# Geologic Conditions Underlying the 2005 17th Street Canal Levee Failure in New Orleans

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ENVIRONMENTAL ENGINEERING AEG GEOLOGISTS

Hurricane Katrina triggered a series of systemic failures of the flood control infrastructure protecting New Orleans

- Around 6 AM on August 29th the 9 ft storm surge swept into the Inner Harbor Navigation Canal area, engulfing the Entergy Power Plant area with waves up to 17 ft high.

- **Miles of levees just disappeared: MRGO levee completely washed away about two miles southeast of Bayou Dupree.**


Flood gate over rail crossing on Florida Ave Lift Bridge was not repaired and inserted across tracks, even though paid for over a year previous after being damaged


The flood wall along the Orleans Drainage Canal was never completed, but stopped 100 yards from Pump Station because of an interagency dispute about who should pay for a new wall on the old pump station, which was built in 1903.

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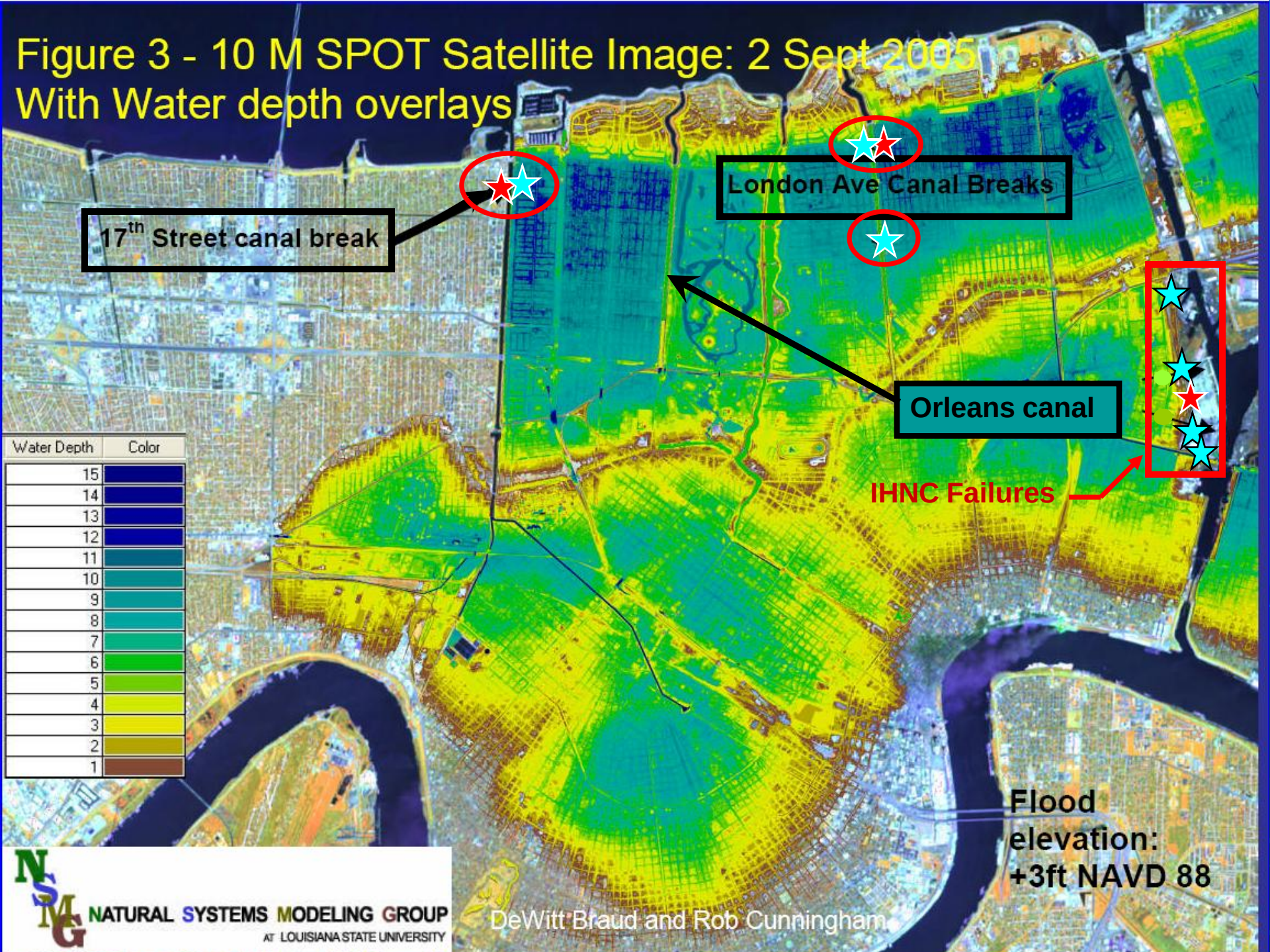
# Figure 3 - 10 M SPOT Satellite Image: 2 Sept 2005 With Water depth overlays




NATURAL SYSTEMS MODELING GROUP
AT LOUISIANA STATE UNIVERSITY
DeWitt Braud and Rob Cunningham

- New Orleans neighborhoods were filled with as much as 12 feet of water, for up to 6 weeks

- Katrina left New Orleans under water, creating the worst flood in American history and the most expensive disaster, causing $24 billion in claims to the National Flood Insurance Program and $200 billion in overall damage.

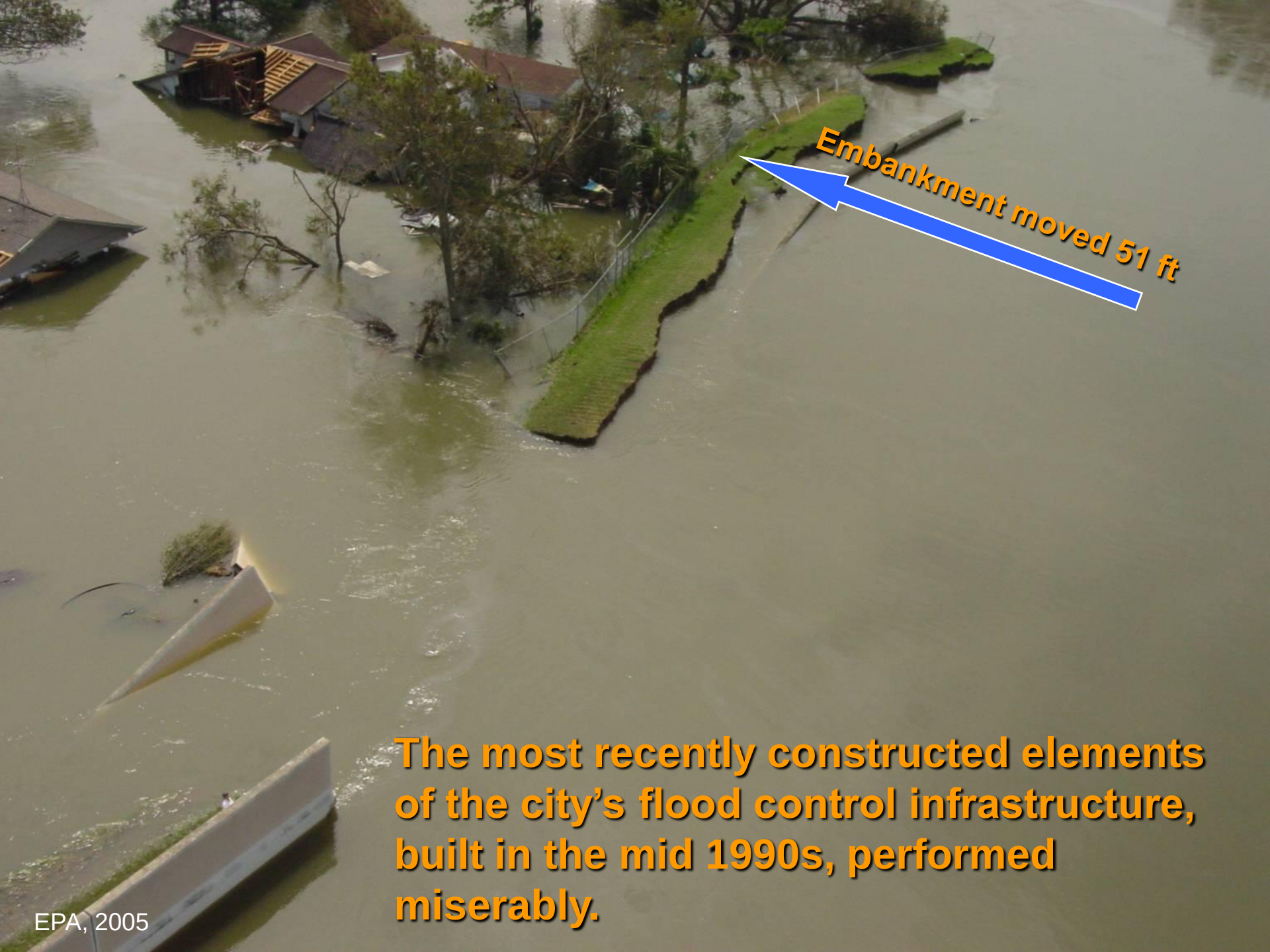
# 17TH Street Drainage Canal Failure:

***How could a system constructed in the 1990s fail so miserably?***

- Breach began with noticeable leakage around 6 AM when the storm surge level reached +6 ft

Eyewitness accounts suggest that the entire breach took about 4 hours to develop, commencing just before 6 AM and enlarging itself until about 10 AM

- Overview of the the 17th Street Levee breach, which was about 450 ft long
- The sheetpile supported floodwall fell forward and backward

