Geotechnical Reconnaissance of the Mississippi River Delta Flood-protection System After Hurricane Katrina

By Ronaldo Luna, David Summers, David Hoffman, J. David Rogers, Adam Sevi, and Emitt C. Witt

This article presents the post-Hurricane Katrina conditions of the flood-protection system of levees and floodwalls that failed in the environs of the Mississippi River Delta and New Orleans, La. Damage conditions and suggested mechanisms of failure are presented from the geotechnical point of view.

Introduction

A group of investigators from the University of Missouri-Rolla's (UMR) Natural Hazards Mitigation Institute (NHMI) and the U.S. Geological Survey's (USGS) Mid-Continent Geographic Science Center (MCGSC) formed a team to collect perishable data in the aftermath of Hurricane Katrina. The field activities took place in the second week of October 2005. The team focused on three topics: transportation structures, flood-protection systems, and the environmental condition of the sediment debris. This article presents the geotechnical considerations of the flood-protection systems, and the two other topics are addressed in separate papers in this circular (Chen and others, this volume). Even though most of the media attention has been on the New Orleans levee/floodwall failures that flooded densely populated areas, our team also observed severe damage to miles of the flood-protection system along the Mississippi River south to the town of Venice, La., on Louisiana Highway 23 (LA-23).

Geologic Setting

The Mississippi River Delta has been laid down by an intricate system of distributary channels. During the last 11,000 years, sea level has risen 350 ft (106.7 m), and the grade of the river has flattened. Channel sands are laterally restricted to major distributary channels, or "passes." The modern Mississippi River Delta has been deposited during the past 6,000 years in four major areas. New Orleans lies within the Mississippi River Deltaic Plain and is located between Lake Pontchartrain on the north and the

Mississippi River to the south. Its geology is highly variable both in the lateral and vertical extents. Much of the city is underlain by thick deposits of dark organic clays mixed with wood, roots, and other organic materials that resulted from extensive marshes and swamps formerly characterizing the area. This material is of a very low density and generally has high water content. It is actively decaying where development has lowered the water table, leading to areas of significant subsidence throughout the city. The St. Bernard and Plaquemines components of the Mississippi River Delta are its youngest features. They deposit nutrient-rich silt, which promotes the growth of freshwater swamps. Most of the St. Bernard Delta has subsided below sea level (Saucier, 1994).

Damage to the Flood-protection System

The flood-protection system for New Orleans and the towns that lie along the Mississippi River down through the delta comprises two separate types of flood-control barriers. The first of these is the earthen levee, and the second is the floodwall with a sheet-pile base. In some instances these two basic forms of flood protection are combined, such as a shorter floodwall over a smaller levee. Complete earthen levee failures were not observed in the New Orleans area, although a number of the earthen levees in locations along the delta of the Mississippi River in Plaquemines Parish exhibited severe damage. In some instances levees suffered complete failure (fig. 1*A*), and in other cases levee banks experienced severe erosion without complete failure (fig. 1*B*).

Examination of aerial photographs from files available at the Plaquemines Parish Web site (e.g., *http://photos.plaqueminesparish.com/displayimage.php?album=16&pos=6*) shows such failures very clearly. The breach at Nairn, La., however, was of a levee tied to a steel piling failure, and these types of flood-protection components were found much more commonly both in New Orleans and along the road on south LA-23 (fig. 2). Figure 2*A* is a view of the levee system that was breached, as seen in the bottom left of the photograph. Figure 2*B* is a partially failed levee with a reduced cross section.

At locations where the floodwall was based on a piling, there were two forms of structure: (1) the piling alone and (2) a concrete overwall sometimes increasing the wall height. Piling failure after overtopping was observed in a number of places, both in New Orleans and in Plaquemines Parish. In large measure, the pattern for failure appeared to be the same in most of these cases (where evidence still remained).

The most likely first step of the failure mechanism was water overtopping the wall, followed immediately by scouring of soil on the landward side adjacent to the wall. In many cases this was the only stage of damage that occurred, and the floodwall itself remained erect. Where the wall adjoined an earthen levee, however, there was additional scouring that could occur at the interface, as shown in figure 3.

