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U.S. DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

NOAA

Performance Evaluation of New Orleans and Southeast Louisiana Hurricane Protection System

Floodwall and Levee Performance Analysis

SOUTH FLORIDA WATER MANAGEMENT DISTRICT

Interagency Performance Evaluation Task Force (IPET)

Harris County
Flood Control District

ERS
ECONOMIC RESEARCH SERVICE
United States Department of Agriculture

National Geodetic Survey

NOAA/NOS CO-OPS

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Floodwall and Levee Performance Analysis

The Performance: How did the floodwalls and levees, individually and acting as an integrated system, perform in response to Hurricane Katrina, and why?

Objective

- **Analyze the levees and floodwalls performance during Hurricane Katrina**
- **Investigate the most likely causes of the damage and failure of the levees and floodwalls in the system**
- **Compare them with similar sections or reaches where the performance was satisfactory**
- **Understand mechanisms that led to the breaches along a reaches in order evaluate the potential performance of the similar un-breached reaches of the protective system**

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Preliminary Results To date

- **Primary Factors Leading to the 17th Street Canal Breach**:
  - **Development of a gap between the wall and the levee fill on the canal side of the wall**
  - **Variation in foundation clay shear strength from levee crest to landside toe**

- **Except for the outfall canals, all other damage to the floodwalls and levees has been due to overtopping**

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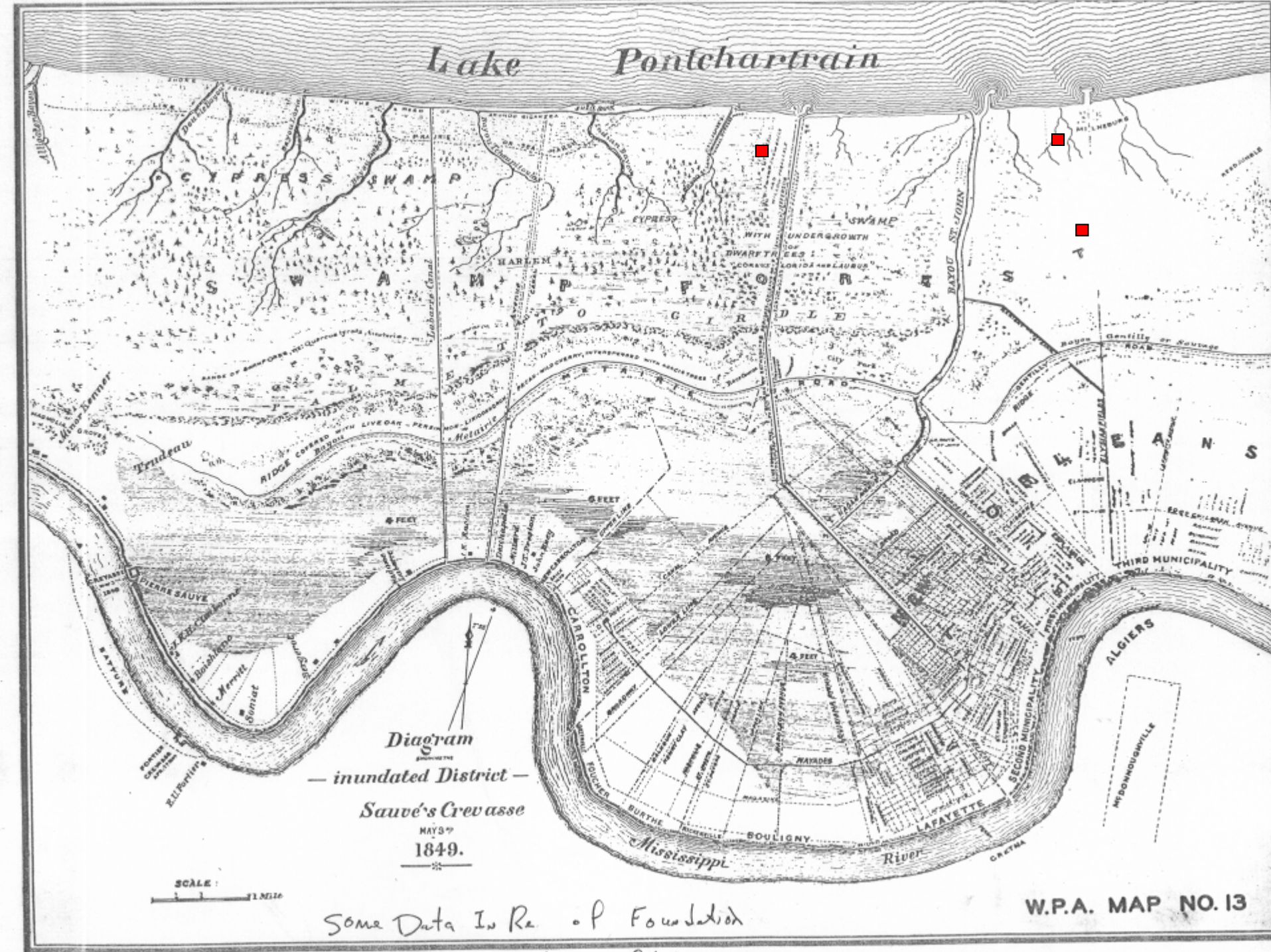
Cross-Sections & Soil Profiles for Use in Analysis