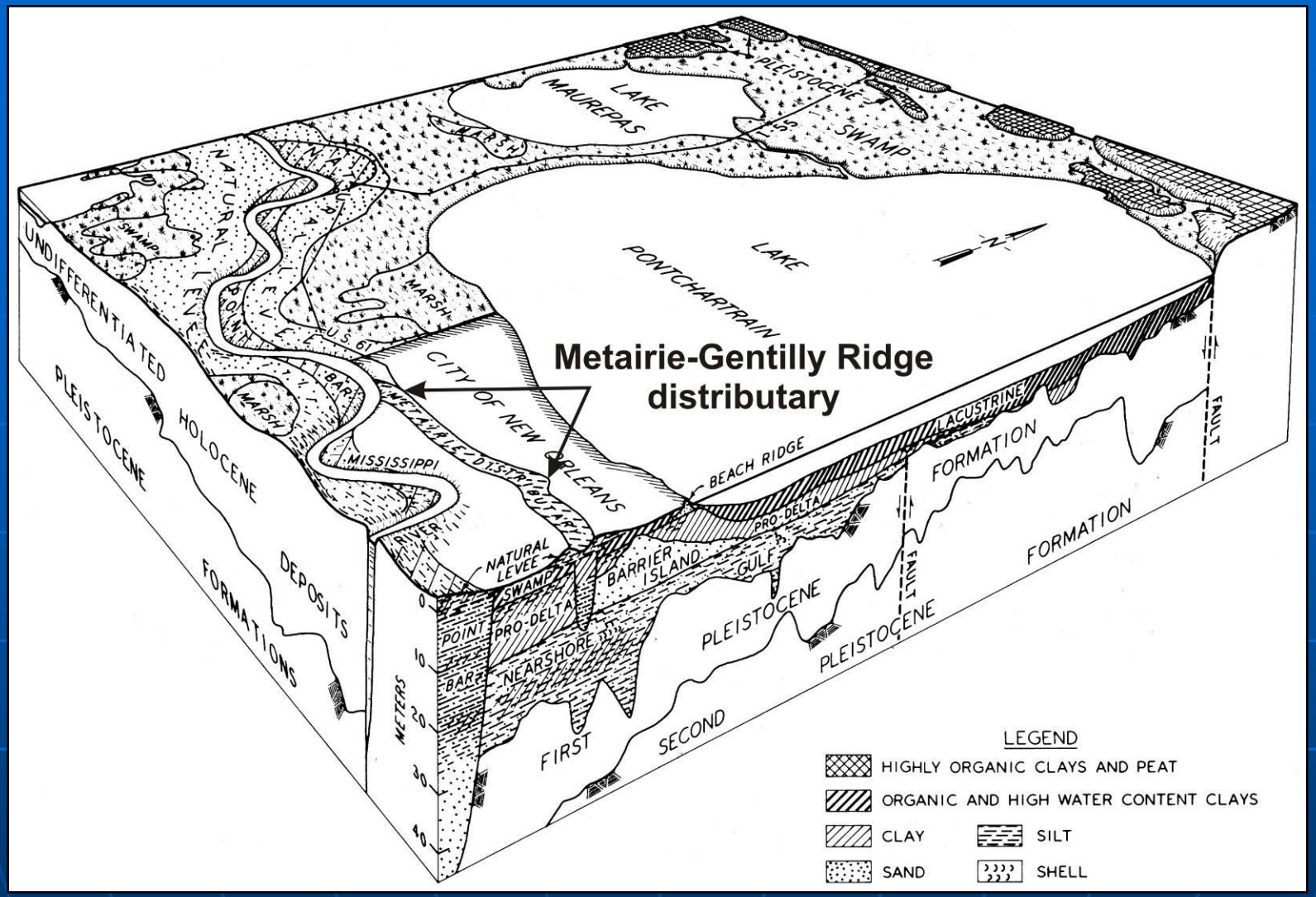



**The most recently constructed elements of the city's flood control infrastructure, built in the mid 1990s, performed miserably.**

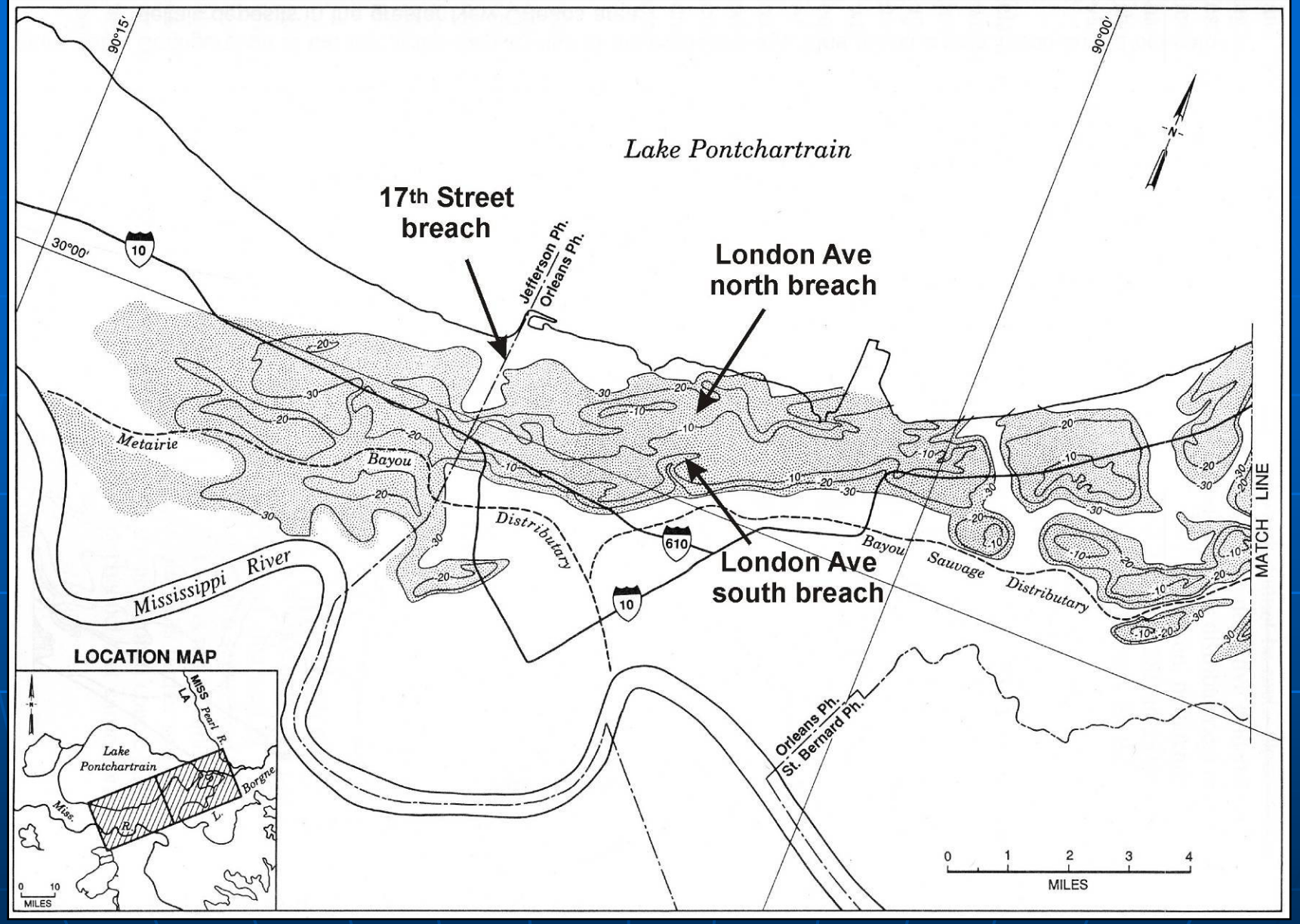
EPA, 2005

- **Army helicopters and contractors worked for weeks to fill the enormous gaps in the levee system, BEFORE pumping could begin.**

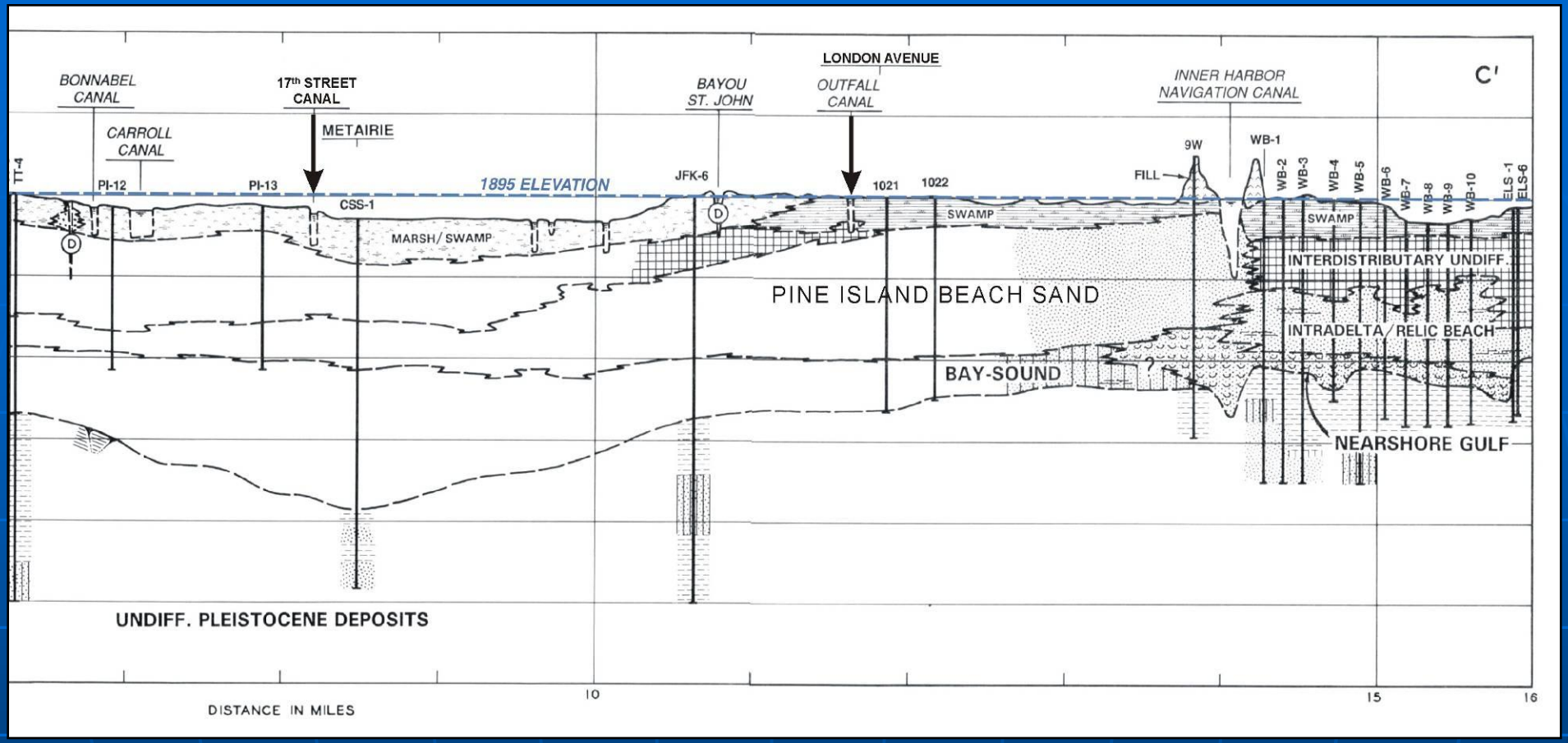
# Subsurface exploration and testing




- **Block diagram of the geology underlying New Orleans. The principal feature dividing New Orleans is the Metairie distributary channel, shown here, which extends to a depth of 50 feet below MGL and separates geologic regimes on either side. Note the underlying faults, beneath Lake Pontchartrain.**



