Reconnaissance of the New Orleans Hurricane and Storm Damage Risk Reduction System after Hurricane Gustav

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ABSTRACT: *On October 2 and 3, 2008, a group of civil engineers sponsored by the National Science Foundation (NSF) and organized by the Geoengineering Extreme Events Reconnaissance (GEER) Association, visited the New Orleans area to assess levee performance during hurricane Gustav. This paper summarizes the team's observations and understanding of the state of the New Orleans Hurricane and Storm Damage Risk Reduction System (HSDRRS) in the fall of 2008 and the performance of elements of the HSDRRS during Hurricane Gustav. The fundamental conclusion was that the HSDRRS performed well under the surge and wave stresses generated by Gustav. The team's observations led to lessons about dangers to floodwalls from boats and barges, the importance of timely preparation for hurricanes, erosion resistance of clay levees, and the need for continued emphasis on evacuation for life protection.*

KEYWORDS: hurricane, flood, levee

SITE LOCATION: Geo-Database

INTRODUCTION

The performance of the levees protecting New Orleans is a key to its social, cultural, and historic conditions. – Interagency Performance Evaluation Task Force (IPET), Executive Summary, 2008.

This paper focuses on geotechnical observations after Hurricane Gustav (2008), but also compares performance observations—especially for different levee systems—with observations made after Hurricane Katrina in 2005. Due to the massive effort after Katrina by the U.S. Army Corps of Engineers (USACE) to reconstruct the levees and associated structures in the Hurricane Protection System (HPS), New Orleans benefitted from a higher level of protection when Gustav hit. The reconnaissance group included engineers who had witnessed failure sites along the New Orleans levee system in the aftermath of Katrina, and the team had the benefit of learning from the extensive investigation performed by the Interagency Performance Evaluation Task Force (IPET) as reported in their ten-volume report, *Performance Evaluation of the New Orleans and Southeast Louisiana Hurricane Protection System*. The team made observations of the upgraded and renamed Hurricane and Storm Damage Risk Reduction System (HSDRRS) after Gustav swept through the region, with the tragedy of Katrina as the backstory.

Figure 1 shows the layout and status of the HSDRRS as reported by the USACE in June 2008, about two months before the arrival of Gustav. Our group visited selected locations along the HSDRRS; specifically, where the team knew breaches occurred during Katrina or where our USACE guides identified areas of interest. Table 1 lists the pre-Katrina HPS and June

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2008 HSDRRS structure elevations from Figure 1 for the various sites that the team visited or researched. The improvements to the HSDRRS as of August 2008 were, in many places, temporary, to provide a heightened interim level of protection until the planned improvements could be fully completed. The USACE reported completion of those improvements in May 2018.

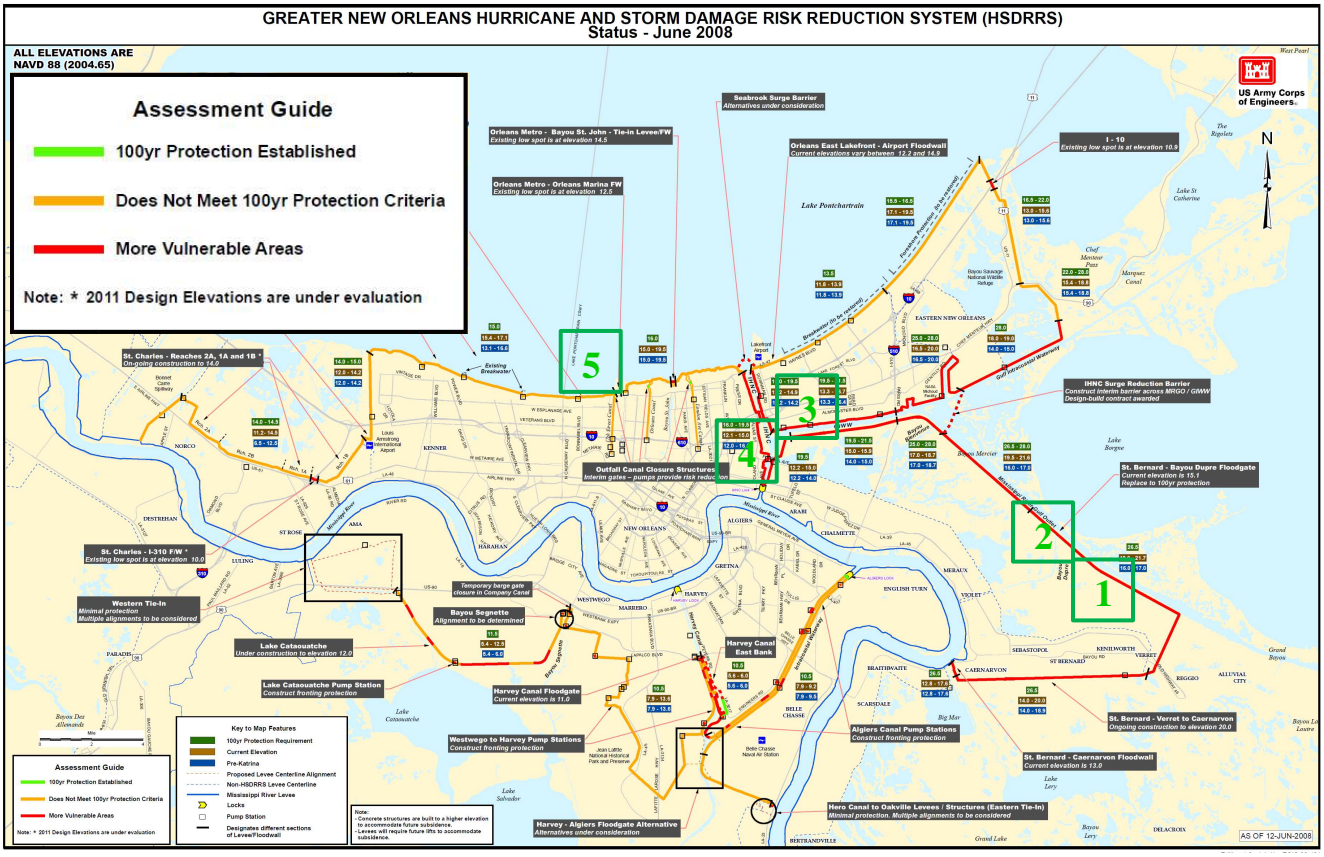


Figure 1. HSDRRS Status Plan, June 2008.
(http://www.mvn.usace.army.mil/hps/pdf/2008_Storm_Vulnerability_Elev_final.pdf)

Table 1. Comparison of pre-Katrina HPS structure elevations and June 2008 HSDRRS structure elevations for sites of interest, from Figure 1.

Site/Structure (see green numbers on Figure 1)	Pre-Katrina HPS Elevations	June 2008 HSDRRS Elevations
1 - Mississippi River Gulf Outlet - Frontage Levee	4.9-5.2 m (16.0-17.0 ft)	5.8-6.6 m (19.0-21.7 ft)
2 - Mississippi River Gulf Outlet - Bayou Dupree Gate	4.6-5.2 m (15.1–17.0 ft)	4.6-6.6 m (15.1-21.7 ft)
3 - Gulf Intracoastal Waterway	4.1-5.0 m (13.3–16.4 ft)	4.1-5.1 m (13.3-16.7 ft)
4 - Inner Harbor Navigation Canal	3.7-5.1 m (12.0-16.6 ft)	3.7-4.6 m (12.1-15.0 ft)
5 - Lake Pontchartrain - Interior Drainage Canals	4.0-5.9 m (13.1-19.5 ft)	4.7-6.0 m (15.4-19.5 ft)

BACKGROUND – KATRINA AND THE HSDRRS

Katrina

Hurricane Katrina changed everything about the flood protection system around New Orleans. The devastation caused by the flooding from Katrina and the subsequent recovery have defined New Orleans since the hurricane's August 29, 2005 landfall. The storm surge generated by Katrina overtopped much of the HPS levees and floodwalls in the New Orleans metropolitan area, and breached levees and floodwalls at many locations. At three or four locations, the floodwalls breached

at flood levels below the tops of the floodwalls, leading to intense scrutiny of design flaws and questioning the stability of all I-type floodwalls (I-walls).
The effects of Katrina awakened the public and the civil engineering profession to the importance of our flood protection infrastructure and, specifically in New Orleans, to the dependence of the city on the levees, floodwalls, gates, pump stations, and operations that separate the city from hurricane storm surges and waves. Prior to Katrina, this system was named the Hurricane Protection System (HPS). The USACE has since renamed the system as the New Orleans Hurricane and Storm Damage Risk Reduction System (HSDRRS) to advise us that the system does not eliminate the flood risk.

The devastating aftermath of Hurricane Katrina taught many lessons, including the identification of multiple deficiencies in the HPS. Most of these deficiencies have been well documented and disseminated to the public by the extensive IPET study and multi-volume report (IPET, 2008). Some of the most important of the documented deficiencies were: lack of overtopping protection, floodwall elements with marginal stability (poor design understanding of failure modes, low strength soils, and underseepage vulnerabilities), erosion at transitions between different components of the system, use of erodible materials for construction of earthen levees, improper design heights for hurricane protection components, varied and shifting vertical control datums, and general lack of resiliency (i.e. capacity to function during and after loading, including loads above design levels such as overtopping) and/or redundancy (more than one level of protection) for critical life safety structures. The IPET report noted that pre-Katrina hurricane protection did not perform as a system because of its incremental design and development over numerous years, resulting in inconsistent levels of protection.