Some Data In Re . P Foundation

W.P.A. MAP NO. 13

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New Orleans Area

LEGEND

Point bar

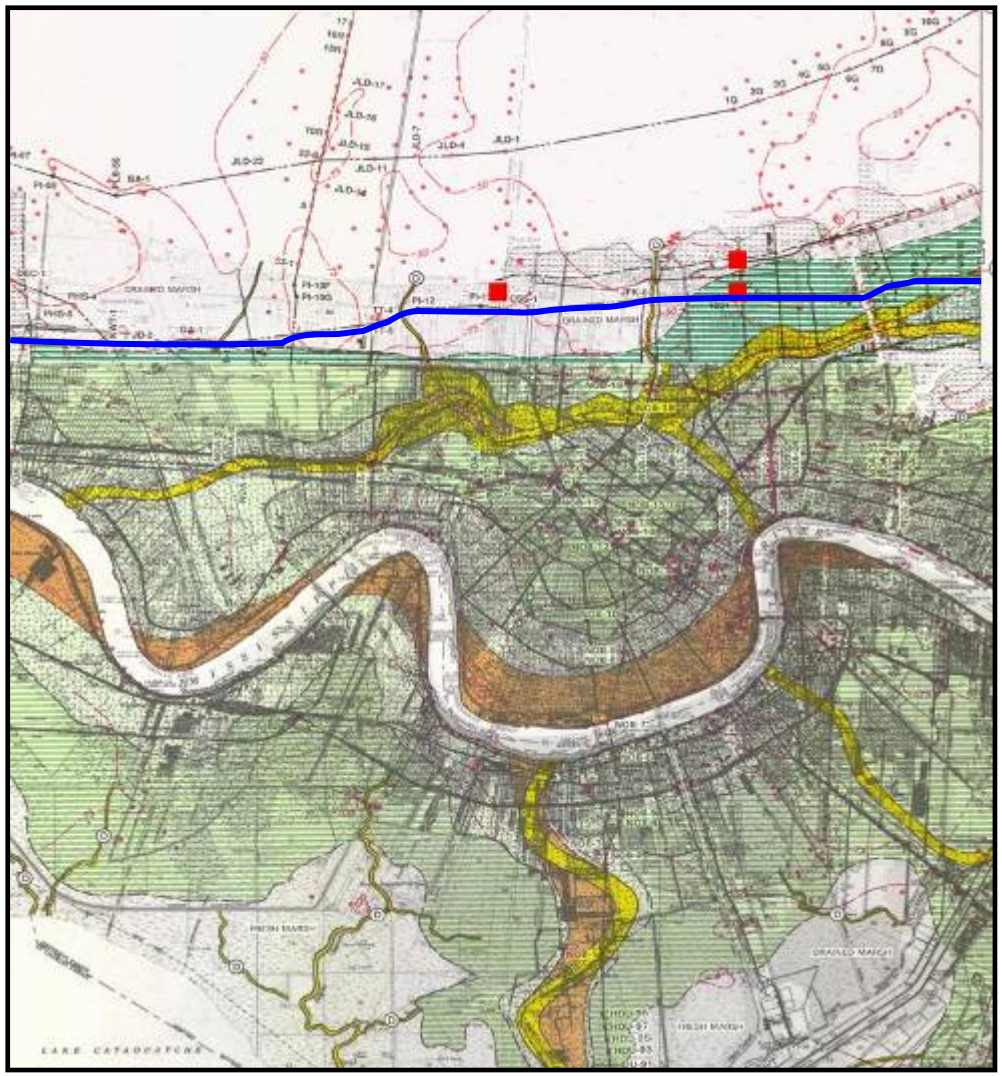