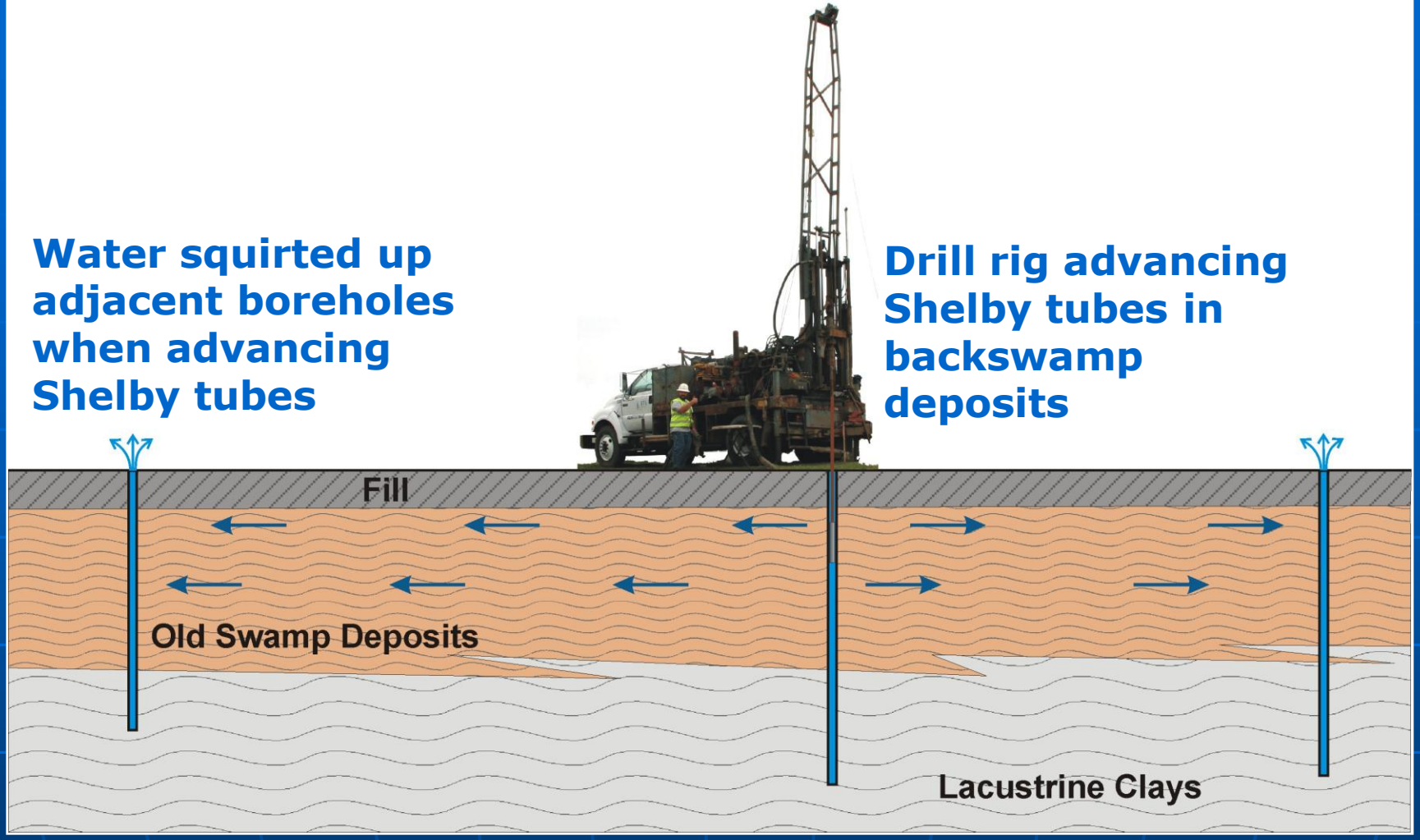

- **Areal distribution and depth to top of formation isopleths for the Pine Island Beach Trend beneath lower New Orleans.**




- Geologic cross section along south shore of Lake Pontchartrain in the Lakeside, Gentilly, and Ninth Ward neighborhoods, where the 17th Street, London Avenue, and IHNC levees failed during Hurricane Katrina on Aug 29, 2005.
- Note the apparent settlement that has occurred since the city survey of 1895 (blue line), and the correlation with the marsh-swamp deposits.

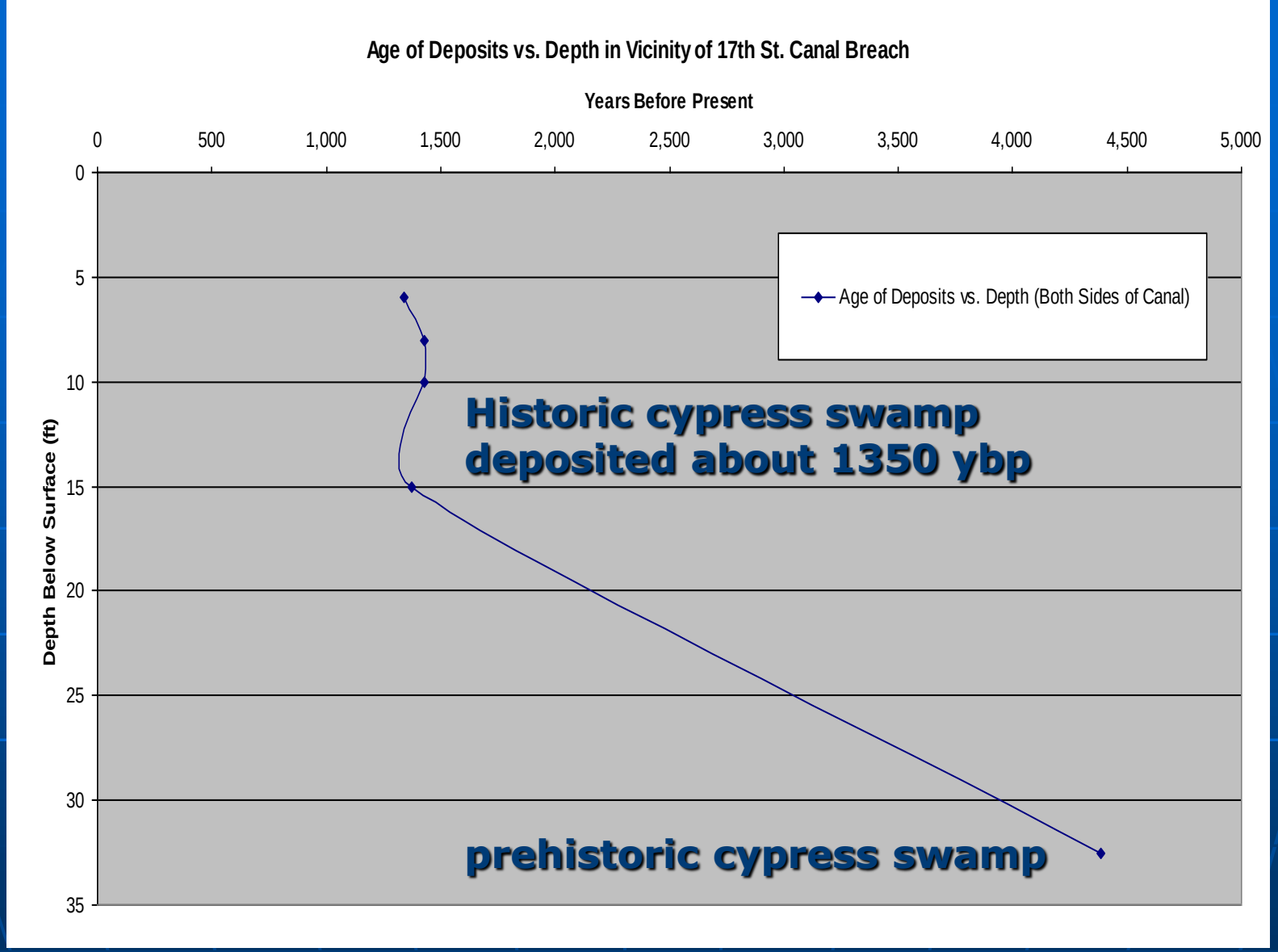
# Subsurface Exploration

- Program supervised by J. David Rogers
- ILIT team soon learned that sampling soft sediments was a tedious process requiring great care
- Former Corps employees and local consultants provided the technical expertise our team needed to make the interpretations

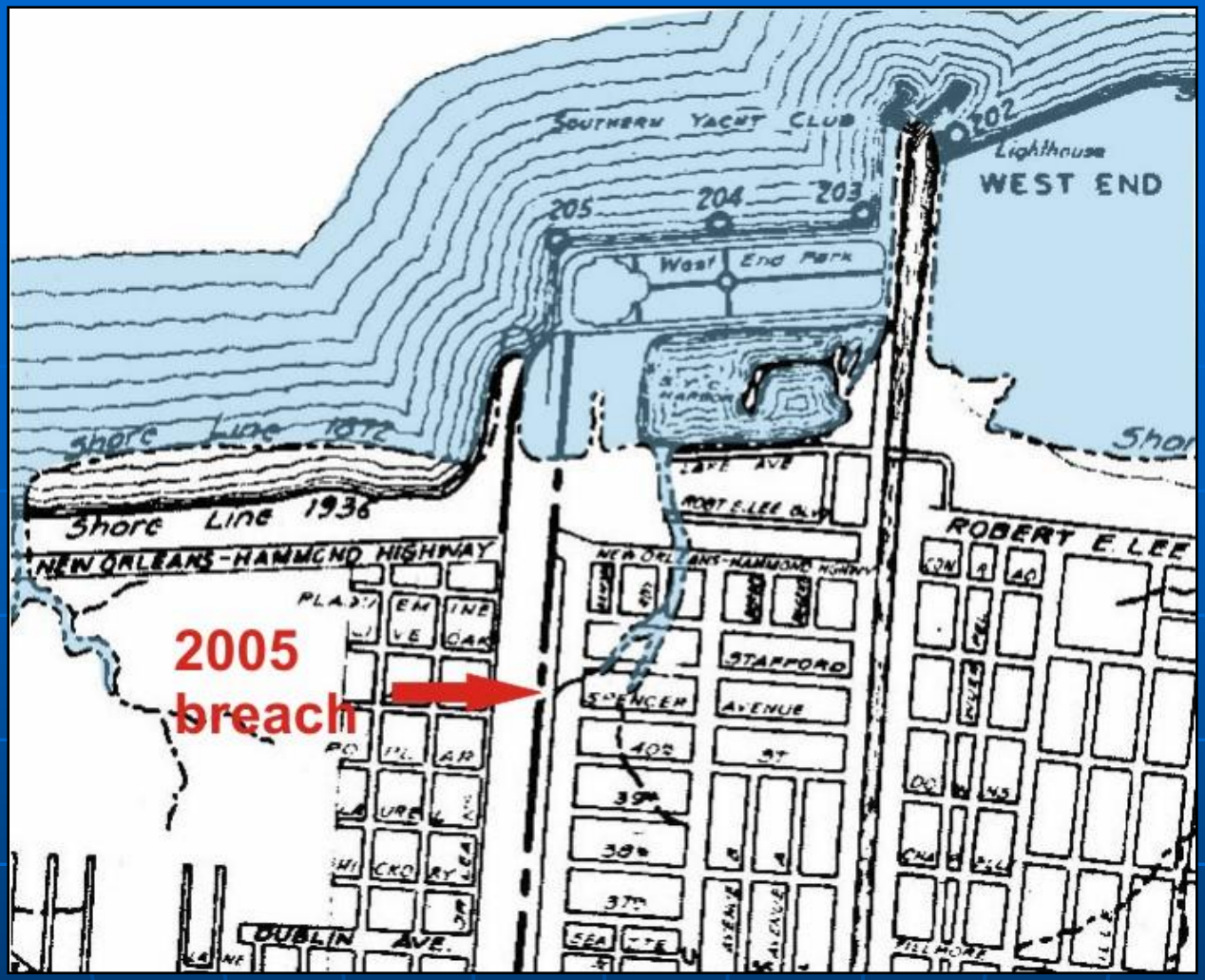



- The porous and *highly conductive* nature of the backswamp deposits was revealed during post-Katrina drilling and sampling operations.
- Highly conductive in horizontal plane, especially, parallel to the line of original surface drainage.