Post-Katrina HSDRRS Repairs and Improvements (2005-2008)

The post-Katrina repairs and improvements to the HSDRRS for the New Orleans area protected the city from the storm surge during Gustav. The condition of the HSDRRS in September 2008 existed because of the efforts of the USACE in the short period of time between Katrina's devastation (2005) and Gustav's arrival (2008). As documented by the IPET study, surges associated with events more frequent than the 100-year event (1% annual probability of occurrence) would overtop the pre-Katrina level of protection provided by the HPS. Katrina did overtop that system in multiple locations and, in several of those locations, obliterated the levees.

The initial efforts by the USACE were to restore a level of hurricane protection until the system could be fully upgraded. By September 2008, levees had been restored to or above their pre-Katrina elevations. In addition to raised levees, the HSDRRS improvements increased the durability of the HSDRRS for events that might overtop the system elements. Specifically, the system elements were designed and constructed to resist erosion if overtopping occurs, to increase existing pump station operability and reliability during storm events, and to maintain pumping capacity in the event that high water levels occur at new pump stations. Specific improvements are described below:

Earthen Levee Reconstruction – The USACE designed and constructed repairs and improvements to the HSDRRS earth levees with two main purposes: (1) to raise the level of protection so that the likelihood of overtopping would be lessened, and (2) to improve the capacity of levees to withstand erosion during overtopping by using clay instead of silty sand fill. Figure 2 shows the eastern part of the HSDRRS plan along the Mississippi River Gulf Outlet (MRGO), which is a typical example of the reconstructed earthen levees, noting the elevations of the pre-Katrina levee crests (blue boxes) and the June 2008 levee crests (brown boxes). Figure 3 is a photograph of the raised earth levee at the southeast corner of the HSDRRS along the MRGO, which is a typical example of the reconstructed earthen levees.

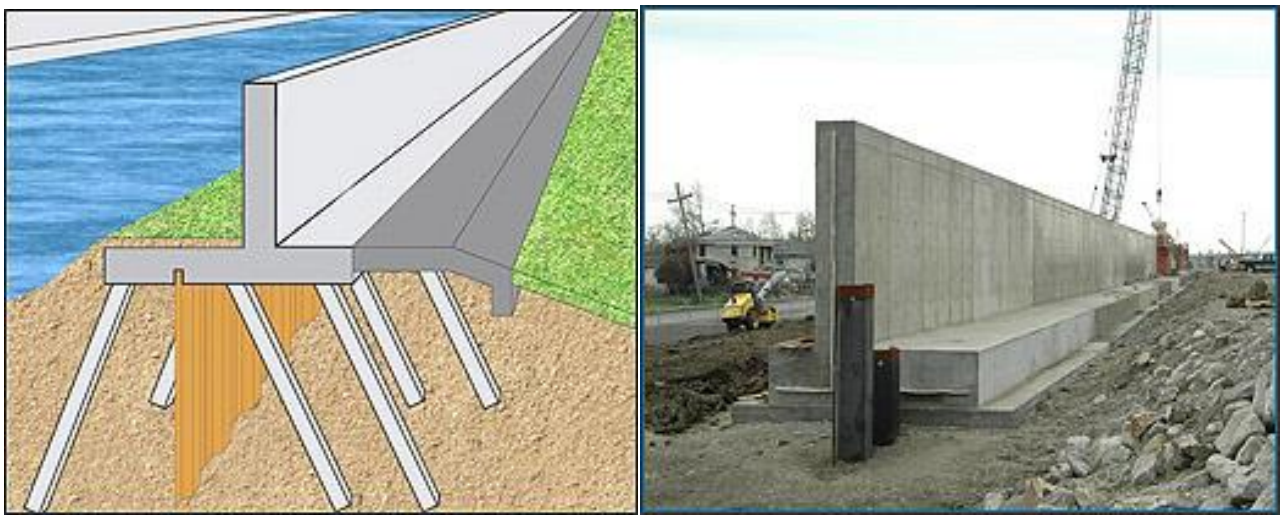
Floodwall Improvements – The USACE improved the HSDRRS floodwall protection by replacing breached and damaged floodwalls, upgrading existing floodwall stability, and hardening the protected side of floodwalls and floodwall-levee transitions. The stability of many I-walls was enhanced by raising the adjacent embankment support, and I-walls with marginal stability were replaced with T-walls or L-walls. Figures 4 and 5 respectively show a T-wall schematic and a photograph taken during the construction of a T-wall. Splash aprons of reinforced concrete or grouted riprap have been placed on the protected side of floodwalls for overtopping scour protection. Figure 6 shows a reinforced concrete splash apron on the protected side of the I-wall and T-wall on the west side of the Inner Harbor Navigation Canal (IHNC) along France Road adjacent to the former container terminal.



Figure 2. Section of HSDRRS plan, eastern New Orleans and St. Bernard Polders. (http://www.mvn.usace.army.mil/hps/pdf/2008_Storm_Vulnerability_Elev_final.pdf)



Figure 3. Southeast corner of the MRGO levee, flood side. (October 2, 2008, 29.8889°N, 89.7617°W)



Figures 4 and 5. T-wall schematic and photograph of T-wall under construction. (http://www.mvn.usace.army.mil/hps2/hps_outfall_canals.asp)



Figure 6. I-wall and splash apron, IHNC west along France Road; new L-wall and splash apron in background. (October 2, 2008, 90.0272° W, 90.0272° W)

Drainage Canal Closures – The USACE increased the flood protection for the drainage canals by constructing interim floodgates at the Lake Pontchartrain end of the canals to block storm surges from flowing into the canals and overloading the I-walls. Large pumping facilities were installed adjacent to the gates to provide a means of evacuating canal storm drainage around the gates when closed. Figure 7 shows a schematic of the canal closure structures.

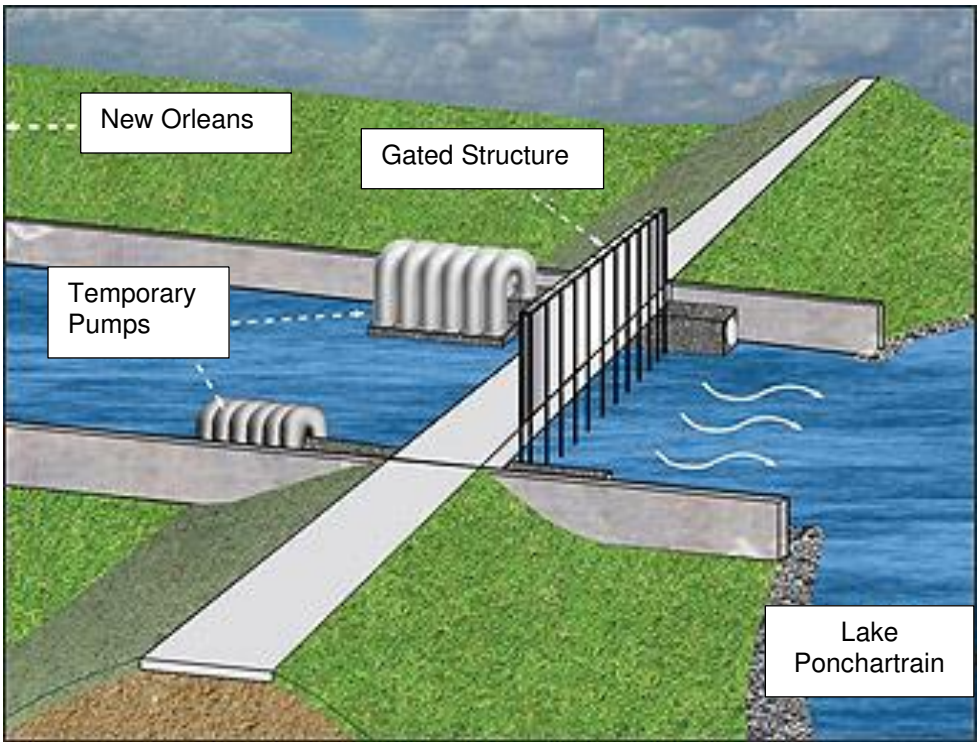


Figure 7. Schematic of canal closure facilities .(http://www.mvn.usace.army.mil/hps2/hps_outfall_canals.asp)

Pump Station Improvements – In 2005, the USACE was in the process of repairing, modifying, and rebuilding thirty of the seventy-three area pump stations by ensuring backup power, strengthening the structures, and flood proofing the facilities and equipment.

Overall System Design and Management – The major finding of the IPET investigation was that the HPS at the time of Katrina "did not perform as a system", citing incomplete elements of the system, datum misinterpretation, variable levels of protection and design, and incremental decisions that "systematically increased the inherent risk in the system without recognition or acknowledgment" (IPET, 2008). In contrast, the HSDRRS was designed by the USACE as a coherent system with consistent and coordinated standards, functions, and redundancies, and has been managed and operated as a system by the USACE in cooperation with two regional Levee Boards instead of the sixteen that existed when Katrina hit.