Distributary channel

Inland swamp

-40

Top of Pleistocene-ft msl

Spoil



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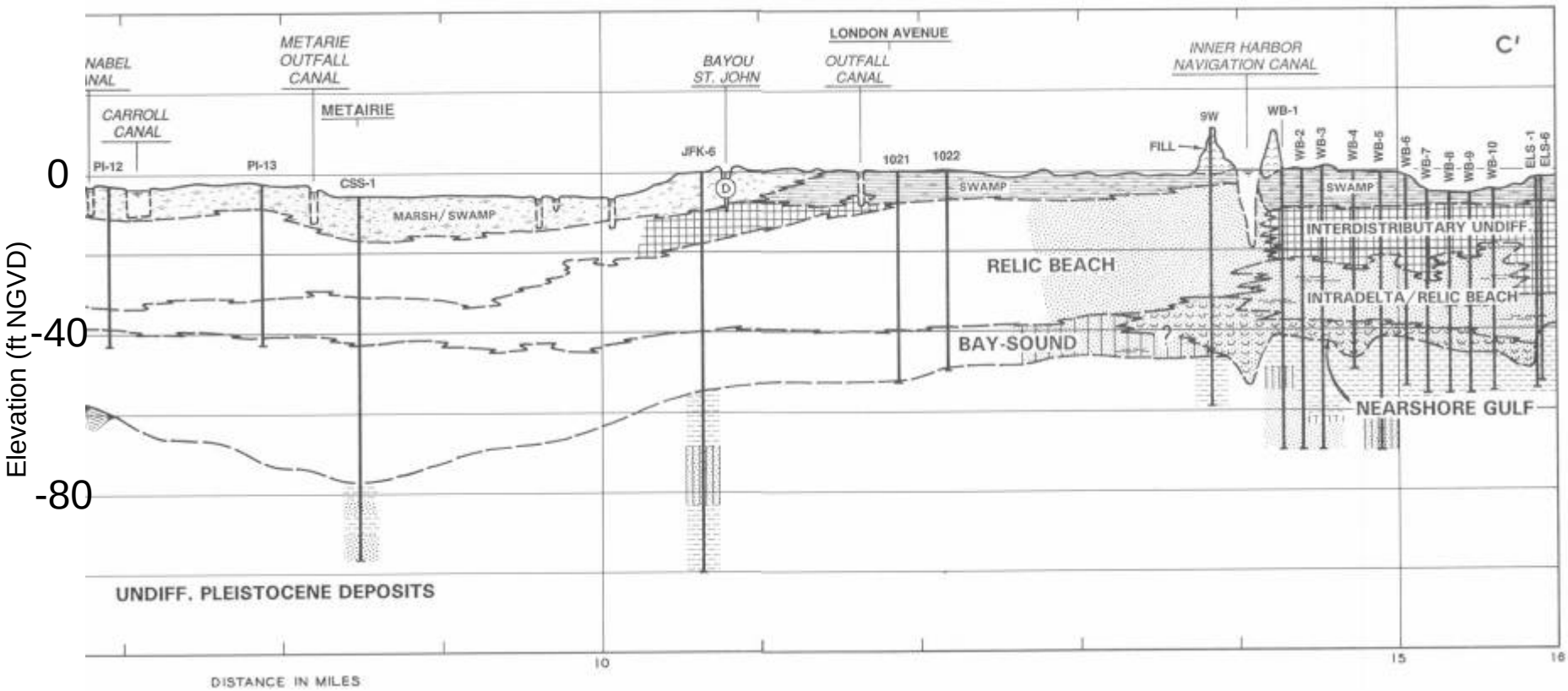
Spanish Fort: X-Section C-C’