- On average, it took us three tries to get one successful sample of the basal slip surface at each place we drilled; or 27 holes to get 9 complete logs



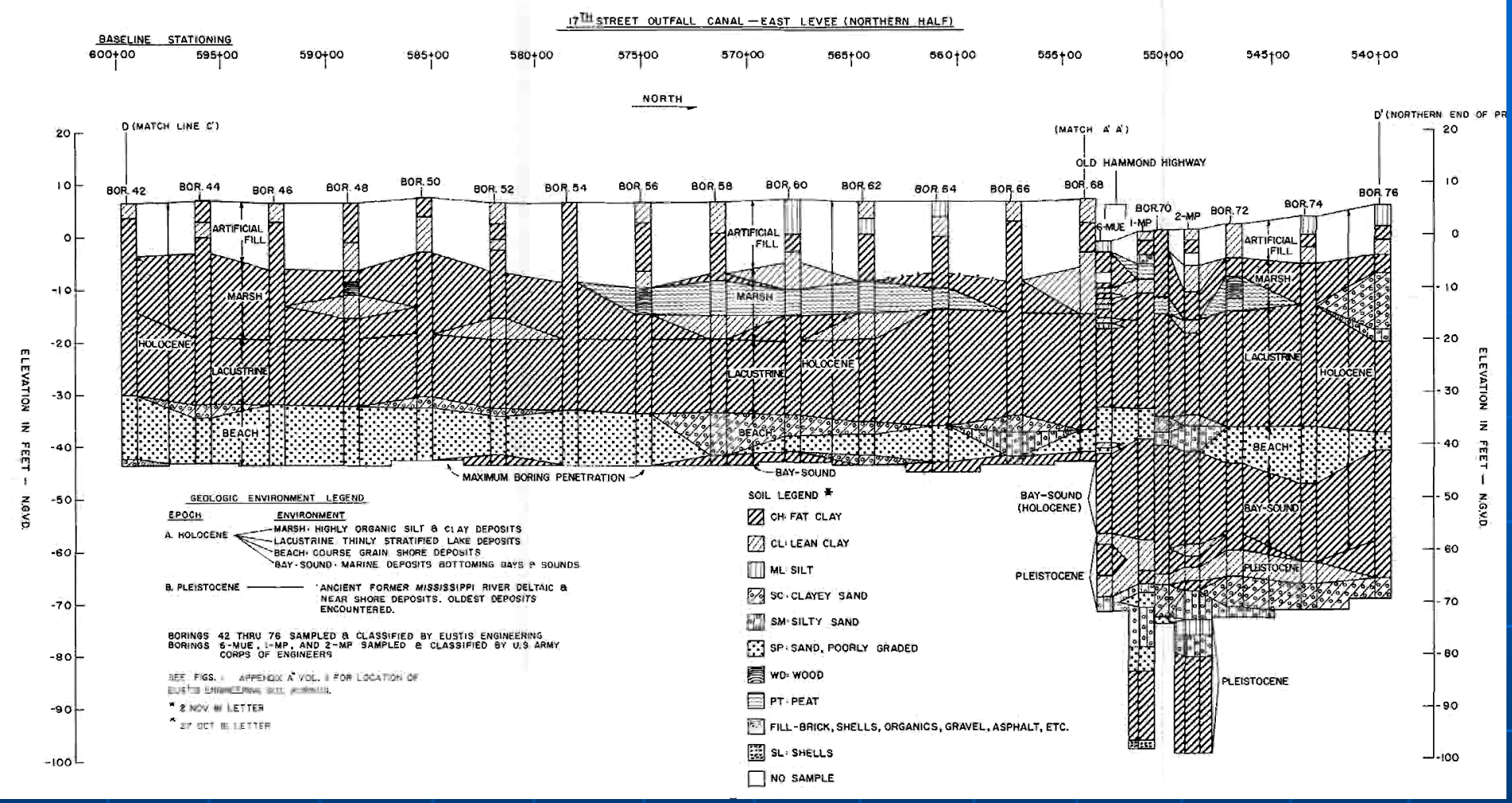

- C14 dates and depths suggest a rapidly filling paludal environment during the late Holocene



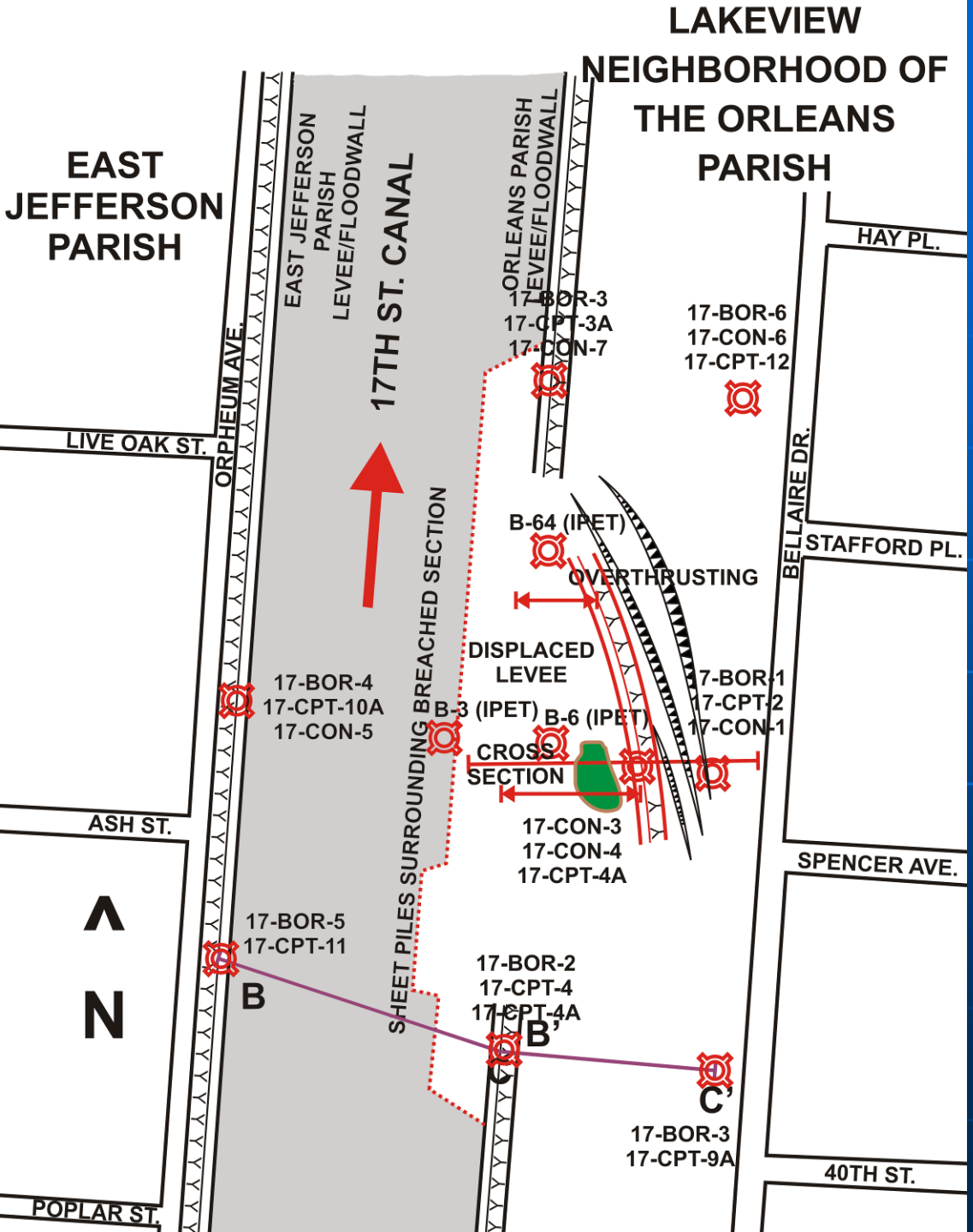

- Map overlaying 1872 Sulakowski map on the 1937 WPA map, showing the 1872 shoreline and sloughs (in blue) along Lake Pontchartrain.
- The position of the 2005 breach along the east side of the 17th Street Canal is indicated by the red arrow.

- Aerial oblique view of flooding adjacent to lower 17th St Canal caused by 1947 hurricane.

- **Flooding of Jefferson Parish and Metairie was caused by a breach along the western side of the 17th Street Canal, across from site of the 2005 breach.**

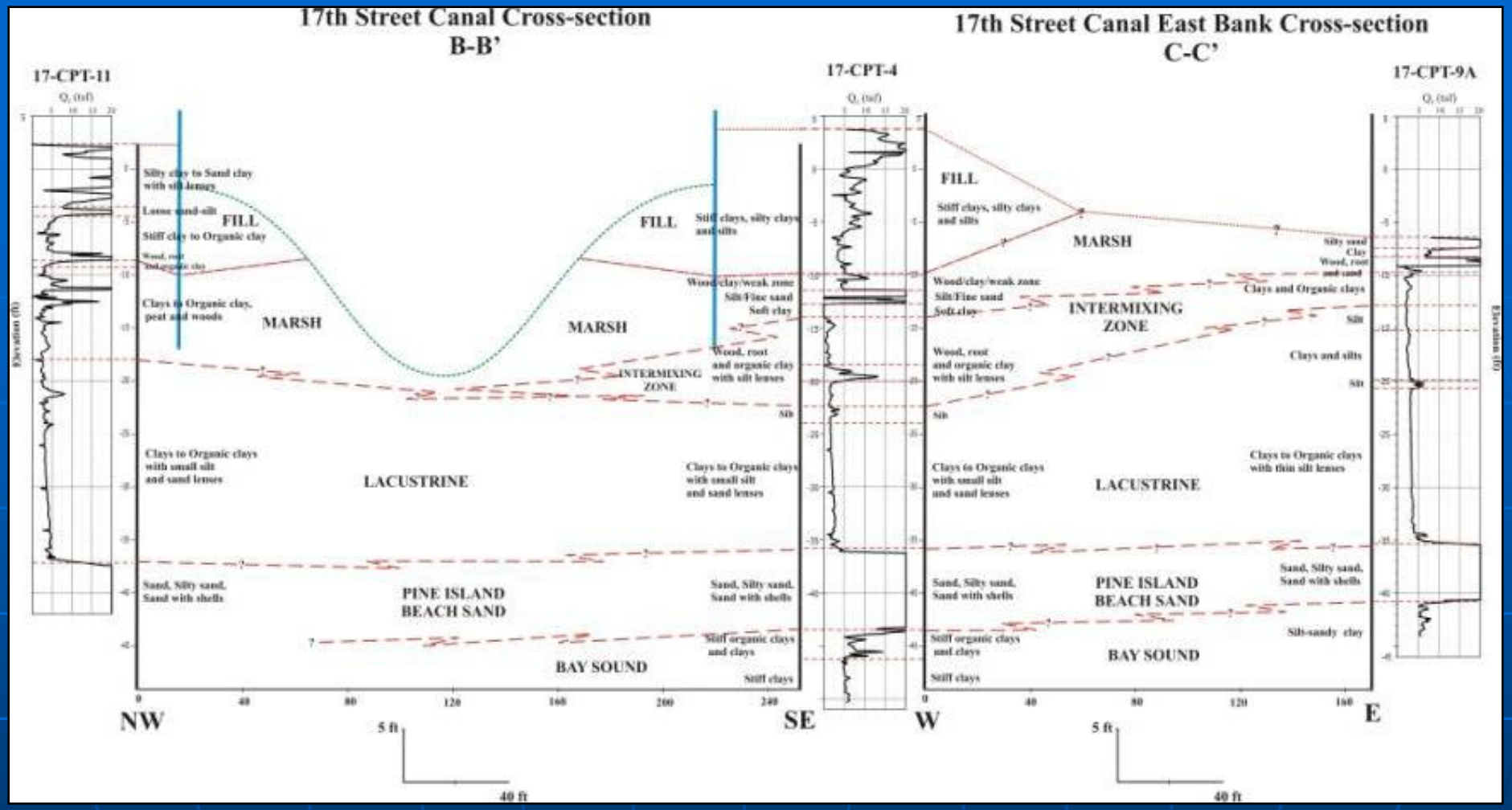



**Geologic profile for the 17th St Canal flood wall prepared by Corps' New Orleans District office in 1990. Three of four holes in vicinity of the 2005 failure (spaced 500 ft apart) had zero sample recovery. These contacts were projected and the sheet pile tips designed, accordingly.**



