embankments to bridge approaches could minimize the risk of them being washed out and rendering the structure unusable (Figures 2-85 and 2-94).

4.0 Conclusions

Katrina caused extensive damage to bridges along the Gulf Coast, primarily superstructures. This was mainly due to water elevations that far exceeded those accounted for in design. The storm surge brought waves up to the elevation of the bridge superstructure and applied strong horizontal loadings. There was evidence of longitudinal pounding of spans against one another, indicating that the waves were stirred up by wind, causing a very turbulent condition that applied violent forces in multiple directions.

As water rose, many bridges became completely submerged. For certain types of construction, air was entrapped between girders, causing an uplift component due to buoyancy. This combined with the wave action to lift unrestrained spans out of position. Many spans of long bridges were displaced or fell off the piers altogether.

Scour undermined many piers in St. Louis Bay but substructures of many other bridges performed adequately in this regard.

Functionality was obviously lost when multiple spans of major structures collapsed. Though not as visually dramatic, attention should be given to the fact that functionality of the majority of moveable bridges in the area was lost when their electrical/mechanical control rooms flooded. Although many of these moveable bridges were repaired and restored to service in the weeks following the storm, some have been permanently damaged.

Smaller bridges farther inland were protected from the worst of the storm surge, and generally did not suffer the same damage. In some instances, however, a bridge survived, but the approach to the bridge was washed out, rendering it impossible to use the bridge until crews could make necessary repairs.

While the surge waters applied loads directly to structures near the coast, it also caused damage when it carried marine vessels, shipping containers, tanks, and miscellaneous debris into bridge. At the Popps Ferry bridge, it appeared that a floating mat or log-jam of debris applied pressure to a bridge as a unit rather than as individual hits.

The varied performance of bridges can be evaluated and used to improve the way we build bridges. For instance, a structure's design features were called upon to resist scour, high winds, impacts and wave forces coincidentally. This phenomenon is one that needs future study to be sure standard codes reflect the potential for its occurrence.

There are some parallels between coastal and seismic engineering for bridges. The understanding of coastal design may be likened to that of earthquake engineering back in the 1970's. Just as the community of researchers in the field of earthquake engineering learned to improve bridge design procedures by investigating performance of bridges after actual events, Katrina can contribute to an advancement of the state of the practice for coastal bridges.

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Appendix A: Inspectors' Daily Journal

Katrina struck the Gulf Coast the morning of August 29, 2005. The following is a journal kept by the authors' during their ground surveillance September 6-11, 2005.

A site number was assigned to bridges where the team stopped. The first digit indicates the day of the month that the bridge was inspected; the second number is a sequential number for the day. Since the team was looking for hurricane damage, some bridges that appeared to sustain no damage were not assigned a number.

Tuesday, September 6, 2005

Gilberto Mosqueda, Paul McAnany, and Jerry O'Connor arrived at Mobile Airport about midday and conducted a field inspection of sites in Alabama. The fourth member of the engineering surveillance team, Keith Porter, arrived later in the day. According to Alabama Department of Transportation Bridge Maintenance Engineer George Conner, damage was restricted to two counties and close to the shore. He provided information on the damaged bridges in Mobile County and Baldwin County. Although Mobile, Alabama was over 100 miles east of the eye of the hurricane, there was some significant damage to bridges.

Site 6-1

We drove in a southerly direction in Mobile County and discovered damage to the northerly approach to the bridge that connected the mainland to Dauphin Island. The newer bridge was in good condition but use was restricted to eliminate looting from the upscale properties on the island. A security checkpoint gave us authorization to proceed onto the island for a period of thirty minutes. At the time, the power company was busy trying to restore power lines to the west of the bridge that had been knocked down by the storm. The Alabama DOT was also busy restoring the east side of the roadway that had been washed out. It was very sandy material. George Conner had said that they have frequently had to make similar repairs, although recent repairs made with a geotextile or geogrid were holding up well.

Author Paul McAnany at Biloxi Bay

The military personnel at the north end of the bridge gave an explanation of what damage had occurred. The bridge was not damaged at all but much of the approach at the north end of the bridge had washed out. They said that it was possible for vehicles to pass, though traffic was restricted to one lane width. When we were there, the approach had already been repaired and paved. Repairs continued on the road north of the bridge.