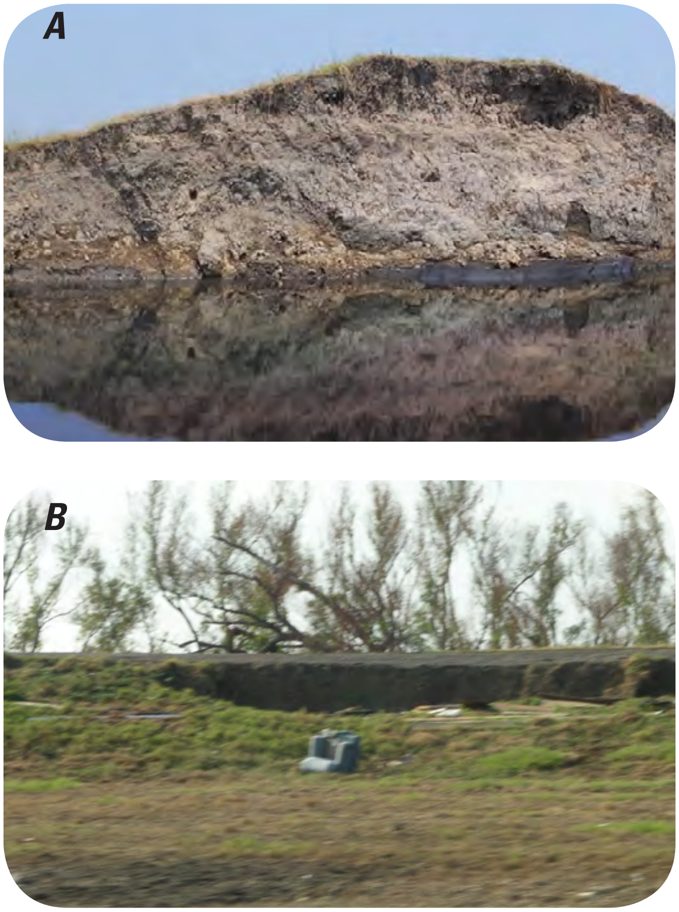

Figure 1. An example of a section of levee failure (*A*), and erosion of a levee during overtopping without failure (*B*).

As the water continued to pour over the wall, it would remove the softened soil and consistently leave a trench on the landward side of the wall, often exposing the underlying piling. A similar event would occur if the piling were heightened with a concrete wall, with the scour opening a channel along the wall on the landward side. This often exposed the underlying piling as shown in figures 4*A* and 4*B*.

This linear scour trench resulted in a higher cantilever length with less foundation embedment, making the system weaker. When a metal sheet-pile wall without a concrete overwall and embedded in disturbed saturated soil was exposed, water pressure would push against the weakened soil until the piling was bent over in a landward (protected side) direction, as shown in figure 5. Similar failure mechanisms are evident at several points along LA-23 (figs. 6*A* and 6*B*).

It is noteworthy that in most cases the piling wall remained connected even when significantly displaced, compromising its functionality. Being more brittle, however, a concrete overwall would separate at the joints, which in some instances led to a complete collapse, as shown in figure 7. With this background, it is interesting to examine some

Figure 2. Complete levee failure at Nairn, La. (*A*), and partial failure with severe loss of cross section (*B*) as a result of Hurricane Katrina in 2005. Photographs are from Plaquemines Parish government and used with permission.