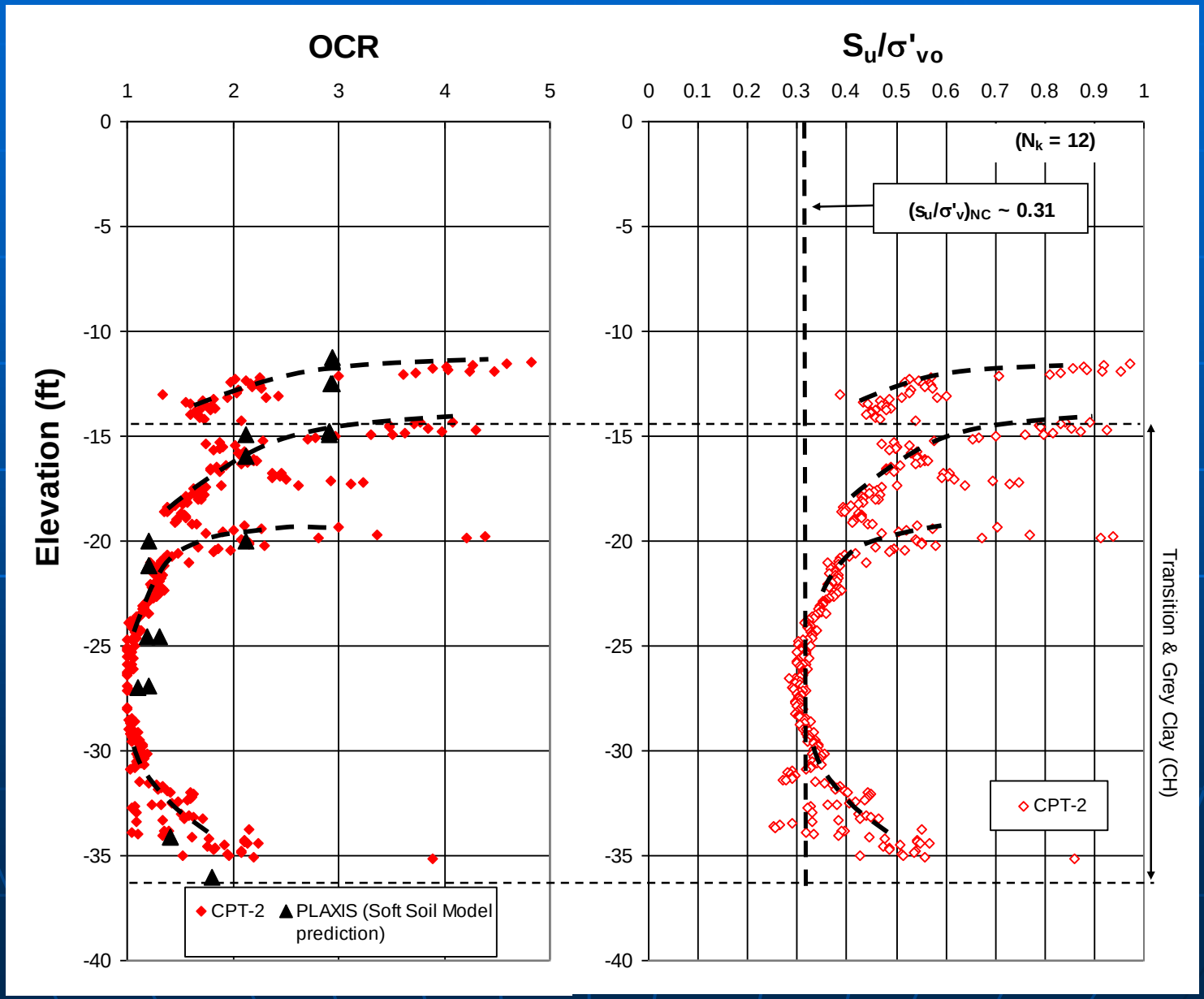

# 17th St Canal failure area

- Plan view of the 17th Street Canal breach site
- Locations of NSF team borings and CPT soundings noted in red
- The red lines indicate the positions of the NSF team's geologic sections.




- **Stratigraphic interpretations across the 17th Street Canal breach. The swamp much appeared to be thinning northerly, as does the underlying Pine Island Beach Trend. The lacustrine clays appear to thicken southward, as shown.**

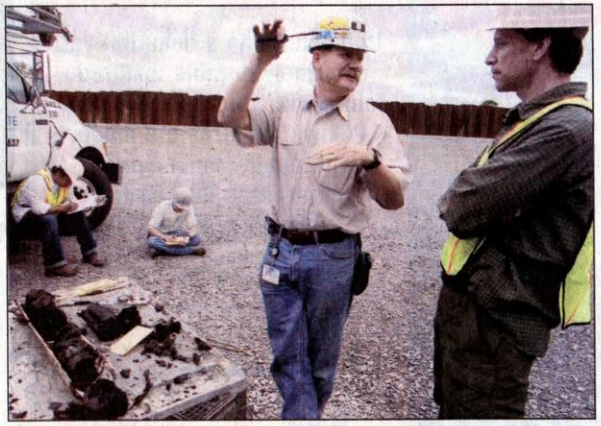
# 17th Street Canal: Soft Gray Clay (CH) Beneath the Toe of the Levee



HURRICANE AFTERMATH

STAFF PHOTOS BY TED JACKSON

This piece of clay was just above the peat area at the site of the 17th Street Canal floodwall breach.



J. David Rogers, center, and Joseph Wartman discuss soil borings at the 17th Street Canal floodwall.

the words "wood" or "shells" written between the lines, indicating a mixture, although the written description of the layers on the log indicates these layers were composed of mostly weak material.

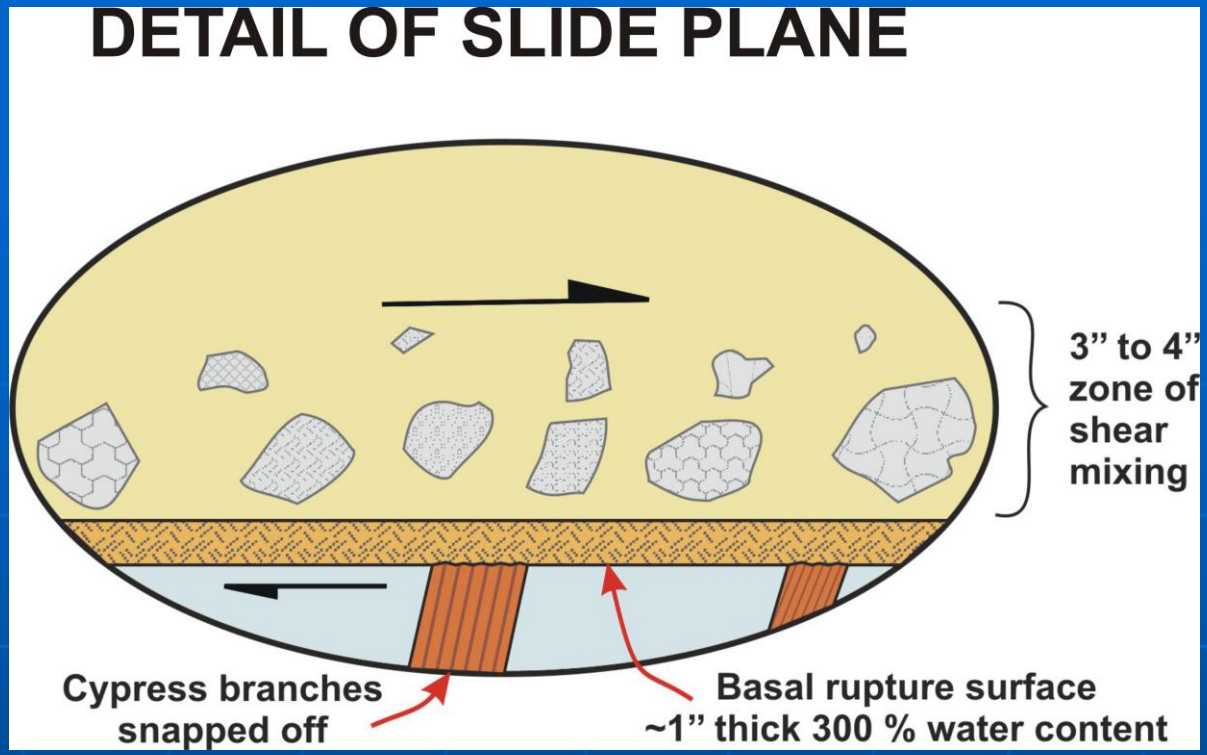
But on the project cross section, that same area shows the symbols for such soils ending at about 15 feet below sea level. Below that depth, the symbols show soils of "fat clay" or "lean clay" — sticky, impervious soils considered very good for resisting water, Rogers said.