About 40 miles south of the City of Mobile is Dauphin Island, which is joined to the mainland by a concrete multigirder bridge built in 1982. It is Route 193 over Grant's Pass. The bridge remains in excellent condition but was temporarily, partially closed to traffic after the hurricane due to a washout of the north approach. The bridge is in good structural condition but access to the island is restricted for security reasons (to prevent looting). The checkpoint guard said that there was always one lane of traffic open, though it was necessary to escort vehicles through the washed out areas. There was also road damage that has already been repaired. ALDOT said that this area repeatedly washes out, though recently repaired stretches that used geotextiles are holding up well. The elevation is less than six feet above sea level.

Site 6-2

In the town of Bayou La Batre, a vertical lift bridge over an inlet had been slightly damaged by the storm. A large boat was in very close proximity to the bridge. According to a DOT maintenance person standing watch, a boat had been moored nearby but had broken loose and swept into the bridges. The bridge had evidence of scrape marks on the paint but no apparent permanent damage was visible. He said their office had been flooded and that water had been several feet above the roadway or "halfway up the fence." The bridge was in a down position and was useable by motor vehicles.

The J. A. Wintzell Memorial Lift Bridge is in the community of Bayou La Batre, Alabama and carries Route 188 over an inlet called Little River. [N 30° 24' 18.4", W 88° 14' 51.6"] According to the ALDOT maintenance person on site, water flooded their office and came up to about half way up the adjacent sidewalk fence or several feet above the roadway. A large boat moored nearby hit the bridge tender's office when it was tossed about in the storm. It caused no major damage, just scrapes along the side of the building. The bridge was open to all traffic.

Site 6-3

We proceeded north. In Mobile we arrived at the site where a large oil drilling platform had hit a new large cable stayed bridge. Since the impact, the bridge has been posted with a weight restriction and traffic has been restricted to one lane in each direction.

The bridge spans the Mobile River and carries US-90, Highway 16. Newspaper accounts of the storm say that the dimensions of these platforms are 300 feet square and that the weight of a fully equipped one is equivalent to two destroyers. Newspaper accounts also said that the platform has been swept inland 60 miles from out in the Gulf of Mexico before it came to rest at the bridge.

The bridge has several hundred feet of clearance underneath and was not easily accessible. From the top, there was damage evident to the concrete barrier and metal railing. Several cable stays were wrapped as if to assure water tightness to the sleeve.

The Concrane-Africatown cable stayed bridge is a large structure in the City of Mobile, Alabama that carries US 90 (also known as Bay Bridge Road and Route 16) over the Mobile River.

Site 6-4

Next we went in an easterly direction and stopped on the west bank of Mobile Bay. At the west abutment of I-10, the fill had eroded. Repairs had been made there recently to insure stability of the abutment and approach. Concrete had been dumped from a mixer at the corners of the wingwalls. Underneath, impromptu formwork utilized plywood and signs when concrete was placed against the spill-through abutment. Above, there was slight evidence of approach settlement. The bridge carries several utilities and it looked like there may have been scour from a water main break underneath.

Site 6-5

On the east side of Mobile Bay is a ramp bridge that connects US-90 EB to I-10 in Baldwin County. The roadway is very close to the water (3 to 4 feet) and suffered significant damage. Several spans of the concrete bridge shifted north, one as much as six feet. The concrete Jersey barrier on the right of that span was in line with the white edge of pavement stripe (looking in the direction of traffic).

The piers appear to be plumb and undisturbed except for slight damage where an anchor clip had broken off.

Wednesday, September 7, 2005

We started early the next morning from where we were staying in Gulf Shores, Alabama and proceeded west into Mississippi. Traveling with us for the day was reporter Martha Baer. She later captured the spirit of the investigation in a human interest story (Baer, 2006). Traffic on I-10 WB was heavy. It was congested due to a lane closure north of Pascagoula. We exited and turned south to follow US-90 which runs E-W close to the coast. Damage to trees and the built environment was noticeably worse as we moved west. On Hwy US-90, we saw numerous fiberglass light poles in the median that had broken off at their base. We also saw several displaced pleasure boats that had been carried by the storm and dropped haphazardly along the road.