HURRICANE GUSTAV

Hurricane Gustav entered the Gulf of Mexico on August 31, 2008, with maximum sustained winds of 135 mph (Category 4) and a minimum central pressure of 958 millibars. The track for Hurricane Gustav is shown in Figure 8. It made landfall just west of Grand Isle in Cocodrie, Louisiana, at about 9:30 AM on September 1, 2008. At landfall, Gustav had maximum sustained winds of about 177 km/hour (110 miles/hr) (Category 2), a minimum central pressure of 955 millibars, and a Radius of Maximum Wind of 46 km (25 nautical miles). Hurricane force winds extended out 129 km (70 nautical miles) from its center at landfall.

As visible in Figure 9, the storm surge from Hurricane Gustav reached a maximum level, almost 4.3 m (14 ft) (North American Vertical Datum of 1988, NAVD 88), southeast of New Orleans in the marsh bordering Black Bay . Along the New Orleans HSDRRS, the greatest storm surge levels were in the Inner Harbor Navigation Canal (IHNC), also referred to as the Industrial Canal. At the IHNC Lock, the peak water level reached 3.4 m (11 ft). In contrast, the peak storm surge levels in the IHNC during Hurricane Katrina were approximately 1 m (3 ft) higher (IPET 2008), given that the measured peak water level at the IHNC Lock during Katrina was 4.4 m (14.4 ft). Figure 10 shows hindcast hydrographs illustrating the difference in flood levels between Katrina and Gustav at the north end of the MRGO waterway levee.

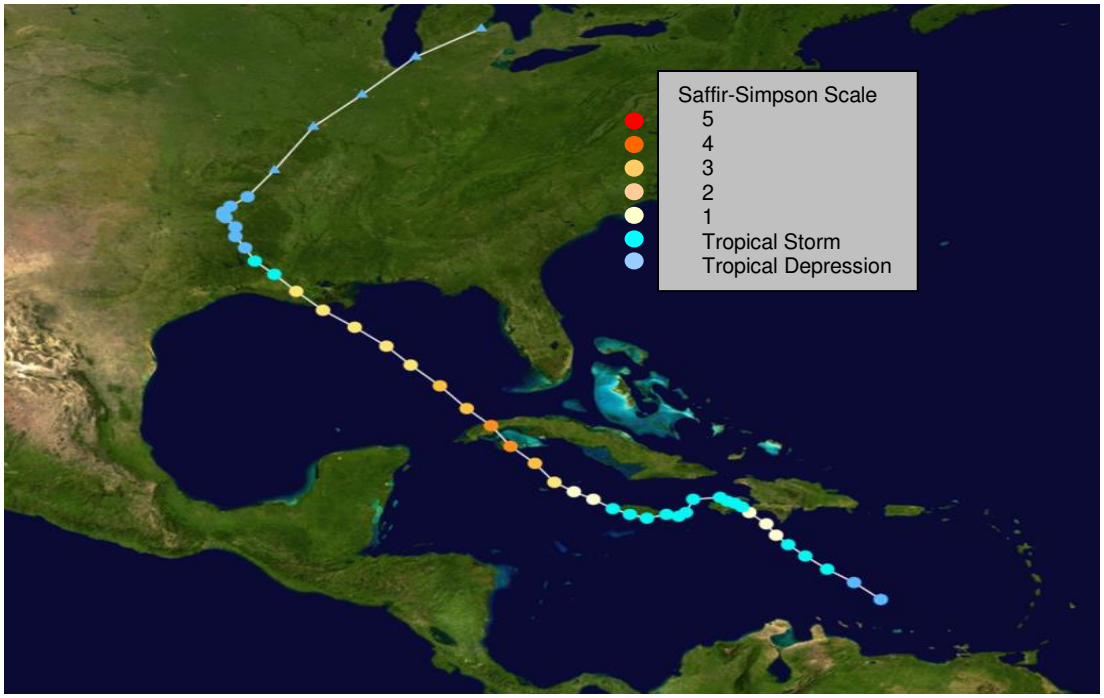


Figure 8. Track of Hurricane Gustav. Picture adapted from National Hurricane Center with background from National Aeronautics and Space Administration (NASA) satellite imagery.

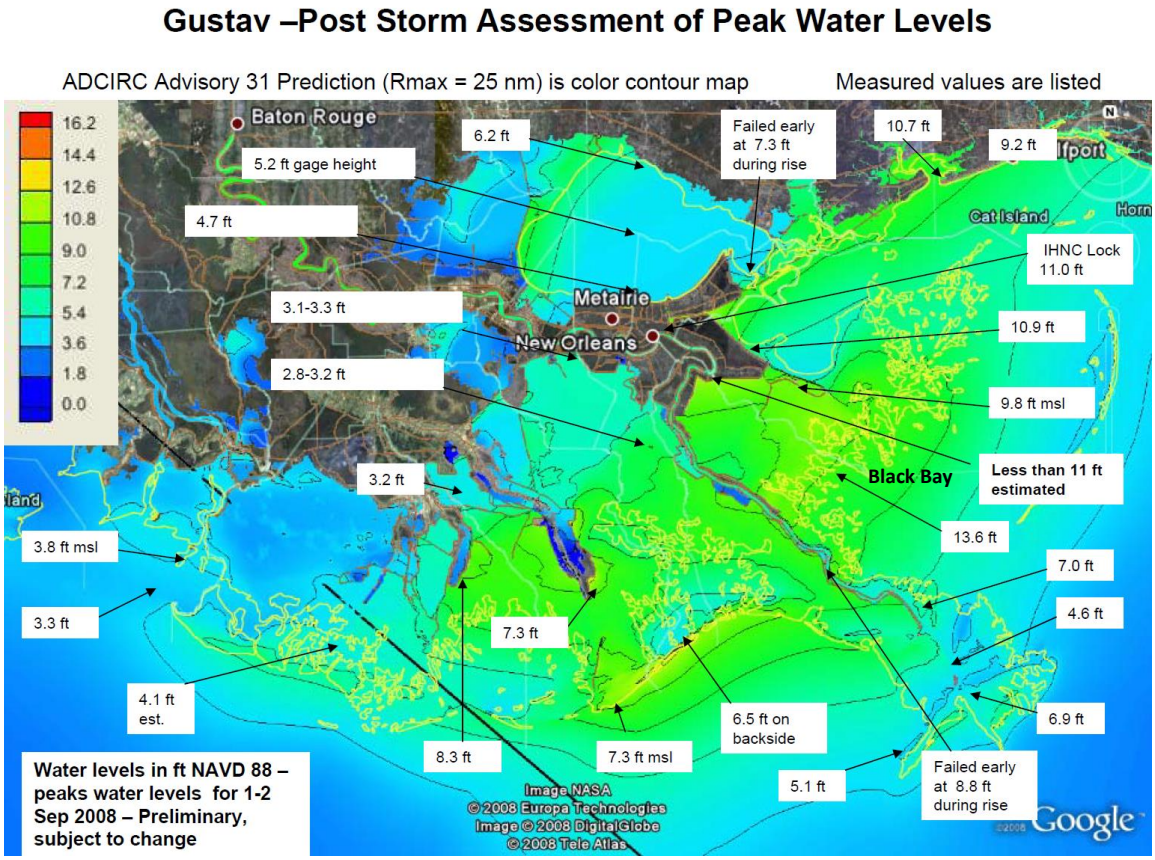


Figure 9. Post-storm assessment of peak water levels during Gustav based on measurements and observations. Only Imperial units were given. Graphic based on preliminary data. (USACE, New Orleans District)

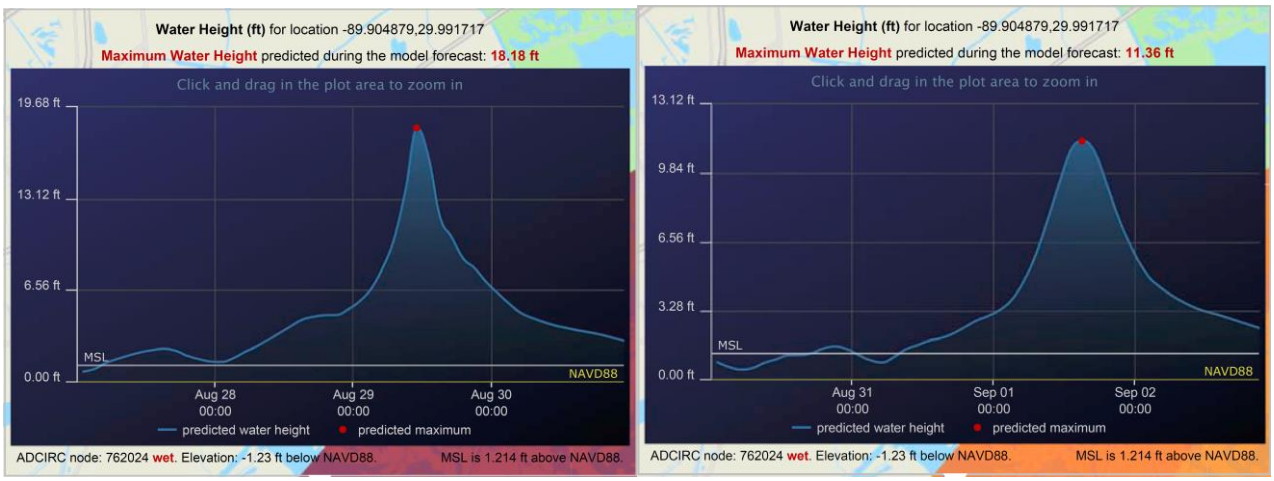


Figure 10. Hindcast hydrographs for Katrina (left, 5.5 m [18.2 ft] peak) and Gustav (right, 3.5 m [11.4 ft] peak) storm surges along MRGO levee. Only Imperial units were retrieved. (https://cera.coastalrisk.live/)

HURRICANE AND STORM DAMAGE RISK REDUCTION SYSTEM PERFORMANCE DURING GUSTAV

It was obvious but perhaps underappreciated that the HSDRRS successfully protected New Orleans during the Gustav storm surge. As a result, our reconnaissance fortunately did not encounter scenes of devastation such as those seen by investigators of the HPS following Katrina.