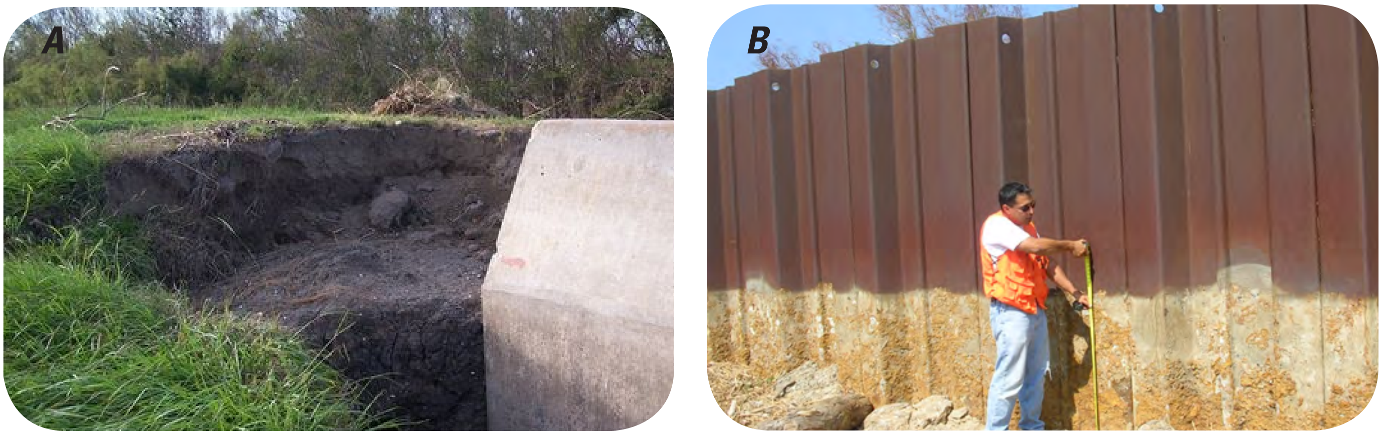

Figure 3. Wall edge showing scour into the adjacent earth wall (*A*), and soil at protected side removed by overtopping (*B*).

of the information from the Inner Harbor Navigation Canal (popularly known as the Industrial Canal), Metairie Outfall Canal (popularly known as the 17th Street Canal), and London Avenue Outfall Canal failures.

The Industrial Canal

Two significant failures occurred along the eastern flood-protection system of the Industrial Canal in New Orleans. At the larger breach (~900 ft wide (274 m wide)) on the south side just north of Louisiana Highway 39 (Claiborne Avenue), the piling was carried an extended distance into the breach (more than 150 ft (46 m)). The flood-protection system consisted of a small (~5 ft high (1.5 m high)) earthen base levee with a partitioned structure called an I-wall on top. The term “I-wall” is used when the structural portion of the wall above the ground is a single vertical panel (I-shaped as opposed to L-shaped) supported on steel sheet piling. More specifically at this location, the I-wall consisted of steel sheet piles embedded 15 ft (4.6 m) in the ground and a concrete panel which extends about 8.5 ft (2.6 m) above the ground. The concrete wall all along the segment was crushed, which is likely the result of a barge impact during the flood (figs. 8–10). The actual timeline and sequence of events or cause of the failure is not known. This barge was carried into the residential area from a significant distance, and the houses that lie behind the barge were protected from the flood waters and experienced less damage. It is clear that the levee failure was worsened by the impact of the barge, which likely caused a substantial portion of the wall to collapse and the piling wall (still largely intact) to be carried a significant distance into the breach.