Site 7-1

At the east end of Biloxi Bay, Highway US-90 came to a halt. The long bridge (1.6 miles) over the bay was out of service. Walking up from the east we saw that the easternmost spans were unusable and ones further to the west were totally missing. The bridge had obviously been badly battered during the storm. The span closest to the east abutment was displaced horizontally 15 feet to the north. Subsequent spans were moved even further north and were twisted, skewed and many were entirely off the piers. The bridge was not designed to be continuous and each span acted independently of one another. Some of the prestressed girders had failed and exhibited severe shear/flexure cracking. The cast-in-place reinforced concrete slabs on several of the spans were also broken up beyond repair. We were able to conduct a walking, hands-on inspection of the first five or six spans and just took photos with a telephoto lens at the spans to the west that had collapsed into the water. The center moveable spans were higher above the water and were still standing.

A tree on the east shore about 200 feet to the north had lots of small debris hung up in its branches (plastic bags, etc). This was a rough indicator of water depth. Water depth probably exceeded 20 feet. The area was also strewn with miscellaneous debris like wires, wood, tanks, small boats, and personal items such as Mardi Gras beads and clothing. Power crews were busy trying to restore power in the area. We saw trucks from power companies from various states that had come to assist with power restoration.

Site 7-1b

Biloxi Bay had three crossings. North of and parallel to US-90 is the original highway crossing. The concrete bridge was about 1930's vintage and designed to carry two 10 foot traffic lanes. Locals said that recently it was used as a pedestrian bridge and fishing wharf. This bridge was also wrecked by the storm, with its spans also thrown to the north by high water and wind. Failure mode of both was very similar.

Site 7-2

To the north of the highway bridges is a railroad (CSX) bridge over Biloxi Bay. This is a newer design (1980's or so) that appears to be structurally intact. The concrete bridge has spans consisting of several prestressed concrete (I or box) beams. A very significant detail that may have saved the bridge is a concrete shear block at each end of each pier cap that successfully restrained motion laterally. This detail has been used recently on highway bridges located where there is a chance of an earthquake that might tend to move the superstructure sideways.

Although the structure itself was well preserved, an inspection from above showed that the bridge was stripped of its tracks. The ballast, ties and rail were entirely gone from the bridge. The continuous rail, with ties still attached, was visible near the east abutment. It had been washed off the north side of the bridge. There was no evidence of broken attachments and later conversations with someone familiar with railroad construction verified that it is standard practice to let the continuous rail float on a bed of crushed stone (ballast) instead of pinning it down. This allows for movement due to thermal expansion.

We then traveled on local bridges into Biloxi to the west terminus of these bridges.

Site 7-3

The Biloxi Bay bridges were part of US-90's E-W route. NW of these bridges was Back Bay where there are two bridges, both running N-S. The worst damage was incurred by the old route into Biloxi (which were referred to as old 110). It is a narrow 1920's vintage concrete bridge with concrete parapet railing. It had obviously been taken out of service as a highway in favor of recreational use as a fishing pier. The curb to curb width was measured to be 20 feet. Walking from the south end, we could see that several sections of the sidewalk (on the East side) and parapet railing had broken off and fallen. Looking at the bridge from the west, one could see the parapets sections hanging from the bridge.

Further north, there were sections of the bridge that had totally failed. The spans were no longer there and even the substructure units were not visible. A local resident verified that prior to the storm, he had been able to walk all the way to the navigation channel. Now, entire sections of the bridge were gone.

Site 7-4

The I-110 bridge just to the west was open to traffic, though the NB direction was restricted to one lane.

Site 7-5

It was late and getting dark when we arrived at the site on I-10 EB where a barge had hit the bridge. It was in the vicinity of Moss Point, over a wide marsh. WB and EB traffic were sharing the WB bridge because several spans of the EB bridge had been push as much as four feet to the north when it was hit. There was also a vertical drop at the bridge joint.

Thursday, September 8, 2005

It was not possible to stop and assess the condition of every bridge. There are many smaller bridges and it was difficult to cover a lot of miles in a day because some roads and bridges were impassable. We decided that if we were going to see the major bridges in the western part of the affected region, we needed to drive as far west as possible without stopping at all of the bridges in between. We wanted to prioritize our work and inspect the bridge with most significant damage first and then get to the ones with less damage or on less traveled routes.