The GEER team reconnaissance focused on areas of the HSDRRS that were stressed during Gustav. Our observations were not comprehensive but selective. Engineers with the USACE acted as our guides and provided supplementary observations, data, and information about the HSDRRS and Gustav. Our reconnaissance would have been much more limited and inefficient without the USACE help. Our observations follow.

Mississippi River Gulf Outlet - Frontage Levee

The frontage levees along the Mississippi River Gulf Outlet (MRGO) channel are the closest elements of the HSDRRS to the open waters of the Gulf. These earthen embankments experienced the earliest and highest water levels during both Gustav and Katrina. The high-water levels during Katrina overwhelmed the MRGO frontage levees, with overtopping along the entire stretch of the MRGO and eroded significant lengths of the levee. Figure 11 shows a section of the MRGO frontage levee and the typical extent of the erosion damage caused by the Katrina overtopping.



Figure 11. Post-Katrina MRGO frontage levee. (October 14, 2005, ~89.8° W, ~29.9° N, L. Harder)

The team observed no signs of either erosion or overtopping during Gustav along the southeast sections of the MRGO frontage levee, which the team believes was representative of the MRGO frontage levees. Based on the limited debris lines along the levee, the high water levels during Gustav were well below the crest of these rebuilt and elevated earthen embankments. The wave and current actions of Gustav also appeared to have caused no erosion on the earth embankments. Figure 12 shows a typical view of the MRGO frontage levee embankment in October 2008.

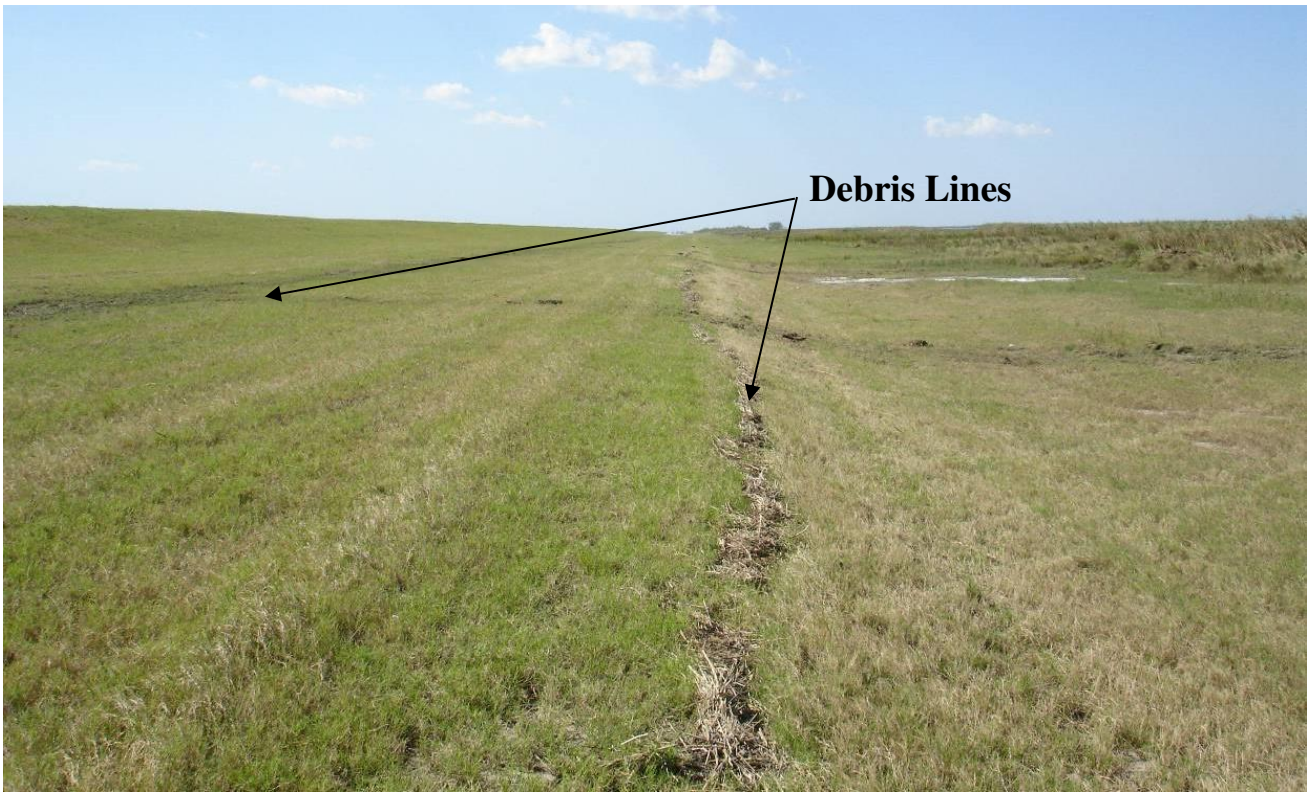


Figure 12. MRGO frontage levee, flood side, looking northwest. Upper debris line, believed to be due to Gustav, was cleared prior to our visit, probably as part of the ongoing efforts to maintain the protective grass cover. The lower debris line may represent the high-water level during hurricane Ike, which followed Gustav in September 2008. (October 2, 2008, 29.8889°N, 89.7617°W)

Mississippi River Gulf Outlet - Bayou Dupree Gate

The Bayou Dupree gate structure on the MRGO suffered several severe breaches during Katrina, which overtopped the entire structure by 0.6 to 1.5 m (2 to 5 ft). Figure 13 is an October 2005 photo of the gate structure following Katrina, showing breaches at the I-wall section and at the transition from the I-wall to the embankment.

Figure 14 shows the improvements constructed by the USACE to the same Bayou Dupree gate structures. The concrete sheet pile I-wall was replaced with a steel sheet pile cofferdam section, and the transitions to the earthen levees on both sides of the gate were elevated and covered with grouted riprap. The use of grouted riprap to harden vulnerable areas around the gate was extensive, as illustrated in Figure 14. Ungrouted riprap was placed as erosion protection at the toe areas of grouted riprap. The team observed no signs of erosion or damage from Gustav's high water and waves at or near the gate. The limited debris line on the northwest flank appeared to indicate that the highest waters from Gustav were about 1 to 1.5 m (3 to 5 ft) below the crest of any of the gate structure elements (see Figure 14).

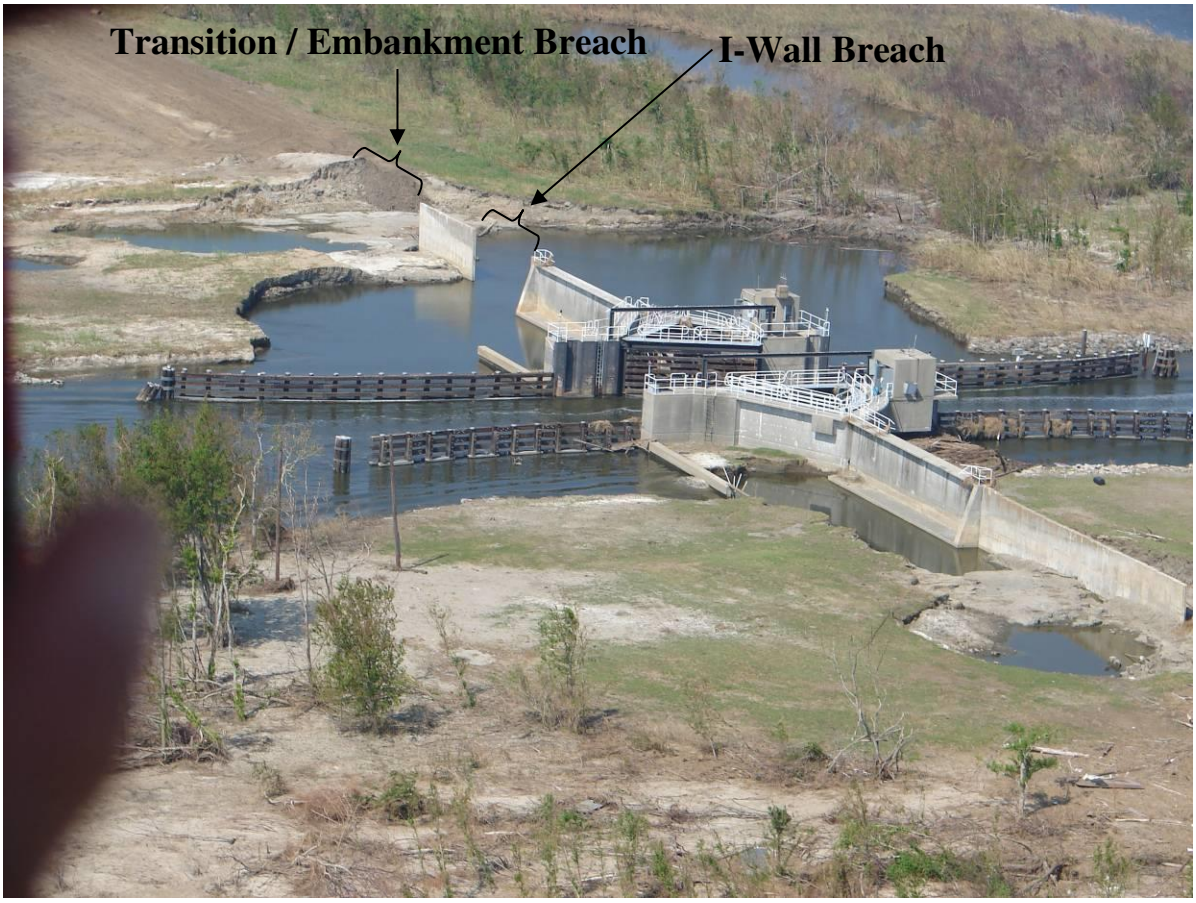


Figure 13. Post-Katrina Bayou Dupree gate. (October 14, 2005, 29.935° N, 89.837° W, L. Harder)