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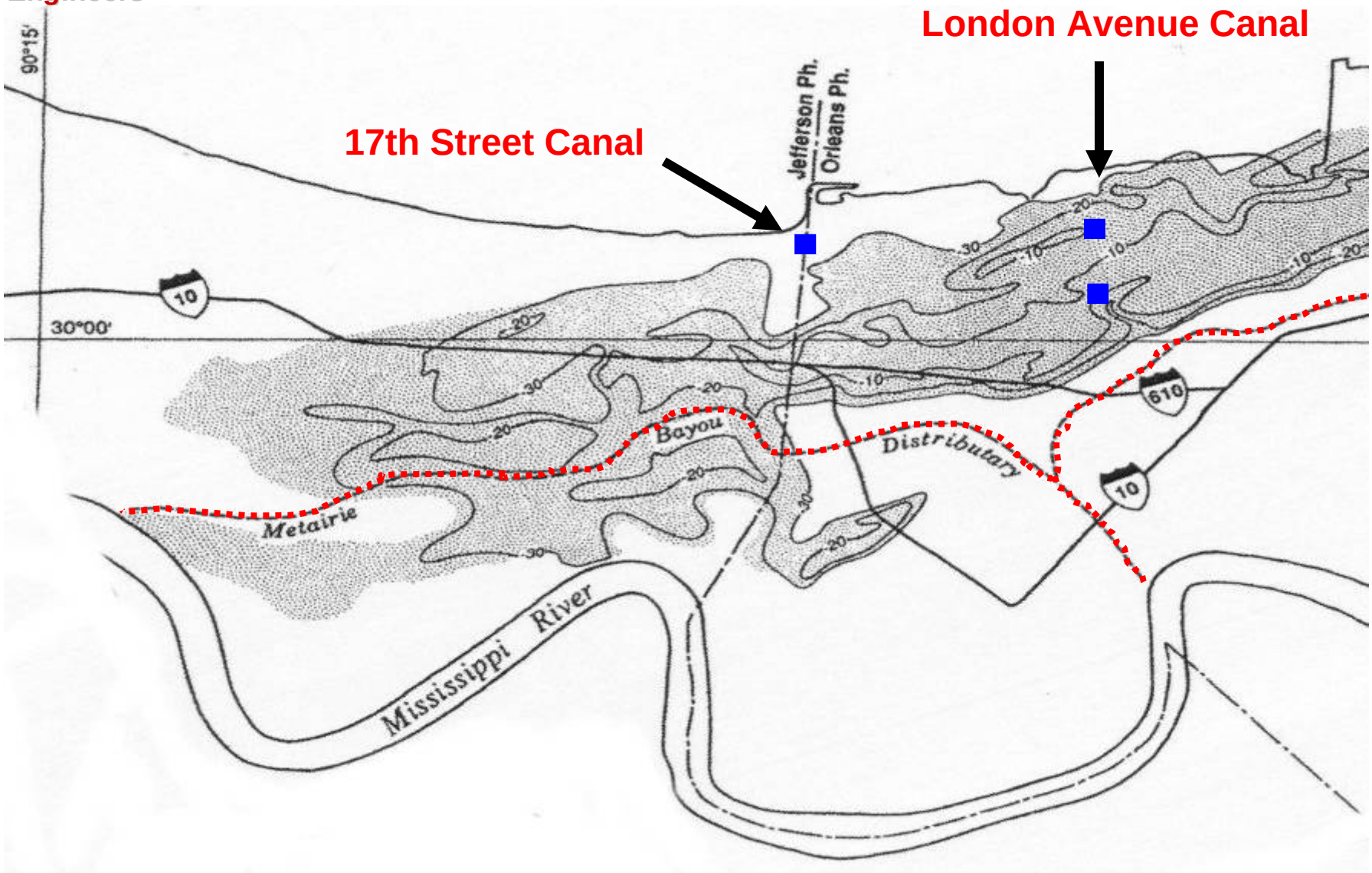
Pine Is Beach Ridge