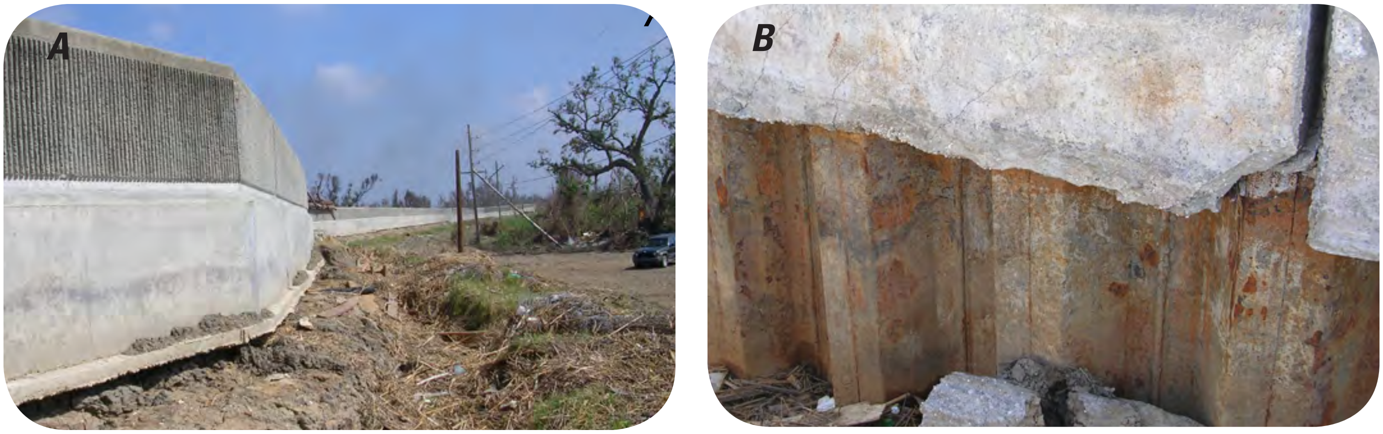

Figure 4. Scour along wall along Louisiana Highway 23 (*A*), and exposed piling under concrete wall near Port Sulphur, La. (*B*), resulting from the effects of Hurricane Katrina in 2005.

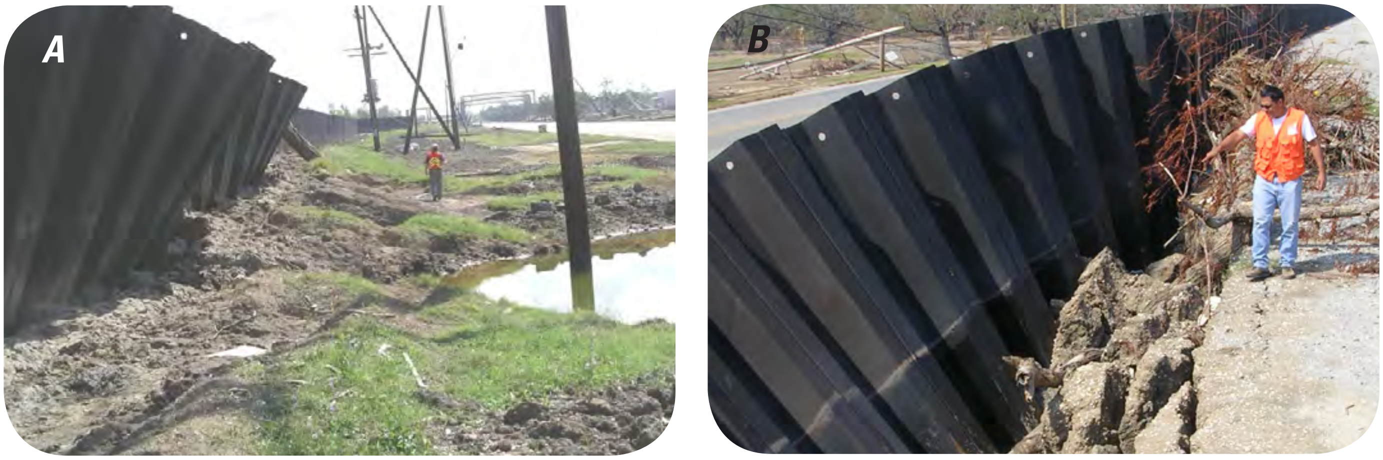

Figure 5. Piling that has rotated about the bottom, forming a lip that creates a stream of water over the wall. Landward side, showing scour of the soil around the pole (*A*), and large deformations shown from water side of piling (*B*).