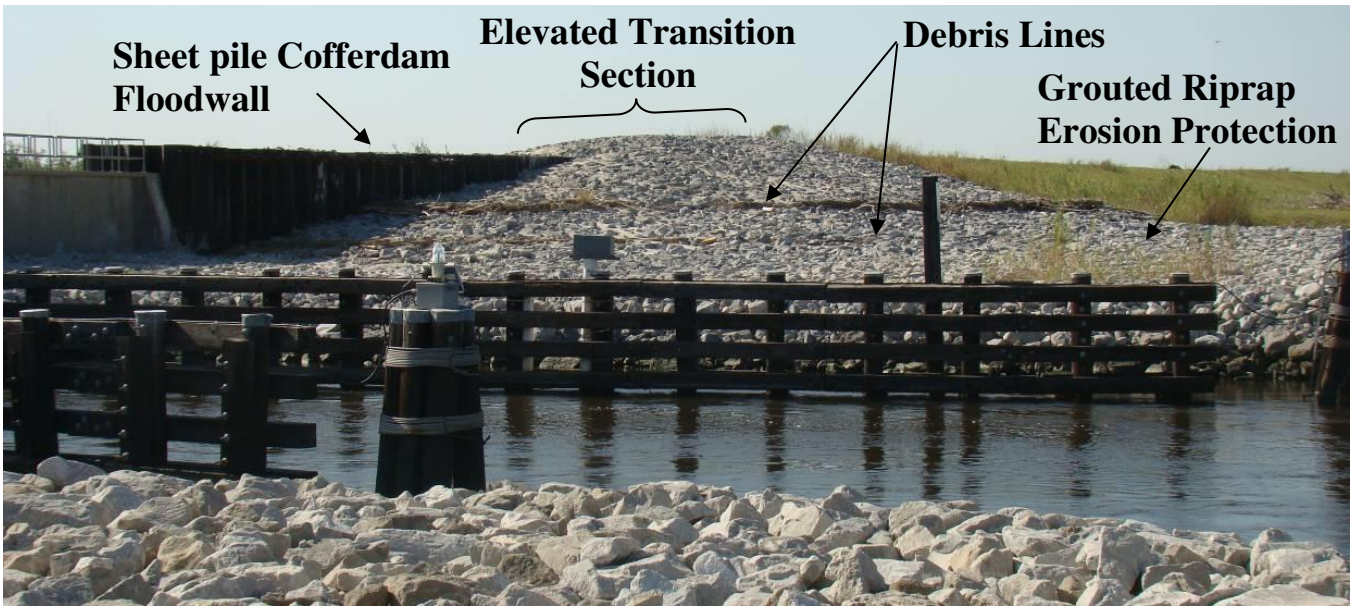


Figure 14. Bayou Dupree gate, northwest flank, MRGO side, looking east. The lower debris line may represent the high-water level during Hurricane Ike. (October 2, 2008, 29.9352° N, 89.8358° W)

Gulf Intracoastal Waterway (As Described by USACE)

The team did not visit the levees along the Gulf Intracoastal Waterway (GIWW) and relied on descriptions provided by USACE representatives. The post-Gustav damage assessments conducted by representatives of USACE and the local levee agencies noted no signs of erosion, overtopping, instability, or seepage of those levees. Furthermore, the levee/structure transitions were all found to be in good condition. Prior to the landfall of Hurricane Gustav, work was being conducted to raise the levees on the south side of the GIWW between IHNC and the GIWW/MRGO confluence. Despite the limited grass growth on the levee, no erosion was observed during the inspection.

Inner Harbor Navigation Canal (IHNC)

The storm surge from Hurricane Gustav in the metro New Orleans area was most dramatic along the IHNC, where several previous floodwall and levee failures resulted in catastrophic damage during Hurricane Katrina. Waves from Gustav overtopped the floodwalls at some locations along the western side of the IHNC. Figure 15 shows the locations of our reconnaissance along the IHNC.

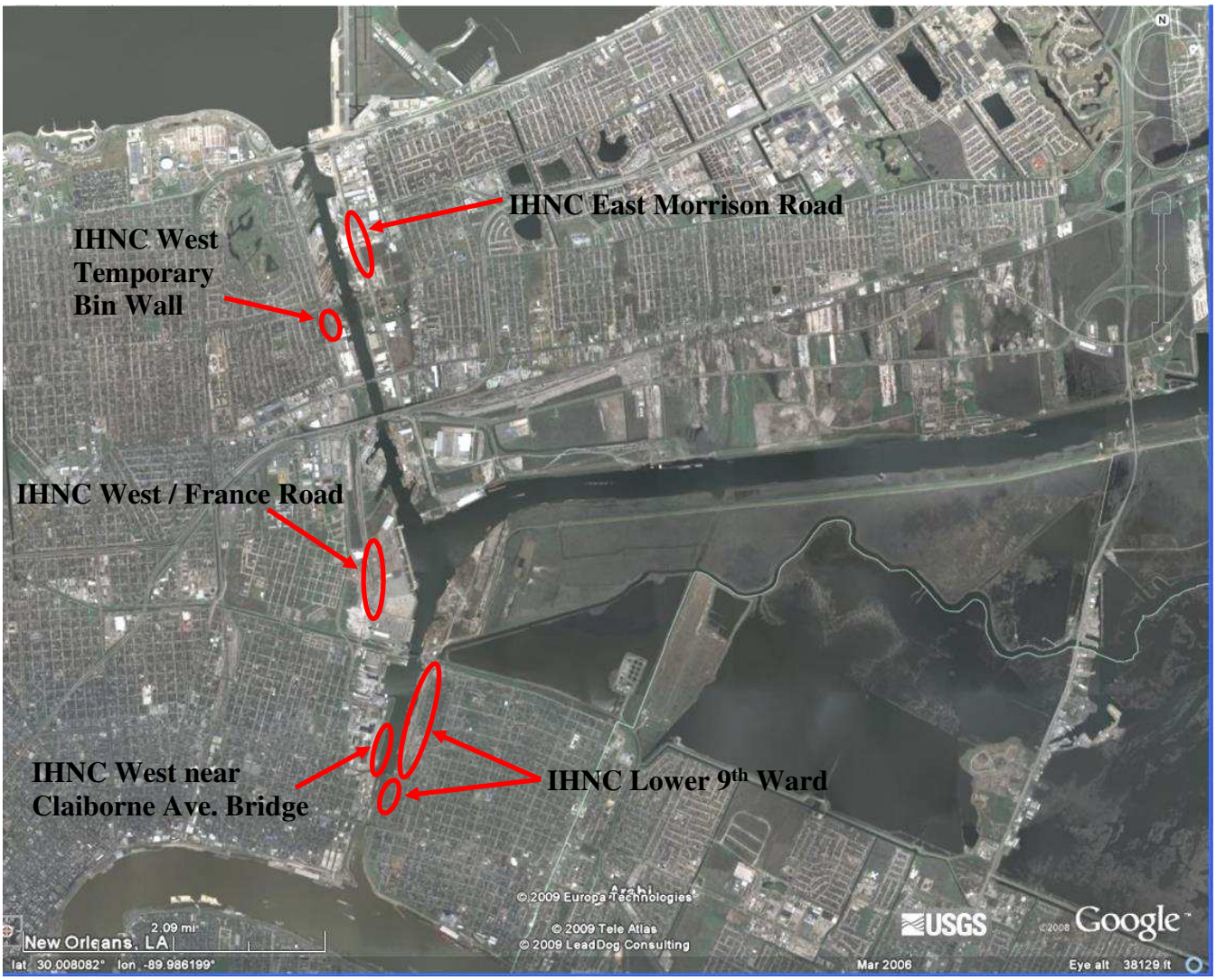


Figure 15. Areas of reconnaissance along IHNC. (Google Earth Image)

IHNC West / France Road

On the western central section of the IHNC (see Figure 15), opposite the junction of the IHNC with the GIWW, the floodwall/levee system is located landward of industrial port facilities, up to about 460 m (1500 ft) from the IHNC. France Road and a railroad parallel much of this part of the HSDRRS. Overtopping surge and waves during Katrina resulted in three breaches in this area.