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17th Street Canal Breach

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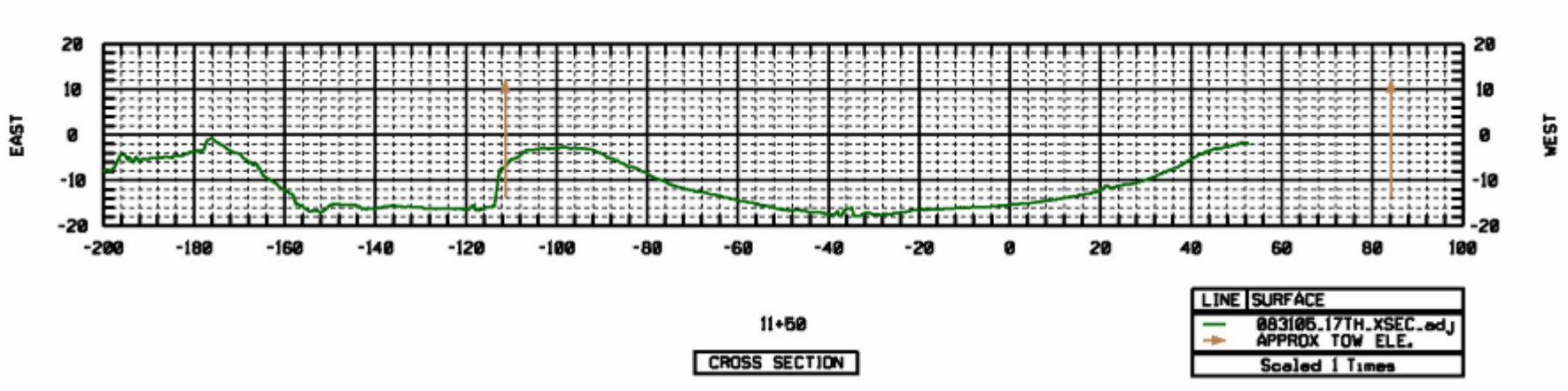
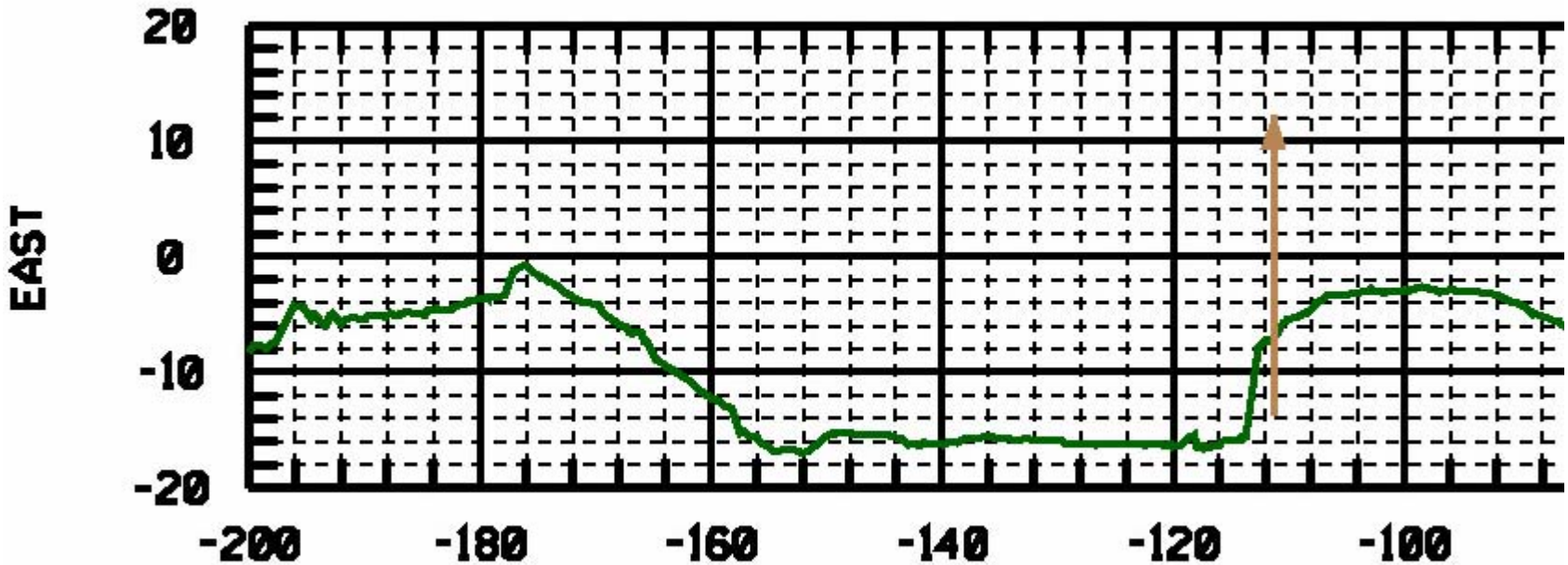
17th Street Canal Breach