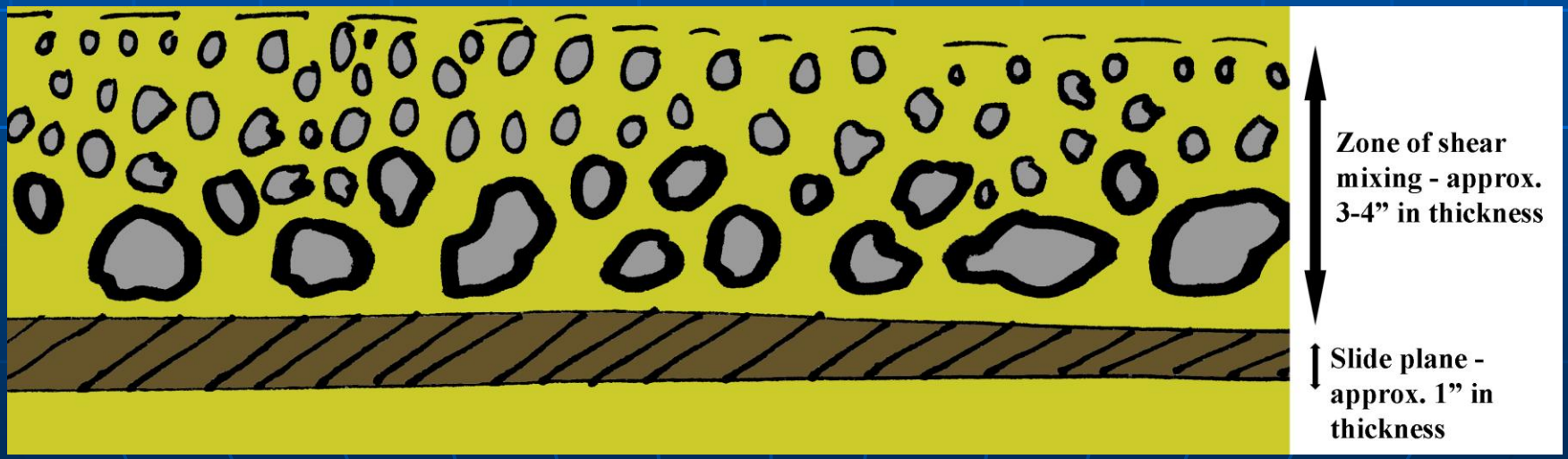
**'Significant finding'**

After doing its own soil borings at the breach this week, the National Science Foundation

# The 17th St Canal slip surface

- Sampling the slip surface was only the first hurdle
- Shear testing of this toothpaste consistency paludal clay proved far more difficult
- The results eventually showed a peak shear strength of 50 psf, degrading to zero after a half inch of rotation

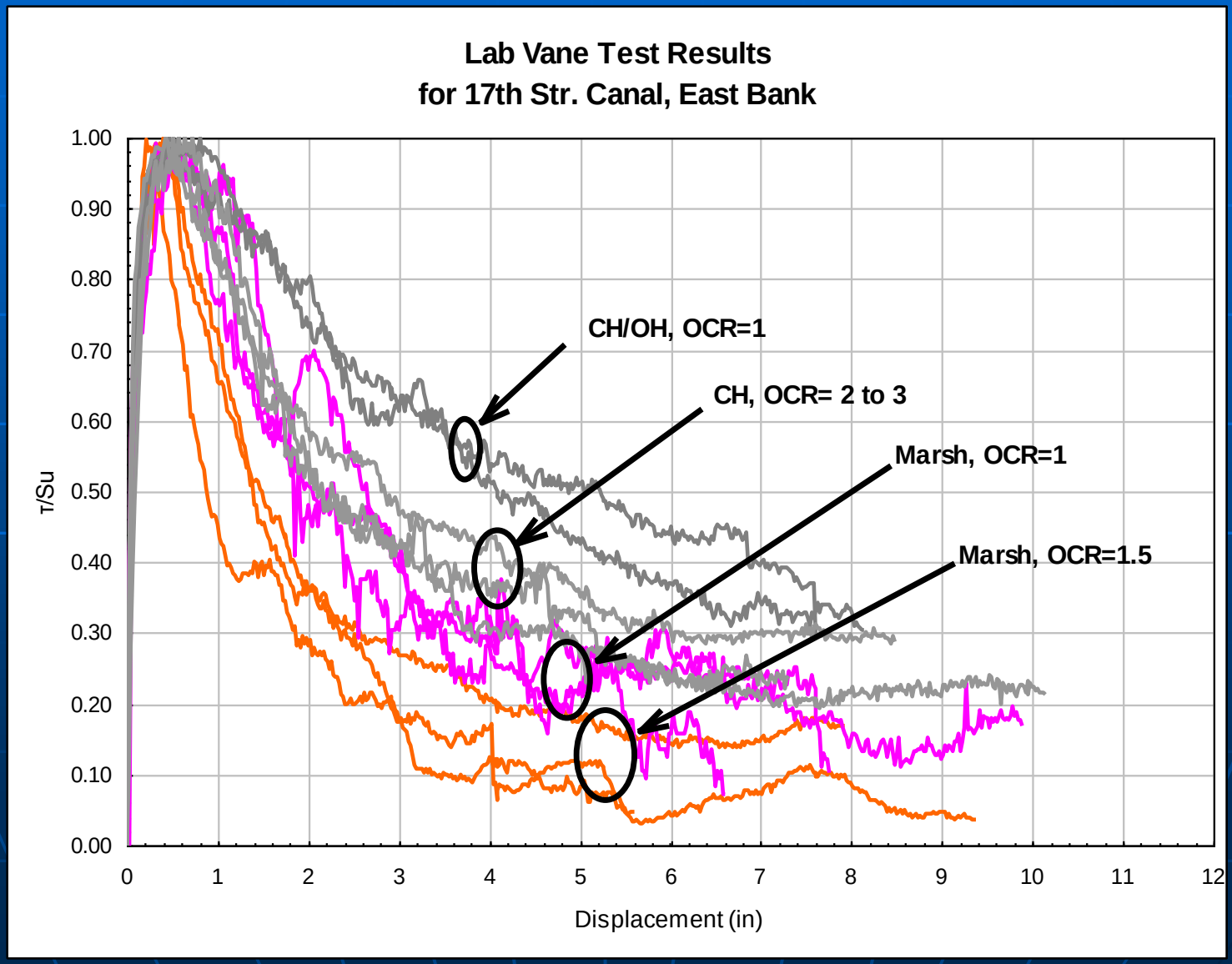



- **Details of the buried slip surface**

# Miniature laboratory vane shear testing at Cal Berkeley

# 17th Street Canal: Sensitivity of the Organic Clay within the Marsh Stratum vs Sensitivity of the Deeper Gray Lacustrine Clay (CH)

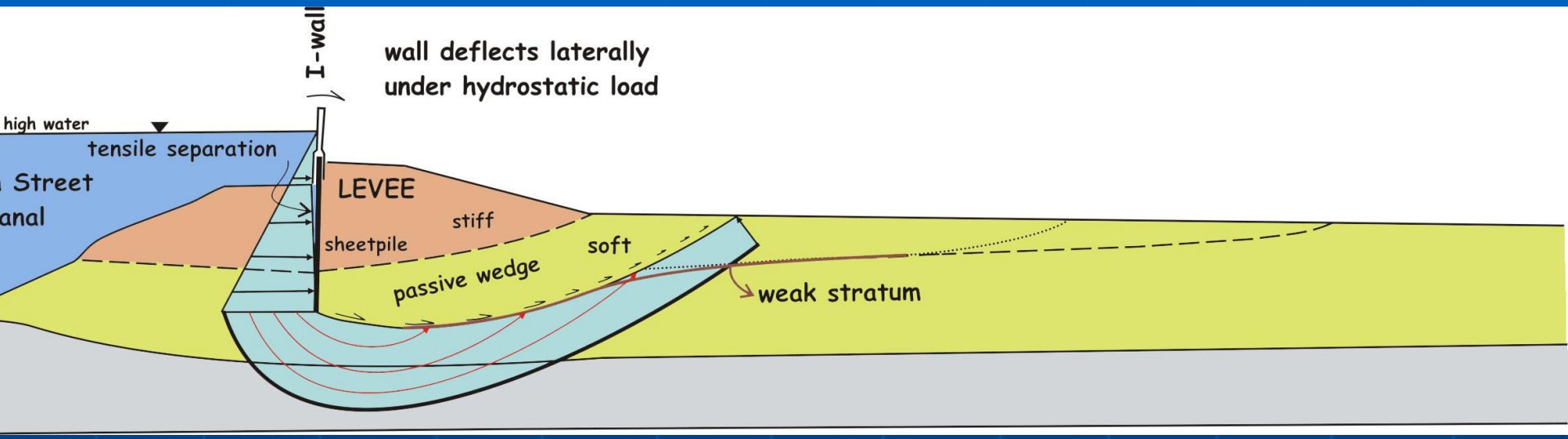


# Reconstruction of the likely failure sequence


# Examining the displaced blocks and the stratigraphy

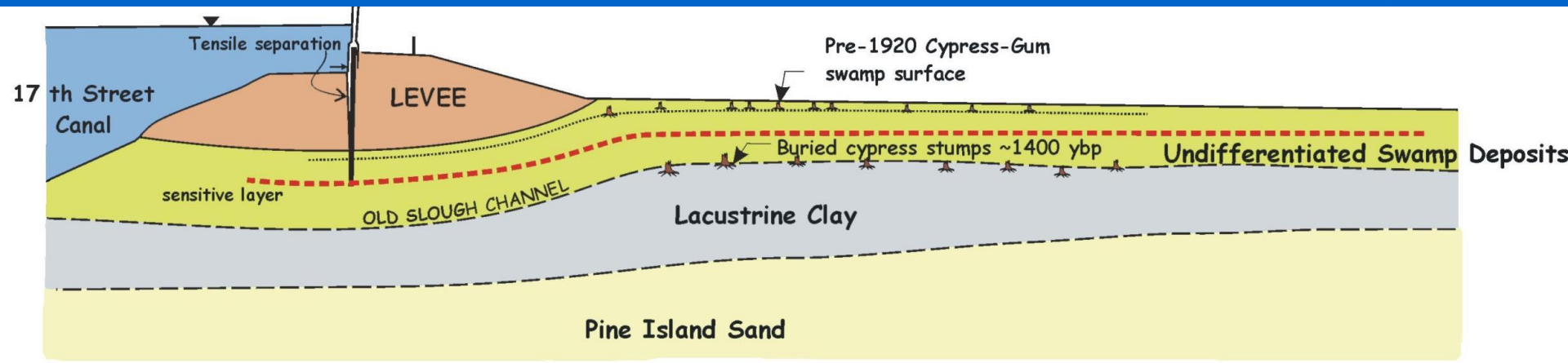
- We examined the displaced block of the 17th Street Levee
- Measured offsets, subsidiary scarps, and took attitudes of slip surfaces and marker beds
- Brunton and tape surveys of thrust plates

As the I-wall tilted, a tension crack, or gap, formed which allowed pore water pressures to be transferred to the passive reaction wedge

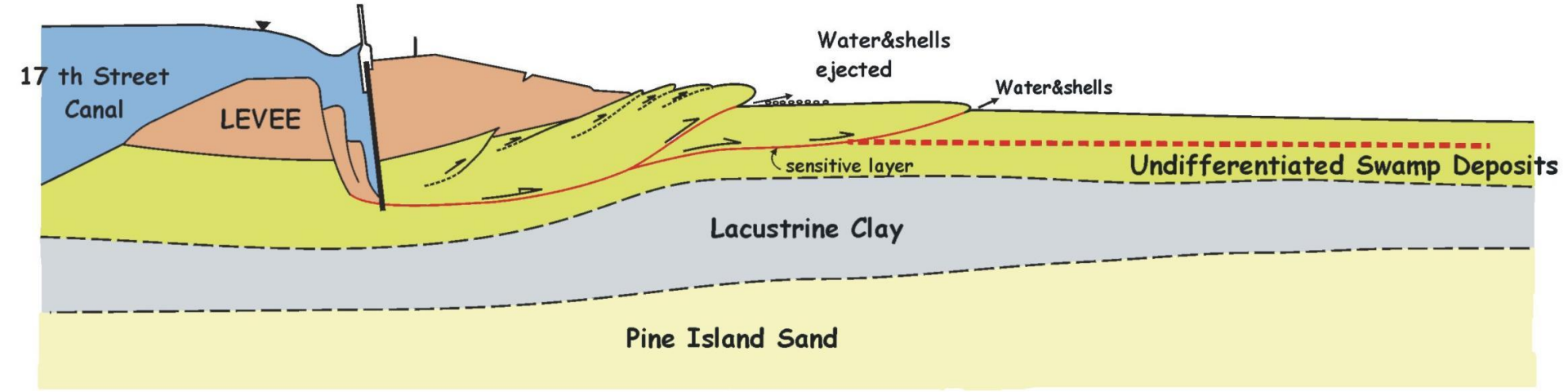



The passive reaction wedge coincided with stratigraphic horizon, which was depressed by the weight of the levee embankment on the compressible cypress marsh deposits