Post-Katrina repairs and improvements of these failed and distressed sections included raising and buttressing embankment sections, armoring of embankment-concrete floodwall transitions, replacement of I-walls with L-walls (T-walls were not used due to space constraints), and buttressing of pre-existing I-wall sections to reduce the stick-up height (the height of wall above finished grade). Figures 16-19 show the post-Katrina (October 2005) and post-Gustav (October 2008) conditions at the locations of the earth levee breach (Figures 16 and 17) and of the I-wall breach (Figures 18 and 19) that occurred during Katrina.



Figure 16. Post-Katrina IHNC West levee breach site, October 2005 (The breach had been temporarily repaired; note scour hole). (October 4, 2005, 29.9880° N, 90.0263° W, L. Wooten)



Figure 17. IHNC West new embankment and floodwall at location of breach, as was shown in Figure 14, in October 2008. (October 2, 2010, 29.9880° N, 90.0263° W)



Figure 18. IHNC West I-wall Katrina breach site, October 2005. (October 4, 2005, 29.9899° N, 90.0272° W, L. Wooten)



Figure 19. New L-wall and old I-wall transition near location of Katrina I-wall breach on IHNC West. (October 2, 2008, 29.9899° N, 90.0272° W)

The repairs and improvements of these sections of the hurricane protection appeared to have performed well in light of clear evidence of wave overtopping. Figure 20 shows the debris left by overtopping waves on the protected side of one section of new L-wall along the IHNC West.

At the transition between the new L-wall and the old I-wall (Figure 6), there was storm debris left on top of and behind the higher L-wall, while the top of the lower I-wall was left clean. It is possible that the water elevation or waves during the peak storm surge exceeded the top of the old I-wall on a more consistent basis (elevation of about 4.3 m [14 ft], NAVD88) at this location, sweeping wave debris from the wall top.



Figure 20. Protected side of new L-wall along IHNC West. Note debris left by overtopping on floodwall and slope protection. October 2008. (October 2, 2008, 29.9899° N, 90.0272° W)

IHNC West, Near Claiborne Ave. Bridge

Clear photographic evidence showed wave overtopping during Hurricane Gustav along the T-wall located on the west side of the IHNC just north of Claiborne Avenue (see Figure 15 for location, and Figures 21 and 22 for photographs during hurricane). This T-wall had previously survived Hurricane Katrina. A concrete splash apron at the toe of the wall on the protected side was added after Katrina to protect from erosion. The wall performed well during Gustav. During the field reconnaissance, the team saw no noticeable sign of distress in the wall, including the joints between concrete panels and in the new concrete splash apron. There was evidence of minor erosion beyond the splash apron on the protected side as well as debris left by the overtopping (Figure 23).



Figure 21. Photograph from September 1, 2008, of Gustav's storm surge. Photograph taken from Claiborne Ave. Bridge looking north. The waves are overtopping the T-wall. (September 1, 2008, 29.969° N, 90.027° W, USACE)



Figure 22. Gustav's storm surge along IHNC East, taken from Claiborne Ave. Bridge looking north at T-wall southeast on September 1, 2008. (September 1, 2008, 29.969° N, 90.027° W, USACE)



Figure 23. Photograph from October 2, 2008, of IHNC West T-wall (same section as shown during Gustav in Figures 20 and 21). (October 2, 2008, 29.970° N, 90.026° W)

IHNC - Lower 9th Ward

Two breaches occurred during Hurricane Katrina on a stretch of I-wall between Claiborne and Florida Avenues on the east side of the IHNC. Water flow through these breaches flooded the Lower 9th Ward. The suspected cause of the southern-most breach was loss of soil support due to overtopping erosion on the protected side of the I-wall (Figure 24), while the suspected cause of the northern-most breach was a stability failure before the surge level reached the top of the wall.

This entire stretch of I-wall, even the section between the two breaches that survived Katrina, was replaced with a T-wall (Figures 3, 4, and 25). The I-wall section south of Claiborne Avenue that did not breach in Katrina was left in place but was reinforced with a larger earthen berm and a buttressing structural concrete splash apron to strengthen the section, reduce the wall height, and provide overtopping scour protection (Figure 26).



Figure 24. Post-Katrina IHNC East floodwall with southern-most breach and the scour, looking north, from the Claiborne Avenue Bridge. (October 11, 2005, 29.9685° N, 90.0238° W, L. Harder)

During Hurricane Gustav, both the old I-wall and the new T-wall sections were loaded to near their pre-Katrina design surge level. The peak still water level was 0.5 m (2 ft) below the top of the new T-wall section (Figure 25). After Gustav, there were no noticeable signs of distress at either the transition between the old I-wall and the new T-wall or along the new stretch of T-wall. Furthermore, there was no visible evidence of underseepage on the protected side. However, a water main leak on the protected side just south of the Florida Avenue Bridge caused water to pond on the ground surface. Consequently, in this area, it was difficult to determine what might have been under-seepage and what was the result of a water main leak.

The team noted a 2- to 3-cm-deep (~1-inch-deep) vertical offset between the pile-supported base of the T-wall and the slab-on-grade concrete splash apron (Figure 27). This offset, if the splash apron was cast to be flush with the base of the wall in the summer of 2006, may indicate a differential settlement of the apron relative to the pile-supported T-wall occurring at a rate of about 1 cm per year (0.5 inch per year) in the upper 21 m (70 ft) of the soil profile.

Along the east side of the IHNC south of Claiborne Avenue, the peak still water level was near the top of the old I-wall, and waves apparently overtopped the wall. The top of this wall was at about an elevation of 4.0 m (13 ft), NAVD88. After Gustav, the wall showed no noticeable signs of distress such as movement of the wall due to the surge load or erosion at the toe due to waves overtopping the wall (Figure 26). Also, there was no visible evidence of underseepage on the protected side.



Figure 25. Gustav storm surge at IHNC East floodwall, taken from the Claiborne Avenue Bridge, looking north toward Florida Avenue Bridge (seen in background) from a perspective similar to that in Figure 18. (September 1, 2008, 29.9686° N, 90.0241° W, USACE)



Figure 26. Hardened I-wall along east side of the IHNC south of Claiborne Avenue looking north (IHNC is to the left and Lower 9th Ward / Holy Cross to the right). (Oct. 2, 2008, 29.9682° N, 90.0250° W)



Figure 27. New T-wall section along the east side of the IHNC between Claiborne and Florida Avenues (shown in Figure 23 during Gustav). (October 2, 2008, 29.9691° N, 90.0236° W)

IHNC - East Morrison Road

The team visited the section of the HSDRRS near East Morrison Road in New Orleans East to investigate the USACE preliminary reports of damage to the relief wells and of soil moving through the wells. Much of the HSDRRS in this section of New Orleans East along the northeast section of the IHNC consisted of I-walls set in earthen embankments with regularly spaced relief wells located at the toe of those embankments (see Figures 28 and 29). These features were in place at the time of Katrina. After Katrina, the USACE added a grouted riprap splash apron on the protected side of the I-walls.



Figure 28. IHNC floodwall near East Morrison Road. Note splash apron (center) and relief wells (left). (October 2, 2008, 30.0248° N, 90.0295° W)

The team observed no signs of damage to the HSDRRS near East Morrison Road due to Hurricane Gustav. The corrugated metal protective casings over the relief well outlets were in various states of deterioration. The team also did not see evidence of extensive sand migration out of the wells, although our observations were made more than a month after Gustav had swept through the region, and the team did not inspect all wells. The inset photo in Figure 28 was taken from the USACE Situation Report dated September 5, 2008, which shows a damaged outlet casing and sand that appears to have discharged from the well.



Figure 29. Relief well cover, as of October 2008, with inset taken from the USACE Hurricane Gustav Damage Assessment Team SITREP on September 5, 2008. (October 2, 2008, 30.0249° N, 90.0294° W)

IHNC - West Temporary Bin Wall

Immediately prior to Gustav, the USACE constructed a ~550-m- (~1800-ft-) long temporary bin wall using HESCO baskets to protect one length of the I-wall along the northwest side of the IHNC that did not meet required stability criteria. Figure 30 shows the temporary bin wall under construction by the USACE, and Figure 31 shows the bin wall immediately after Gustav.



Figure 30. Temporary bin wall under construction, IHNC West along France Road. (August 2008, 30.0157° N, 90.0324° W, http://www.mvn.usace.army.mil/HPS/Status%20Report%20Newsletters/Sept_9_2008.pdf)



Figure 31. End of temporary bin wall at tie-in to I-Wall, post-Gustav (September 20008, 30.0122° N, 90.0313° W, http://www.mvn.usace.army.mil/HPS/Status%20Report%20Newsletters/Sept_9_2008.pdf)

The majority of the bin wall was constructed about 15 m (50 ft) outboard of and parallel to the I-wall, with two tiers of baskets. The lower tier was four baskets wide and the upper tier was two baskets wide. The top of the bin wall was about 0.6 to 1.0 m (2 to 3 ft) lower than the top of the adjacent floodwall. Surge and waves from Gustav left debris on the first tier (with a height of 0.9 m [3 ft]) of the bin wall but not on the top of the second tier. The bin wall appears to have protected this section of floodwall from any loading during Gustav. If Gustav had generated a storm surge higher than the bin wall, the existing I-wall would have been loaded but to a lesser degree because of the bin wall. Specifically, the bin wall would have: (1) reduced the period of loading, (2) reduced wave loading, and (3) lengthened the seepage path during pre-overtopping periods.