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17th Street Canal Breach

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17 Street Canal Swamp

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17th Street Slide Block

17th Street Slide Block

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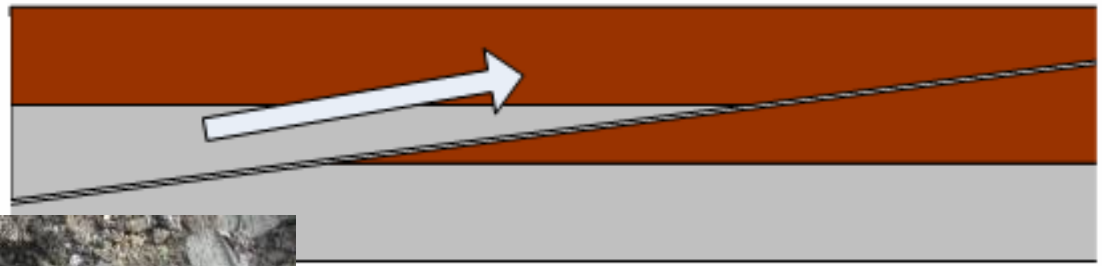

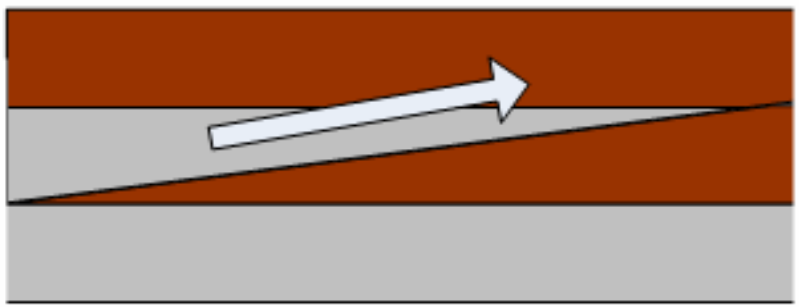

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17th Street Canal I-wall
Soil Strength and Stability

