

- than four feet of sheet pile was cut off due to unexpected hard driving.
- 2) Borings along Orleans East Bank did not identify a layer of extremely soft soils. Excessive settling of the steel sheet pile cofferdam — a temporary, watertight enclosure pumped dry to expose the bottom of a body of water — for the 17<sup>th</sup> Avenue Outfall Canal occurred during dewatering.
  - 3) At New Orleans East, South Point to the Gulf Intracoastal Waterway, a berm began to slide and crack. A modification was issued to lower and widen the berm.
  - 4) In St. Charles Parish north of Airline Highway, pile-driving obstructions forced contract modifications.
  - 5) The fifth modification concerned the contract for Jefferson Parish Lakefront Levee Pump Station No. 2. To correct a survey error, the break-water was moved 70 feet to the west to obtain better alignment.

### Findings

- With some sections not scheduled for completion until 2015, the hurricane protection system was generally built as designed.
- Some sections were built below specified design elevations, usually because of error in interpreting the relation between land-based and water-level-based elevation reference points.

- System weaknesses included incompleteness, inconsistency in levels of protection and lack of redundancy — the duplication of critical components for increased reliability.
- No findings indicate government or contractor negligence or malfeasance.
- Trees and other features on the levees were not obvious causes of breaching but could have contributed to the breaching process.
- The lack of a CSX railroad gate prevented the system from operating as designed.

### Lessons Learned

Among the lessons learned from Hurricane Katrina, the IPET reported that:

- 1) Design methods and designs need periodic review to determine whether they represent best practice and knowledge.
- 2) Designs also need to consider resilience, adaptation and redundancy to accommodate unanticipated conditions or structural performances.
- 3) Designs should be based on a system-wide understanding of how each component depends upon and interacts with others.

For more information on this topic, please refer to Volume III of the IPET Report.

The New Orleans and Southeast Louisiana Hurricane Protection System was conceived as a way to buffer the area from hurricane flooding. The system is a network of levees, floodwalls, reinforced bridges, and dikes spanning five parishes. The system was designed to protect southeastern Louisiana from catastrophic flooding in the event of a Standard Project Hurricane, a model of severe meteorological conditions considered reasonably characteristic for the region in 1965.

The U.S. Army Corps of Engineers established the Interagency Performance Evaluation Task Force (IPET) in fall 2005 to provide scientific and engineering answers to questions about the hurricane protection system's performance during Hurricane Katrina on August 29, 2005. This summary of Volume III of the nine-volume IPET Draft Final Report, released on June 1, 2006,



Figure 3-1: Aerial view of the New Orleans and Southeast Louisiana Hurricane Protection System, showing the network of levees, floodwalls, reinforced bridges, and dikes spanning five parishes.



provides an overview of relevant findings and lessons learned and discusses

- the design criteria for the hurricane protection system and design characteristics of the system as it existed before Hurricane Katrina
- the inspection and maintenance history of the system
- whether the construction and maintenance conditions of the system met design criteria

### Design Criteria and Characteristics

Southeast Louisiana soils consist of geologically young sedimentary layers that tend to compact when loads are applied. Consequently, designers working on the hurricane protection system were concerned with soil settlement and stability. Building over weak and compressible soils meant projects had to be completed in stages to allow the soil to settle and compress. Except in select locations where firmer soils were deposited, structures were built with substan-

tial pile foundations to resist settlement or were designed to tolerate long-term settlement of up to several feet.

Subsurface exploration, or soil sampling, and geotechnical laboratory testing were conducted before designing hurricane protection system projects. Borings usually were 50 to 80 feet deep, though sometimes as deep as 100 feet. Generally, borings were spaced between 350 to 650 feet apart where floodwalls were planned and 700 to 1,500 feet apart in remote areas.

Borings so spaced may not have disclosed all pockets of weak soils, even though the subsurface conditions found under some failed levees covered large areas. Soils where suspected foundation failures occurred contained varying thicknesses of peat and/or clay overlying sand and/or clay layers.

The interior drainage system, reported ready and in good condition before August 29, 2005, is a series of overland flows, storm sewers, roadside ditches, roadway flows, collector ditches, interior canals, interior pump (lift) stations, outfall pump stations and outfall canals. The system is designed to remove storm water following a heavy rain, not to remove water from overtopping or breaching of levees and floodwalls. Canals, which also remove seepage from the Gulf of Mexico, Lake Ponchartrain and the Mississippi River, direct accumulated water into pumping stations. Of the nearly 100 pumping stations in the greater New Orleans area, some are

almost 100 years old. Some are powered by diesel engines, and some use electricity with diesel backup. Historically, pumping stations have not been considered part of the hurricane protection system.

### Inspection and Maintenance

Annual inspections showed the hurricane protection system to be at least acceptable, and sometimes outstanding. These inspections were not rigorous, however, and did not include findings and documentation. Every five years the Corps of Engineers usually conducts inspections of completed federal civil works projects, and certain projects of local interest are inspected every three years. Inspected under this program before Hurricane Katrina, three structures — the Bayou Bienvenue Control Structure and Bayou Dupree Control Structure in St. Bernard Parish and the Empire Floodgate in Plaquemines Parish — were found to be in good operating condition.

The veracity of tests to determine conditions on which to base designs was confirmed by examining 50 contracts. Only five were modified, of which four were changed due to differences between actual conditions and assumed conditions based on tests:

- 1) Between two stations on the east side of the 17<sup>th</sup> Street Canal, more

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