IHNC - Bridges, Ships, Boats, and Barges

The empty barge that floated into the Lower 9th Ward following Katrina and Rita has been well-documented (see Figures 24 and 32). There has been speculation that this barge or another barge could have contributed to the failure of the Lower 9th Ward I-wall. The high winds of a hurricane can easily push an empty vessel with enough force to break mooring lines and force the vessel into structures along the IHNC. Such was the case during Hurricane Gustav. The U.S. Coast Guard (USCG) has jurisdiction over the ships and barges in the IHNC.

Figure 33 shows how ships and barges were pushed during Gustav against the dolphins protecting the northern railroad bridge that crosses the IHNC just south of the I-10 bridge. This railroad bridge was in the lowered position and thus remained underwater during periods of high water. The Florida Avenue Bridge to the south of these barges and ships was in a slightly raised position so as to be out of the water, but low enough to keep wind loads from having leverage on the support towers. In these positions, both bridges would have confined the ships and barges to the central part of the canal. In preparation for the subsequent hurricane, Ike, the USCG ordered all ships and barges removed from the IHNC.



Figure 32. Barge in the Lower 9th Ward after Katrina. (October 4, 2005, 29.9703° N, 90.0230° W, L. Wooten)



Figure 33. Ships and barges pushed against a railroad bridge after Gustav. (September 1, 2008, 30.0050° N, 90.0251° W, Eric Gay, Associated Press)

Lake Pontchartrain - Interior Drainage Canals

The performance of the HSDRRS along the interior drainage canals (London Avenue, Orleans Avenue, and 17th Street Canals) is critical to the protection of New Orleans, especially in light of the three major breaches that occurred during the Katrina storm surge. Failures of the 17th Street Canal and London Avenue Canal floodwalls were responsible for a significant portion of the flooding in New Orleans because those breaches extended below sea level and continued to flow after the Katrina storm surge receded.

As of September 2008, the USACE had constructed canal closure gates and pumping systems at the north ends of each of the three interior drainage canals. A safe water elevation (SWE) was established for each canal. The gates at the 17th Street Canal and at the London Avenue Canal were closed on the evening of September 1, 2008, when water levels came within 0.3 m (1 ft) of the SWE (El. 2 m [5 ft] for 17th Street and El. 1.8 m [6 ft] for London Avenue). The pumping systems at these two structures were also activated to allow the Sewerage and Water Board of New Orleans to continue operation of their storm water system pumps, which dumped into the canals. All systems performed well, and canal levels were kept between El. 0.6 m and 0.8 m (2.0 ft and 2.5 ft). The gates and pumps on the Orleans Avenue Canal were not operated because storm surge levels did not approach the SWE (El. 2.4 m [8 ft]) for that canal.

Floodwall and levee repairs and improvements to close and upgrade the breaches along the 17th Street and London Avenue Canals showed no effects from the modest loads imposed by Gustav prior to and after gate closure. T-walls replacements at the breached I-wall locations were not distressed, nor were the walls subjected to significant loads, due to the protection provided by the canal gates and pumps. The additional wave energy and overtopping protection that was added at the entrances of the interior drainage canals and at transitions provided a higher level of resiliency, which was not severely tested by Gustav.

Lake Front Levees and Floodwalls

The USACE reported no signs of erosion, overtopping, instability, or seepage distress from Gustav along the lakefront levees and floodwalls. Our limited observations were consistent with the USACE reports. High water levels only reached about El. 1.4 m (4.7 ft) on the lakefront in New Orleans.

PLAQUEMINES PARISH NON-FEDERAL LOCAL LEVEE

The team visited one length of non-federal back levee, which was constructed and maintained by Plaquemines Parish and which is not considered part of the New Orleans area HSDRRS. Our team observed about half of the northeastern-most back levee of the Parish, located as shown in Figure 34.

Plaquemines Parish workers, emergency workers from St. Bernard and Orleans Parishes, and the USACE were reported to have responded during Gustav to help prevent a breach of the levee. The Caernarvon Mississippi River Diversion gates were also reported to have been opened in an effort to drain high flood waters in the Clearwater Canal, which abuts the northeastern edge of the back levee, to the lower level of the Mississippi River (Vanacore 2008).

At the time of our visit, multiple sections of the levee crest were still covered with a slit-film woven geotextile, held in place with a continuous sand bag berm on the flood side and by intermittent sand bags on the protected side of the crest. Based on our observations and on interviews with a pump station operator, it appears that much of the back levee was overtopped and that a slope slide or slough had occurred on the protected side of the levee along one ~90-m- (~300-ft-) long levee section as shown in Figure 35. Figure 36 shows a part of the scarp for that slough. The team also observed that desiccation cracks were prevalent along parts of the levee. The desiccation cracks may have contributed to the slide by allowing overtopping water pressures into embankment zones critical to slope stability. The placement water content, compaction, and organic content of the back-levee soils were not known and may be factors in the susceptibility of the levee soils to desiccation cracks and erosion.

Along more southerly sections of the levee, the team observed signs of overtopping with less dramatic effects. Debris from overtopping and erosion gullies, often covered with sand bags, was prevalent along all sections of the levee.

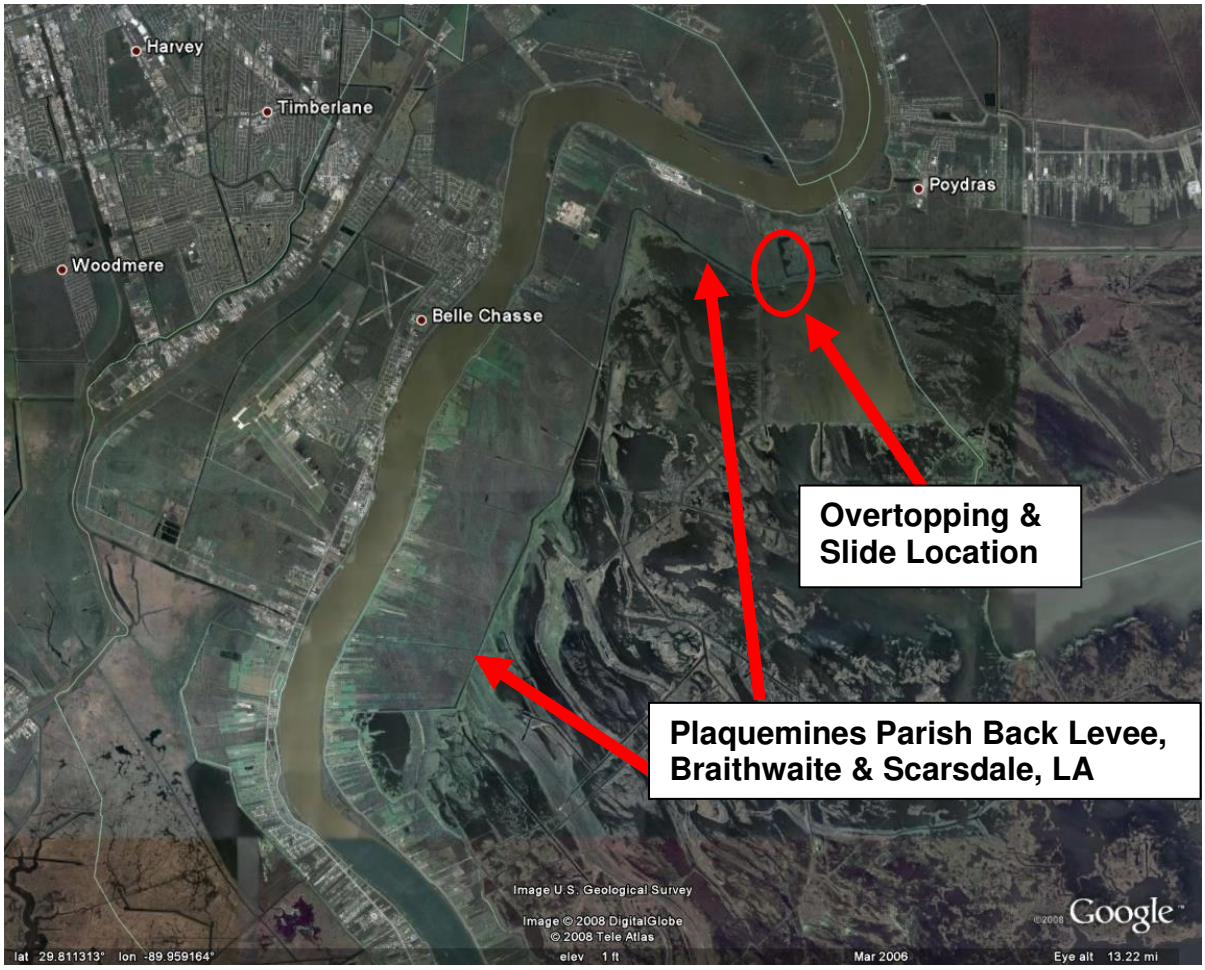


Figure 34. Plaquemines Parish back levee near Braithwaite and Scarsdale, LA. (Google Earth / USGS Imagery)



Figure 35. Protected side slope of the Plaquemines Parish back levee and slide. (October3, 2008, 29.8506° N, 89.9085° W)