The 17th Street and London Avenue Canals

In contrast to the previously described failures that initiated with overtopping of the floodwalls, the 17th Street Canal and London Avenue Outfall Canal breaches did not follow this failure mode. The location of the 17th Street Canal breach was just south of the Robert E. Lee Boulevard on its west bank. The breach of the 17th Street Canal levee was not the result of overtopping, as the water was approximately 3 ft (0.9 m) below the top of the wall, as indicated by water marks and other gages in the area (Seed and others, 2005). The levee failed because of water pressure causing it to slide approximately 50 ft (15 m) atop weak foundation materials that consisted of organic-rich marsh and swamp deposits. Trees, fences, and other features on or near the levee moved horizontally but experienced very little rotation, except at the very toe of the slide. The foundation soils consist of very soft, organic clay and peat and decomposing wood as can be seen in the dark soils shown in figure 11*B*. These extremely weak soil conditions are the most likely causes for the failure at this location, resulting in a major breach about 450 ft (137 m) wide, which caused flooding in the Lakeview residential area (fig. 12).

Two major breaches occurred along the London Avenue Outfall Canal, one north on its west bank and the other on Maribeau Avenue on its east bank. The subsurface soils at these two breaches tend to be more sandy than do those along the 17th Street Canal. They consist of a relatively thick deposit of sands, overlain by a thinner layer of marsh and peat deposits that vary in thickness. The failure mechanisms at these sites are less well understood but may result from a combination of underseepage and the length of sheet-pile embedment (Seed

Figure 6. Rotational failure of the piling with possible toe movement (*A*), and total collapse of piling at Empire, La. (*B*), as a result of Hurricane Katrina in 2005.

Figure 7. Failure of a concrete overwall; note that the underlying piling keeps the wall segments in place. Landward (protected) side (*A*), and water side (*B*).

and others, 2005). It was surprising that the levee continued to leak in the middle of October 2005 after the levees were temporarily repaired, since the piling remained intact in other places. One hypothesis based on exposed locations at the base of the concrete I-wall is that the piling may not have been continuous or was too short.

Conclusion

The flood-protection system of the Mississippi River Delta consisted of a combination of earthen levees, sheet-pile walls, and concrete overwalls. Performance of the system during and after Katrina and its ability to hold back the resultant flood waters was mixed, and numerous failures of the system made this one of the most devastating disasters in U.S. history. The most prevalent failure mechanism was the overtopping of walls, with scour at the base of the protected side and subsequent overturning of the system. In other locations where the soil conditions were uniquely soft or permeable, the designed protective system was not able to resist the lateral pressure of flood waters before failure.

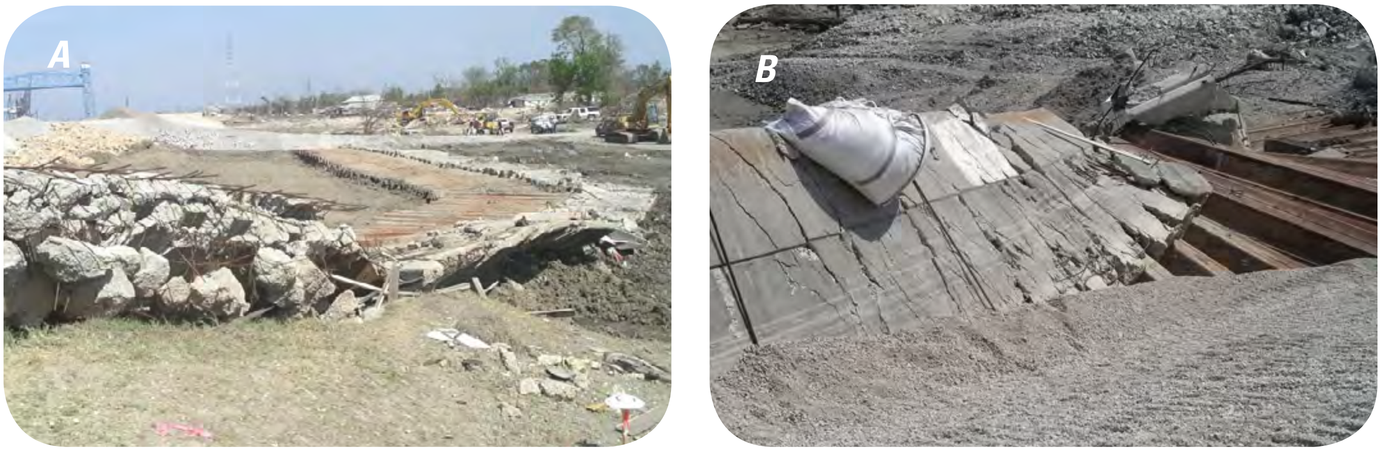

Figure 8. The fractured concrete and continuous sheet piling pushed ~150 ft (46 m) away from levee alignment looking north at the Inner Harbor Navigational Canal (popularly known as the Industrial Canal) (*A*), and northern section still attached to remaining floodwall at the Industrial Canal (*B*), New Orleans, La., resulting from the effects of Hurricane Katrina.