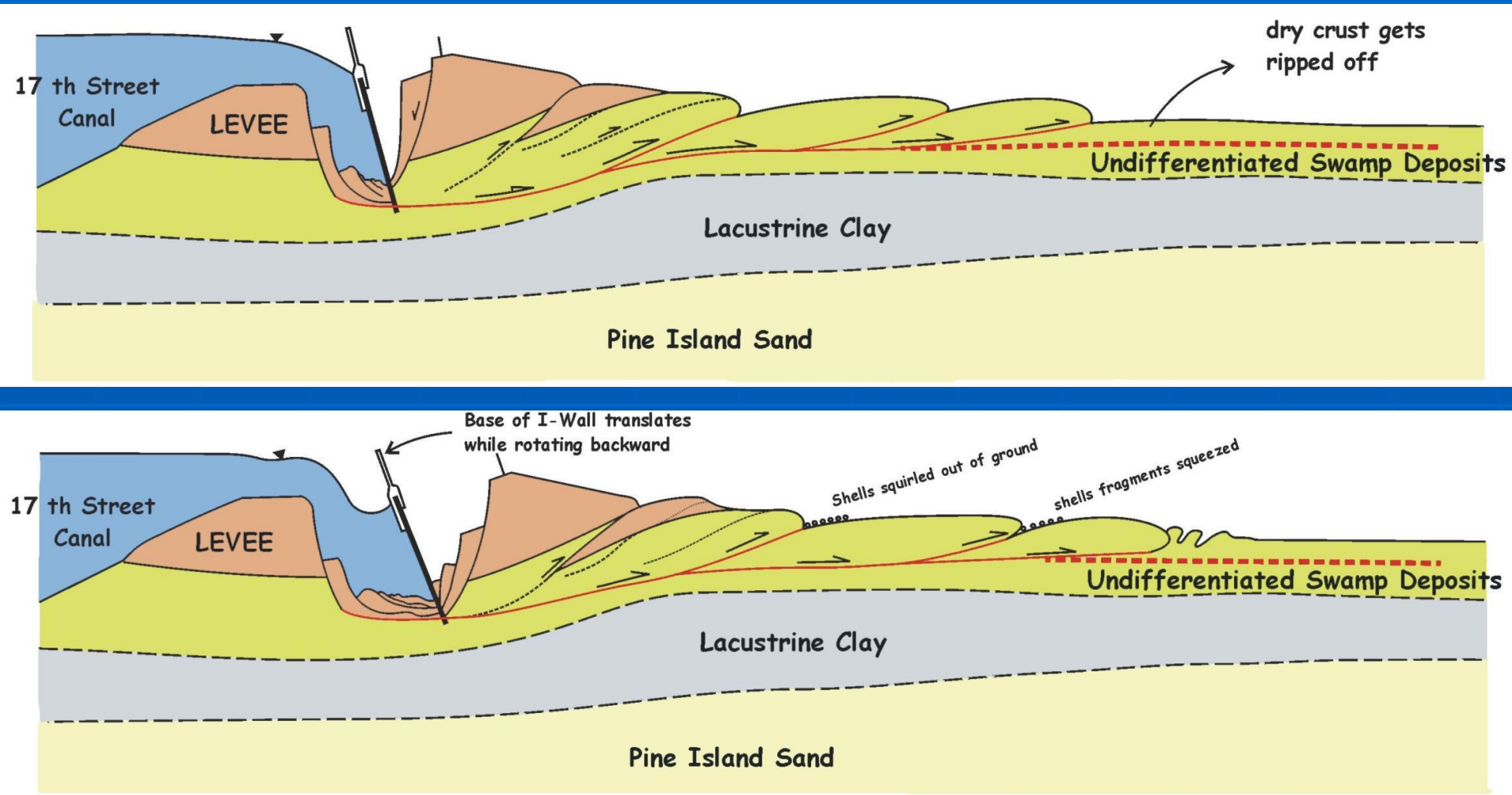
Passive reaction wedge coincided with stratigraphic horizon depressed by weight of the levee embankment on the compressible cypress marsh deposits



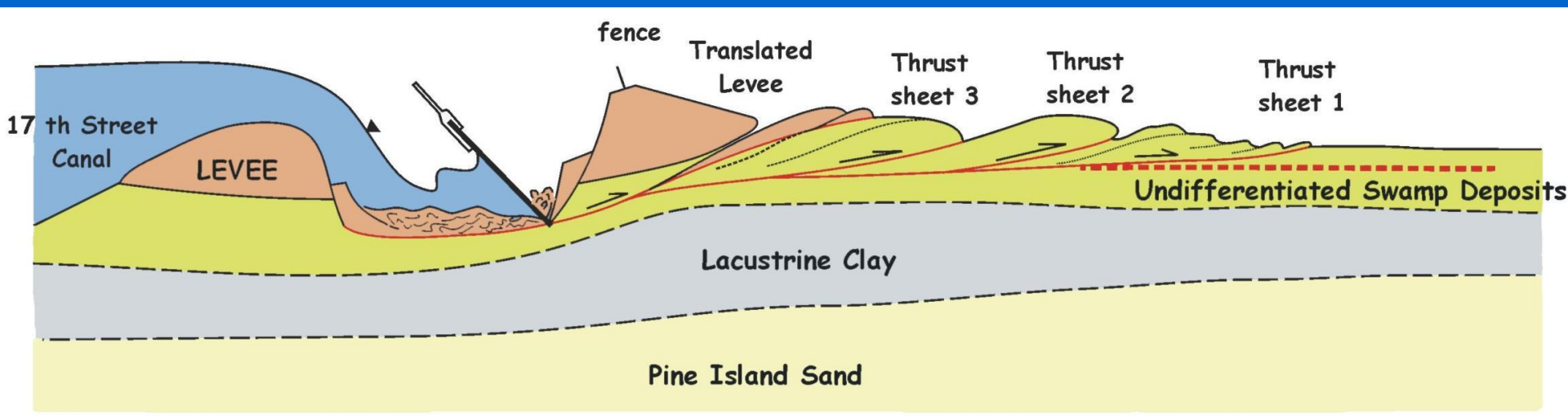

En-echelon traction shears noted along base of original embankment. Note initial back rotation component of motion and development of planar thrusting



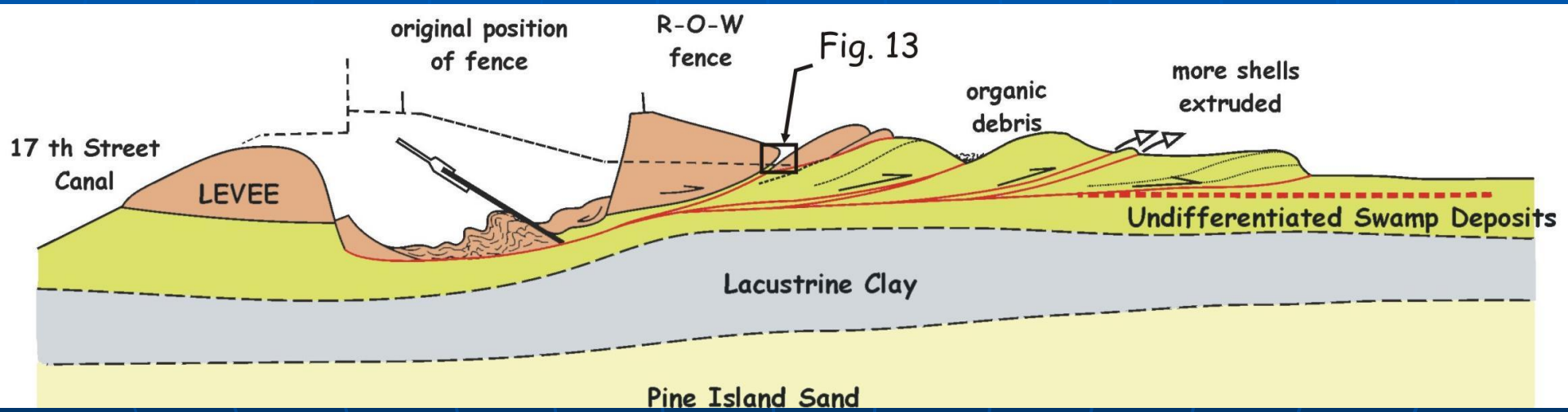

Initial loading conditions. Storm surge rises to within 4 feet of flood wall crest. Hydrostatic pressures on sheetpile supported I-wall highlighted in blue. Translational failure begins.




**Progression of translational failure sequence. Multiple thrust sheets develop in partially saturated crust, comprised of sandy fill on top of organic cypress swamp deposits. The upper crust buckles like a rug being rolled up.**




Some sheetpile supported I-walls fell backward; others fell forward




Final stages of translational failure sequence. Lower section shows failed levee after 51 feet of displacement. The void was quickly backfilled with gravel as part of sealing the breach.