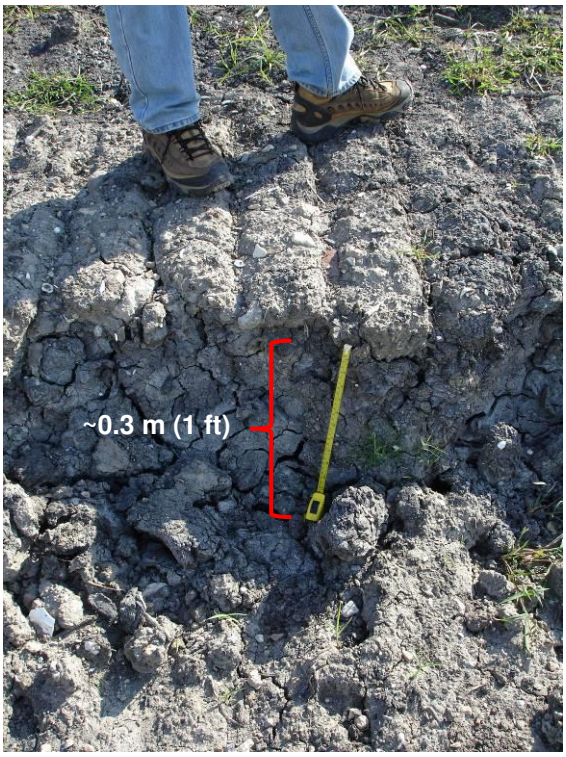


Figure 36. Scarp above slide on Plaquemines back levee. (October3, 2008, 29.8506° N, 89.9085° W)

CONCLUSIONS AND LESSONS LEARNED

Our fundamental conclusion was that the HSDRRS around New Orleans performed well under the surge and wave stresses generated by Gustav. The team observed no signs of distress in the HSDRRS as a result of that hurricane. Performance of the levees and floodwalls after Gustav demonstrated a significant improvement of the system since Katrina. Many of the most serious deficiencies identified after Katrina were addressed. Where storm surge waters and waves reached or exceeded the heights of levees and floodwalls along the IHNC, the flood protection showed an improved durability. The increased heights of a number of levee sections provided protection greater than that provided by the HPS prior to Katrina, and potential levee or floodwall breaching and resulting damage may have been averted due to these improvements.

Gustav imposed lower water levels and loads on the HSDRRS than did Katrina. A storm reaching or exceeding Katrina's level can be expected to occur in the future, and the performance during Gustav may not provide an accurate representation of the level of protection (or damage) that could occur during such an event.

Significant further improvements, such as the Lake Borgne Barrier gate structures created to prevent storm surges into the IHNC, have been constructed since Gustav. Completion of the entire suite of HSDRRS improvements has significantly increased the capacity, durability, and resiliency of various components of the system. Of particular note during our visit was the armoring provided to resist overtopping scour behind floodwalls, the hardening /armoring of critical transitions between disparate components, the reconstruction, heightening and reduced slopes (some with buttresses) of earth embankments with compacted, less erodible materials, and addition of hurricane barrier gates and pump stations at the entrances of the interior drainage canals. Both the 2008 and the subsequent HSDRRS upgrades completed in 2018 are significantly superior to the pre-Katrina HPS.

The non-federal local back levee in Plaquemines Parish was overtopped by Gustav flood levels and was in danger of failure at the location of the slope slide. Desiccation cracks on the levee may have contributed to the slide by allowing overtopping water pressures into embankment zones critical to slope stability. The placement water content, compaction, and organic

content of the back-levee soils were not known and may be factors in the susceptibility of the levee soils to desiccation cracks and erosion.

Gustav tested the HSDRRS and offered some lessons for flood protection systems.

- Boats, barges, or other large objects (e.g. rail cars, tanks, shipping containers) that float could impose a risk to floodwalls. The USCG's evacuation of waterways near storm barriers, walls, and levees before high wind events is critical to protection of the HSDRRS.

- Preparation for a hurricane requires timely action by all responsible parties. Delays by railroads, salvage yards, boat and barge operators, and/or operators of facilities on the flood side of the HSDRRS in clearing potential hazards could put the HSDRRS at risk.

- The erosion resistance of non-federal local levees in Plaquemines Parish (not part of the HSDRRS) during overtopping was noted during Katrina. The clay back levees in Plaquemines Parish resisted erosion during Gustav but may have demonstrated a potential vulnerability due to desiccation cracks. Improved control of placement water content and compaction, revised material requirements relative to plasticity and organic content, or landscaping measures such as the establishment of dense vegetation and use of irrigation may be required to prevent desiccation.

- Protection of life in the southern Louisiana area will require continued emphasis on evacuation. Storm surges larger than those created by Gustav and Katrina should be anticipated. The New Orleans area evacuation was 98% effective during Gustav (Amdal and Swigart, 2010) as compared to the 70% to 80% effectiveness of the evacuation during Katrina (IPET, 2008). Most of the 727 New Orleans area lives lost during Katrina (IPET, 2008) would have been saved at the Gustav level of evacuation. While the flood barriers performed better in Gustav and will likely perform even better now ($17 billion later), it is still important that everyone in the New Orleans vicinity remove themselves from harm's way during major hurricanes and tropical storms. Evacuations before significant storms must inarguably continue; if a future storm like Hurricane Harvey dumps 127+ cm (50+ inches) of rain into the New Orleans polders or generates 500-year-return-period storm surges, the flooding would be devastating no matter how well the pumps and barriers work.

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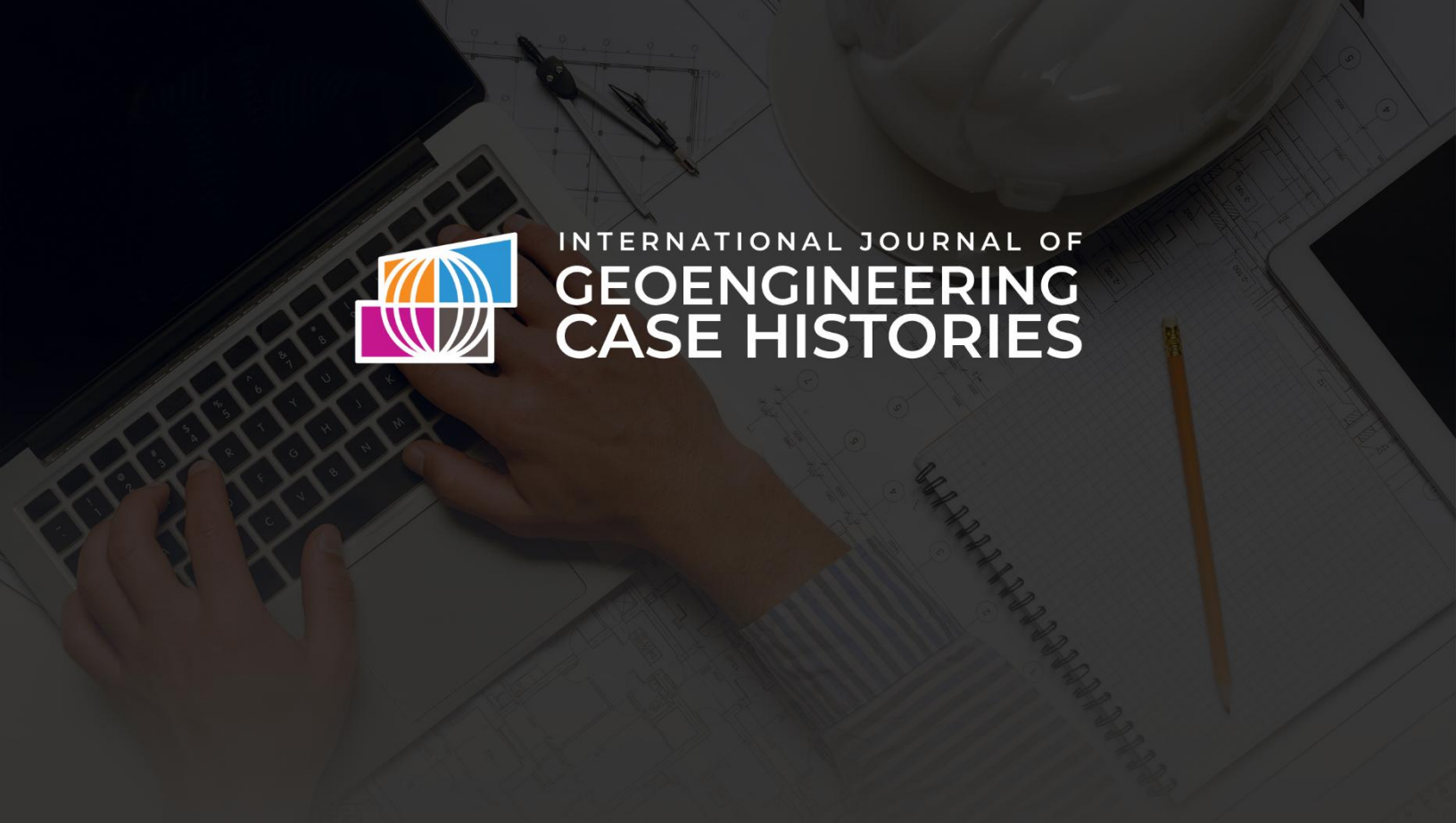
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