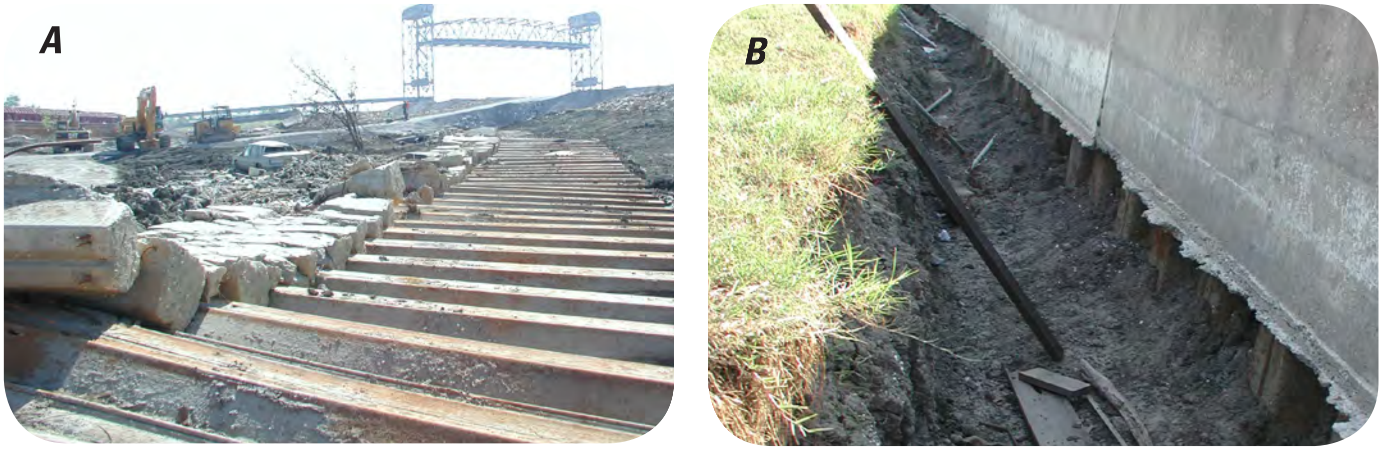

Figure 9. Details of Inner Harbor Navigational Canal (popularly known as the Industrial Canal) concrete wall fragmentation, looking south (*A*), and pronounced scour trench 5 ft (1.5 m) deep and 5 ft (1.5 m) wide (*B*), New Orleans, La., resulting from the effects of Hurricane Katrina in 2005.

References

Saucier, R.T., 1994, Geomorphology and quaternary geologic history of the lower Mississippi Valley: Vicksburg, Miss., U.S. Army Corps of Engineers Waterways Experiment Station.

Seed, R.B., Nicholson, P.G., Dalrymple, R.A., Battjes, J., Bea, R.G., Boutwell G., Bray, J.D., Collins, B.D., Harder, L.F., Headland, J.R., Inamine, M., Kayen, R.E., Kuhr, R., Pestana, J.M., Sanders, R., Silva-Tulla, F., Storesund, R., Tanaka, S., Wartman, J., Wolff, T.F., Wooten, L., and Zimmie, T., 2005, Preliminary report on the performance of the New Orleans levee systems in Hurricane Katrina on August 29, 2005: UCB/CITRIS report no. 05-01, 129 p.

Figure 10. Panoramic view from the lift bridge seen in background in figure 9*A*. Note the barge on the right and the temporary levee repair by the U.S. Army Corps of Engineers.