As we drove I-10 WB through the western part of Mississippi, we could see a marked change in the damage we saw. There were large trees uprooted or broken off high off the ground. Most highway signs were down, making our navigation a little more challenging. High outdoor advertising structures were severely damaged or destroyed.

Site 8-1

Site 8-1 is I-10 WB over Lake Pontchartrain.

The concrete parapets and aluminum bridge railing broke off of many spans, apparently from the vertical uplift and subsequent dropping of the spans on the pier cap.

Site 8-2

Site 8-2 is I-10 EB over Lake Pontchartrain.

The parallel structure is Eastbound (EB) I-10 bridge, and it is also closed to all traffic. It carried traffic in a Northeast direction out of New Orleans toward Slidell, Louisiana. The Lake Pontchartrain crossing was built in about 1963. The type of construction is modular prestressed (P/S) concrete spans, with a four lane highway bridge over them.

A local resident approached us by boat and described the storm's behavior. He said that the eye of the storm was east of this location so the counterclockwise winds that are characteristic of hurricanes hit this structure from the north.

As we approached the bridge that carries I-10 WB into New Orleans, there was a military checkpoint with armed guards. After explaining our mission, we were allowed to pass and approached the bridge, driving around a boat that had been grounded on the highway. Even though we were traversing the ground with a four wheel drive Jeep, caution was necessary because of the nature of the debris cluttering the area. There was a lot of plywood and pressure treated lumber with protruding nails on the ground. When out of the vehicle these also presented a walking hazard because seaweed and grass covered much of the debris laying on the ground. As we walked onto the bridge, we saw another boat stranded in the middle of the driving lanes. There was also grass, bottles and other debris remaining on top of the bridges. The high water level was most likely over the roadway but it was impossible to estimate how deep it actually was.

Author Jerome O'Connor standing on closed I-10.

I-10 consists of two distinct bridges, EB and WB. As the two bridges touched the east shore of Lake Pontchartrain, they became connected with a bridge structure built between them. We walked out onto the WB structure as far as possible, first observing the failure modes on the WB bridge and then walking back, observing the EB bridge. The space between the parallel E-W bridges was about 100 feet. From the WB bridge we could look south and clearly see the type of construction used. Both bridges were made the same type. They each consisted of concrete bents spaced at about 65 feet with a prefabricated modular unit simply supported between them. It seemed most likely that the sections had been cast as a unit on dry land, then brought out by barge for placement. The bridges are fairly close to the water, (say 10 feet).

As we walked west onto the bridge, we noted that sections of the bridge had been displaced to our left (i.e., to the south). Walking another few spans, the shift became even greater (several feet) and was the same for several more spans (about 5 or 6).

An interesting phenomenon became evident further out to the west. On many spans, the parapet section on the north side of the bridge was broken off and hanging down toward the water. After studying the cracks and other damage to the concrete, we conjectured that the spans had been picked up by the rising water and hit with the high winds coming from the north so that the north edge got picked up and slammed down several times. There were other parts of the deck that displayed evidence that the span had been picked up and dropped. The EB bridge to the south was slightly protected from this wind action and did not suffer the same damage.

From the WB lanes, we could see a pattern in the failure mode of the EB bridge. There might be a series of four spans that had collapsed. There always seemed to be one that started the chain reaction. It appeared that one had worked its way out laterally to the south and dropped into the water. Once that section was gone, the adjacent spans could move longitudinally somewhat under the dynamic loading of the storm and become unseated. These spans would drop into the water at one end while the other end dropped and landed in a position leaning against the pier. The series of inclined spans appears similar to what has been found after earthquakes have unseated spans.

Eventually, it was not possible to walk out farther west. Since these bridges are several miles long, there are many spans that could not be inspected from the ground. An aerial survey was better suited because it allowed a more global perspective on the failure patterns. There were at least two cars that were left stranded on the bridges, trapped by gaps in the bridge ahead and behind.

Site 8-3

Site 8-3 is a small bridge near Slidell, LA that was choked with debris so that there was no remaining waterway opening.

Site 8-4

Site 8-4 is Highway US-11 over Lake Pontchartrain. We approached the bridge from the north and were cleared by a military guard. The two lane bridge is functional but traffic is restricted for security reasons. This is one of two means of entering New Orleans form the north, the other being the Causeway which is further west.