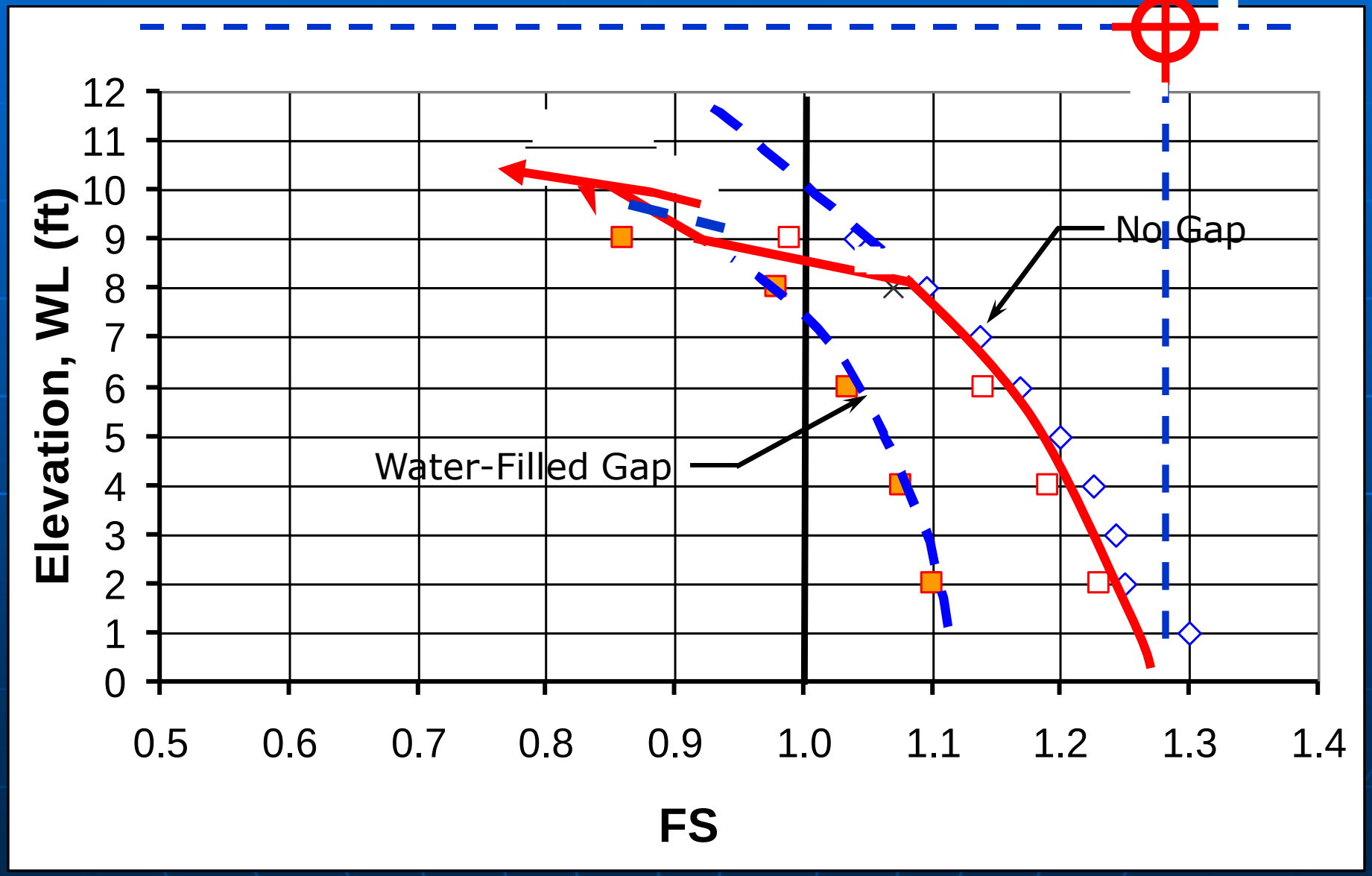
# Conclusions

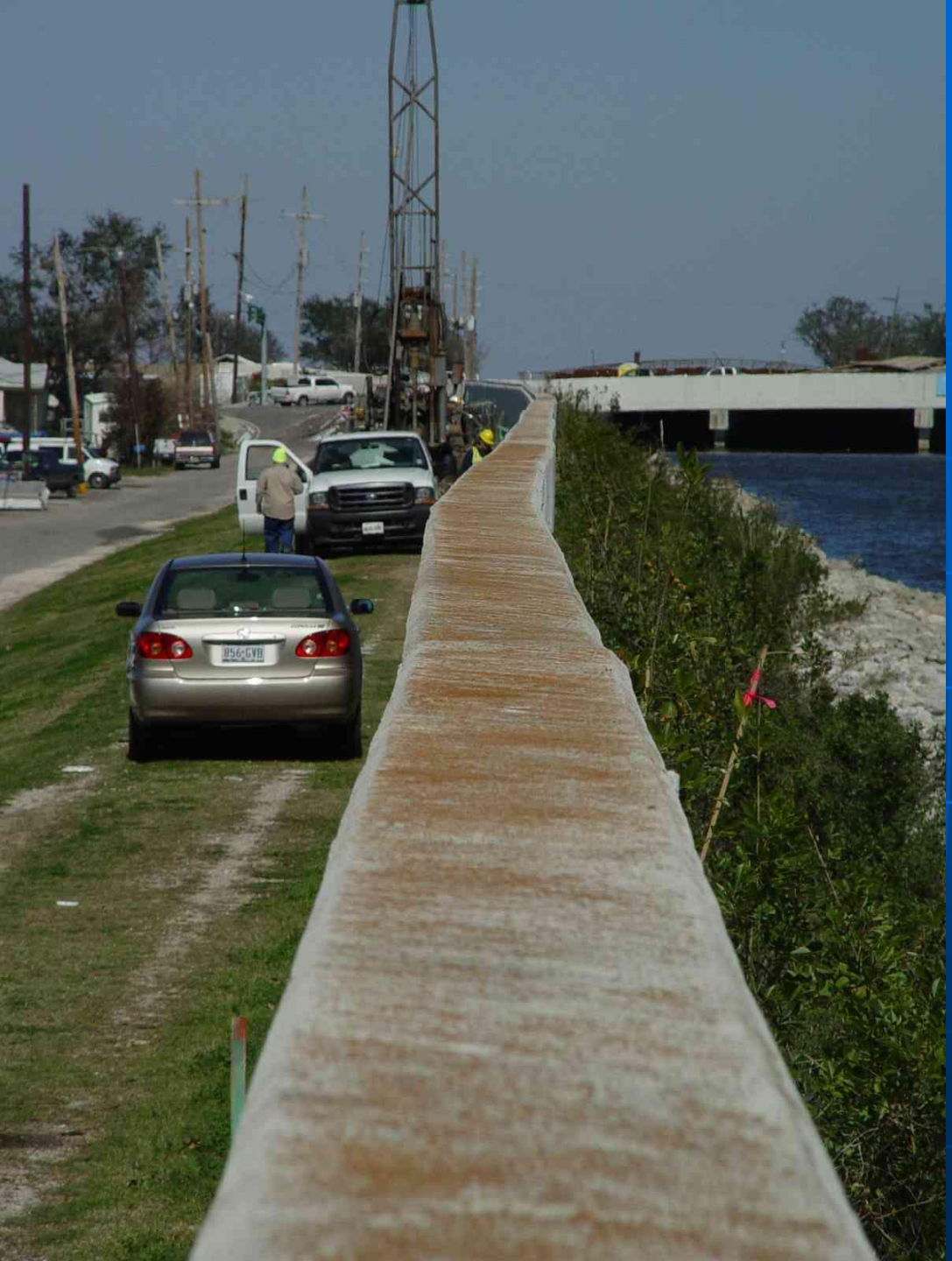
1) *geology matters more than most engineers realize; and,*
2) *it essentially controlled everything bad that occurred!*

# 17th Street Canal East Side Analysis

(Water Elev. +12.5 feet)

(FS = 1.3)

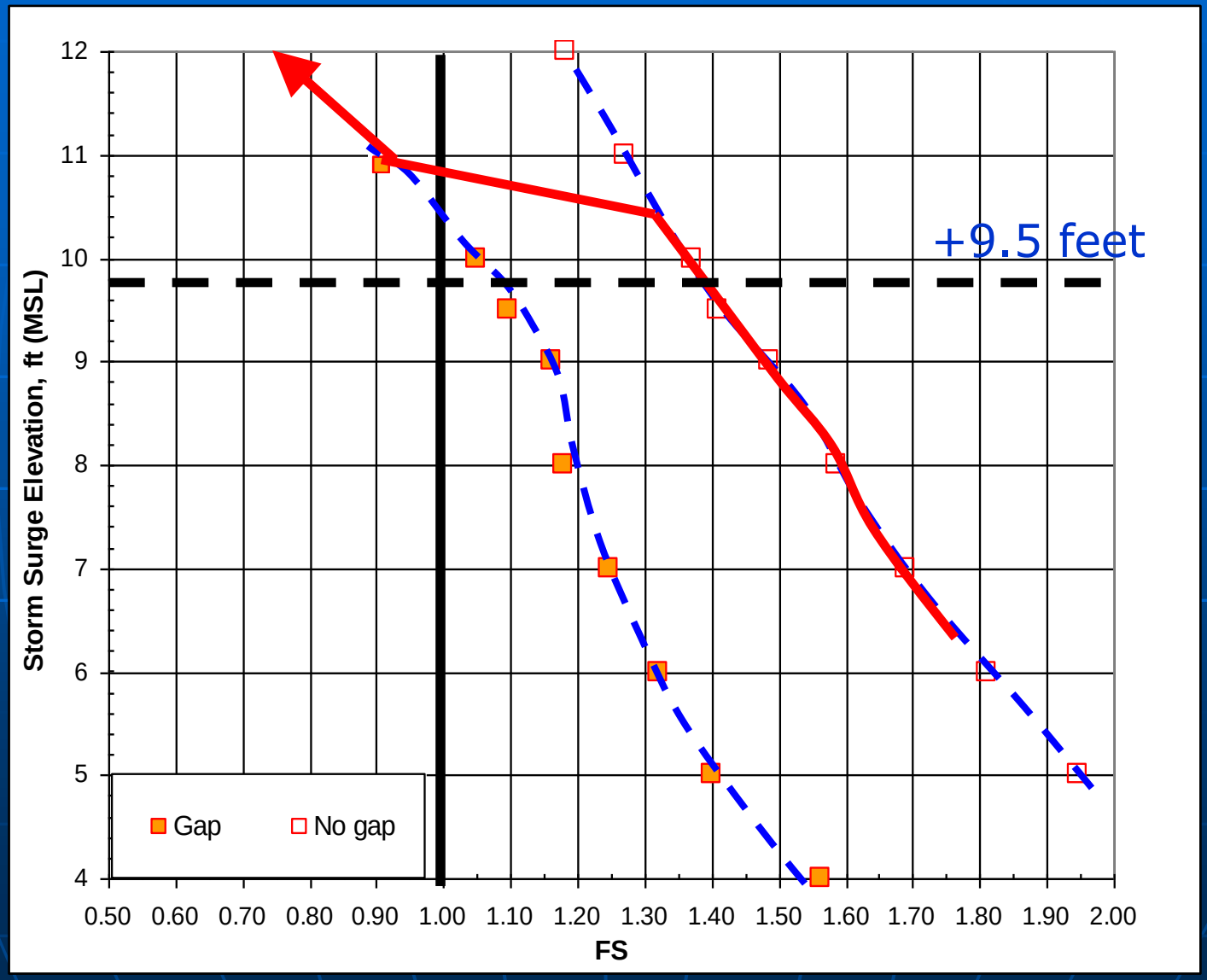




# The tilting wall controversy

- The NSF team assuaged that the bend in the flood wall on the west (unfailed) side of the 17th St Canal was evidence of an incipient failure
- This section of the underlying levee failed in 1947, before the flood wall was built

# 17th Street Canal, West Bank Analysis



# The design of the 17th St Canal I-walls violated three "deadly sins"

- 1) Never allow yourself to draw geologic cross sections using a ruler. *There is no such thing as a ruler straight line in geology*.
- 2) Always construct multiple cross sections without vertical exaggeration to ascertain loading and reaction geometry, just like a *free body diagram*. Use multiple orientations to appreciate apparent dips of various units.
- 3) Never *average* shear strength values when you get a low factor of safety. *Slope failures tend to occur along the weakest horizons* – finding and sampling those horizons is almost always difficult, requiring considerable judgment and experience.

**This lecture will be posted at**

**www.mst.edu/~rogersda/levees**

in .pdf format for easy downloading and use by others.