Figure 11. Failed concrete wall at the Metairie Outfall Canal (popularly known as the 17th Street Canal) breach (*A*), and horizontal translation of fence that used to be only 10 ft (3 m) from wall is now about 50 ft (15 m) away (*B*) resulting from the effects of Hurricane Katrina in 2005. Note the dark soft soil which formed a weak foundation for these structures.

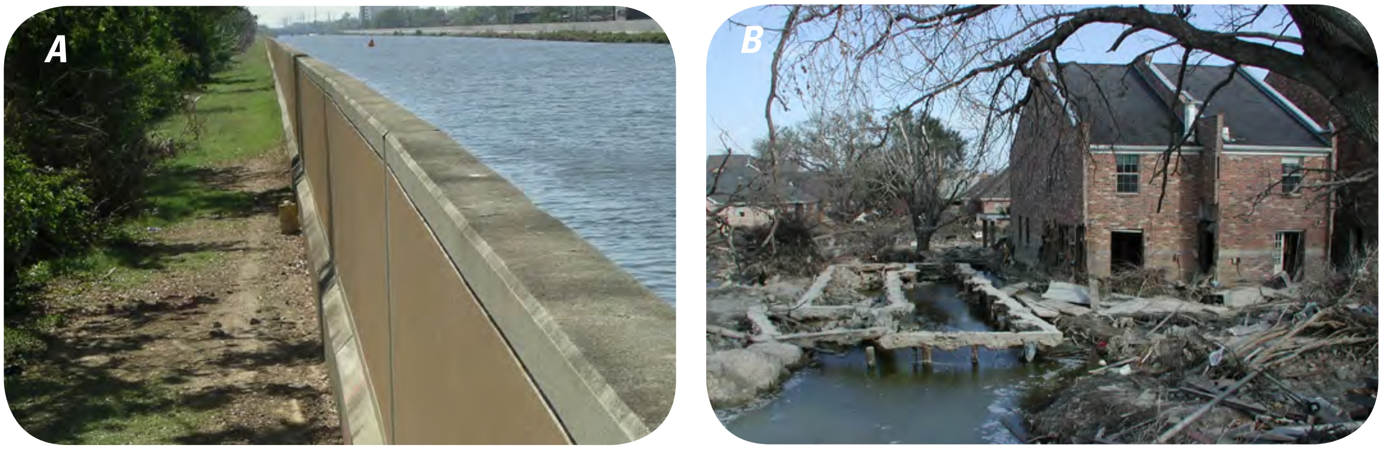

Figure 12. Area in the protected side of floodwall with no scour (*A*), and residential area with only foundations left in soils with high organics (*B*).

Contact Information

Ronaldo Luna, Associate Professor (*rluna@umr.edu*)
Department of Civil, Architectural, and Environmental Engineering
130 Butler-Carlton Hall
University of Missouri-Rolla
Rolla, MO 65409

David A. Summers, Professor and Director, Rock Mechanics and Explosives Research Center (*dsummers@umr.edu*)
University of Missouri-Rolla
1006 Kingshighway
Rolla, MO 65401

David Hoffman, Associate Research Engineer (*dhoffman@umr.edu*)
Department of Civil, Architectural, and Environmental Engineering
Natural Hazards Mitigation Center
University of Missouri-Rolla
Rolla, MO 65409

J. David Rogers, Associate Professor, Karl F. Hasselmann Chair (*rogersda@umr.edu*)
Department of Geological Sciences and Engineering
University of Missouri-Rolla129 McNutt Hall
Rolla, MO 65409-0230

Adam F. Sevi, Graduate Research Assistant (*asevi@umr.edu*)
Department of Civil, Architectural, and Environmental Engineering
117 Butler-Carlton Hall
University of Missouri-Rolla
Rolla, MO 65409

Emitt C. Witt III, Director, Mid-Continent Geographic Science Center (*ecwitt@usgs.gov*)
U.S. Department of the Interior
U.S. Geological Survey
Mid-Continent Geographic Science Center
1400 Independence Rd.
Rolla, MO 65401