As we drove south, there was a slight dip in the road profile. We asked the bridge gate keeper about it and she said confidently that that had been there for a long time and was not caused by Katrina. (We discovered later on *www.usgs.gov* that this may be over a geological fault.)

When we reached the lift span of the bridge, we stopped and talked with the operator. She said that this was her first day back on the job and that she had pleaded that she be allowed to come back to work so that she could begin to get back to a normal life. The tender's office had broken windows and debris in it that she was cleaning up. The bridge itself was operational though restricted to emergency response vehicles and employees of the railroad who were working on a parallel structure. There was still no power and there was some damage to the control mechanism but she was able to open the bridge as necessary by starting up a backup diesel generator.

When a boat approached and needed to pass, she had to go to the west side of the bridge and start up a diesel engine manually to lift the bridge. She said that her grandfather had worked on the original construction 87 years ago (someone else told us it was built in 1927). When asked about the new concrete deck, she knew immediately that it had been done in 2001. Since this bridge had survived so well, it appeared that the deck project was designed to make the bridge continuous for live load by tying the various spans together. This retrofit approach may have saved the bridge from collapsing in a domino fashion as the I-10 bridges had.

There were several sections of concrete railing that had failed and fallen into the roadway. This was a nonstructural failure apparently caused by severely corroded reinforcement between the deck and the railing.

Site 8-5

Site 8-5 is a railroad bridge over Lake Pontchartrain generally parallel to but just west of US-11.

Norfolk-Southern railroad was busy restoring track to their bridge which also runs N-S but sits just to the west of US-11. Looking from US-11, the structure seemed to be sound with damage limited to the tracks. The tracks were apparently stripped off by the storm similar to what we had seen at Biloxi Bay. Newspaper accounts (USA Today September 16, 2005) reported that this bridge became operational again on September 15, 2005.

The railroad bridge to the east of Route 11 was being repaired on September 8. Lengths of track and ties had been displaced, some entirely off the bridge into the water.

Site 8-7

The main span of the bridge carrying US Route 90 over the Chef Menteur Channel between Lake Pontchartrain and Lake Borgne is a steel truss on a turntable. It was built about 1930 and has suffered damage from previous hurricanes. The truss seemed to be in good condition with damage limited to pier settlement of the approach spans. The bridge was apparently closed prior to the hurricane for safety reasons and the main span was in its open position. This position offered the best protection from the storm, prevented use by vehicular traffic and allowed navigation in the aftermath of the storm. The Jersey barrier on the West side of the S approach has been hit with some sort of debris that caused extensive damage to the point of impact. This is nonstructural damage.

Site 8-8

We briefly saw some bridges in New Orleans but continued out of town so as not to get in the way of search and rescue operations. Inundated ramps were being used as boat launches.

Site 8-9

The toll Causeway over Lake Pontchartrain in Louisiana was reached September 8, 2005 about 7:00 p.m. This is a 24 mile long bridge leading into the City of New Orleans from the north. It normally carries four lanes of traffic but was closed after the passing of Hurricane Katrina on August 29, 2005. When the north end of the southbound (SB) bridge was reached by the reconnaissance team on September 8, both the NB and SB bridges were fully functional, but open for restricted use only. There were military security checkpoints established to prevent use by unauthorized persons. According to the guard, the only damage suffered as a result of the hurricane was at the north end of the SB bridge. The approach had been washed out and since repaired. The closure is not for structural reasons, it is to control access to New Orleans which is still operating under martial law. The Mayor has ordered all residents to vacate the city.

Friday, September 9, 2005

We had spent several very long days in the field and were getting behind on our reporting so we spent the day organizing field notes and photos and report writing.

Saturday, September 10, 2005

We left early Saturday morning and drove to the far west of Mississippi to inspect a few bridges that we knew had damage that we had not inspected yet.

Site 10-1

Highway 433 over Salt Bayou: This five-span concrete bridge was passable. It is oriented in a N-S direction. A person approached in a pickup truck and explained that his business in the NW quadrant of the bridge was wiped out so he was there assessing damage. He said that the bridge had also survived Hurricane Camille in 1969 but was left with some uneven settlement. He said that there was some new settlement this time. Pier settlement was obvious when looking at the elevation of the bridge and a sighting along the top of the parapets showed a broken curve. When we asked about water depth, he described a two story masonry building a few miles north where his son had had a business. He said it must have been deep because it took away the entire structure and only left evidence of where it stood because of remnants of a sign that was visible.

Site 10-2

Highway US-90 over the Channel between Lake Pontchartrain and Lake Borgne: Historic Fort Pike was at the south end of the bridge. After returning home, we learned that the bridge is also called the Rigolets Bridge. It is a long bridge with many spans on each end of the navigation channel. It was passable for motor vehicles but the moveable span was not operable. DOT maintenance crews were on hand to clean up debris and the mechanical systems.

The roadway had evidently been under water because there was an abundant amount of grass and other debris caught on the lower chord of the truss on the southeast side of the bridge.

The approach slab at the south end of the bridge was severely undermined, although it was still carrying traffic without distress. The surface exhibited no settlement and no cracking of the pavement.

Site 10-3

Highway US-90 over Chef Menteur Pass: This is a 1930’s vintage moveable bridge with multiple approach spans. The center truss span of the bridge was designed to swing open for navigation. When inspected from the west end on September 8, the bridge was found open (i.e., closed to vehicular traffic). It was in the same state today, reportedly so the Coast Guard could continue to use the channel for access to New Orleans. This looked to have been done prior to the Hurricane. It was still locked in the same position.

There was evidence of high water though difficult to determine a precise depth. No mud lines were left behind, just seaweed and grass, primarily caught on the lower chord of the SE truss.

The only evidence of damage was on the SW end of the bridge. One pier appeared slightly tipped as it would from undermining. This and adjacent piers appear to have suffered similar distress previously. Repairs had been made and extra shoring was in place. A slight shift in the superstructure was evident from above and looked like a recent change. The paint stripe was not continuous across the joint, indicating that the spans had moved relative to one another.

In this same area of the bridge, the concrete barrier on the west side had been hit by debris and caused damage.

We backtracked from Chef's Pass, going further eastward in Louisiana on US-90, going toward Mississippi. On Highway US-90, there are a series of five bridges; a vertical lift bridge over the West Pearl River, three almost identical multispan bridges, each of which has three old pony trusses in the center, and another moveable bridge over the East Pearl River. The river constitutes the border between the Louisiana and Mississippi

Site 10-4

Vertical lift bridge carrying US-90 over West Pearl River: This is where Bob's shrimp boat came down. Bob shared a harrowing story of being out on his shrimp boat when the storm hit. He had been trying to move the boat to refuge farther inland but the bridge was not operable so he was caught on the ocean side of the inlet. He felt lucky to survive.

Site 10-5 through 10-7

Between the West and East Pearl River, US-90 has three riveted truss spans that were freshly painted a silver color. There was no apparent damage. The painters scaffolding must have been hanging from the underside of the bridge because it was still tied off and visible over the edge. There was a lot of grass and seaweed hung up on the lower chord of the south trusses. Depth of water may have been more but measurements that day indicate that it must have been at least two feet above the roadway.

Site 10-8

US-90 over the East Pearl River: We drove up to this bridge from the west and talked with the foreman of the DOT maintenance crew. They were making repairs to the approach at the west end of the bridge.

The swing bridge was inoperable. It was in a position for navigation (closed to vehicular traffic). They said that the operator's office on the bridge had been flooded and that the electro-mechanical systems had been damaged. The mechanisms were binding up.

When I asked if they had any idea how high the water had been, the crews pointed to a utility pole with seaweed hanging from the wires. The pole was about 40 feet tall and the wires were just a few feet lower.

The foreman also pointed to a shrimp boat moored nearby and said that the owner was one of two people that he knew about that had ridden out the storm and survived. He pointed to a large tree that had a ten wheeler truck parked under it. He was told that only four feet of a tall tree was visible during the storm. By proportioning, I estimated that the tree to be almost 50 feet tall.

Site 10-8b

We stopped at a bridge that had severe erosion at the abutment even though it was a road crossing several miles from the coast.

Site 10-9 US-90 in Bay St. Louis

Site 10-10 CSX Railroad over St. Louis Bay

Site 10-11 Henderson Point

This site number was assigned to the site of a displaced span at Henderson Point, just east of where US-90 touches down on the east side of St. Louis Bay. The site was not investigated from the ground but was photographed during the aerial inspections of September 11, 2008. It is cited here to put it in context with other St. Louis Bay damage.

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