17th Street Canal C/L Failure Section

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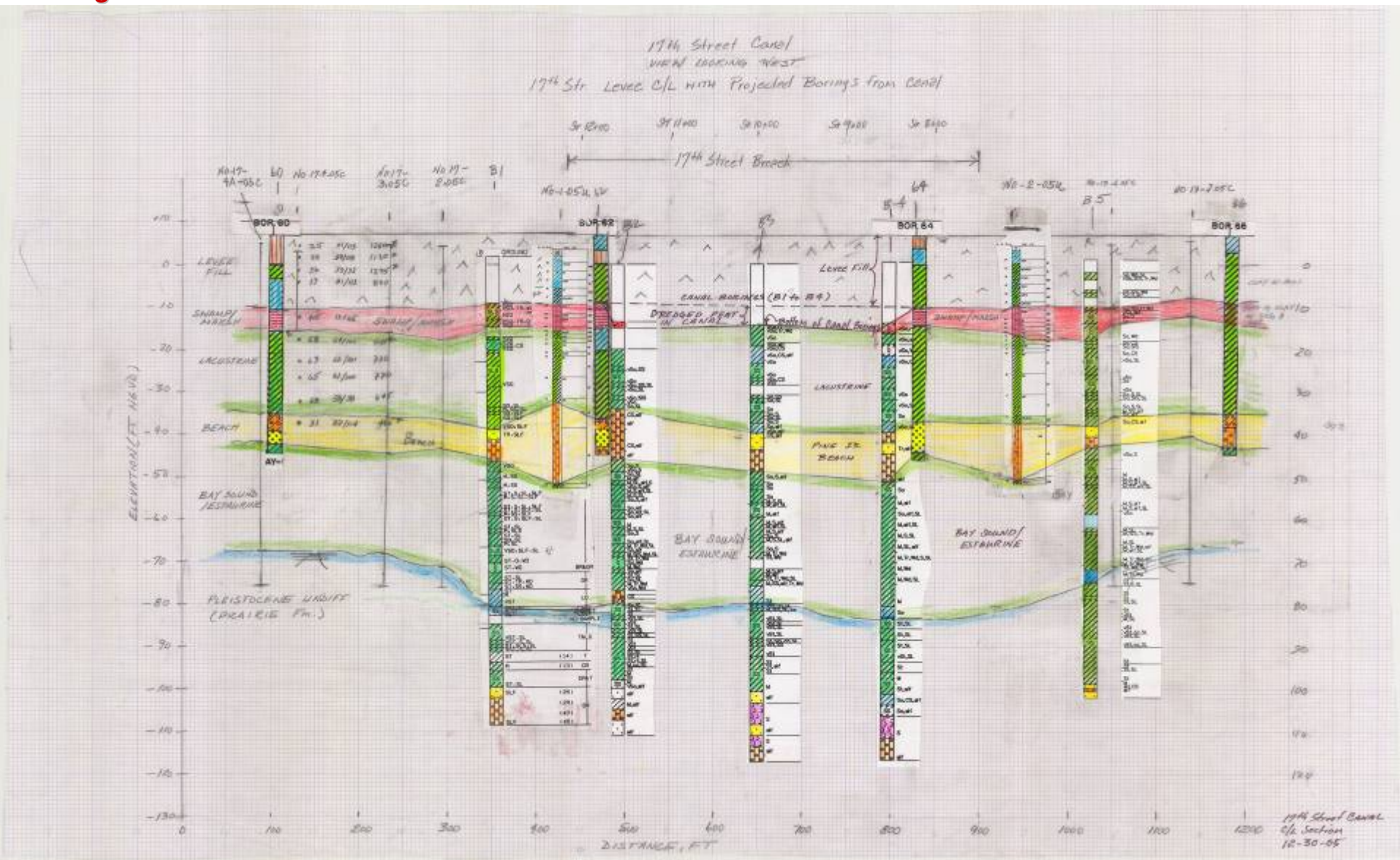

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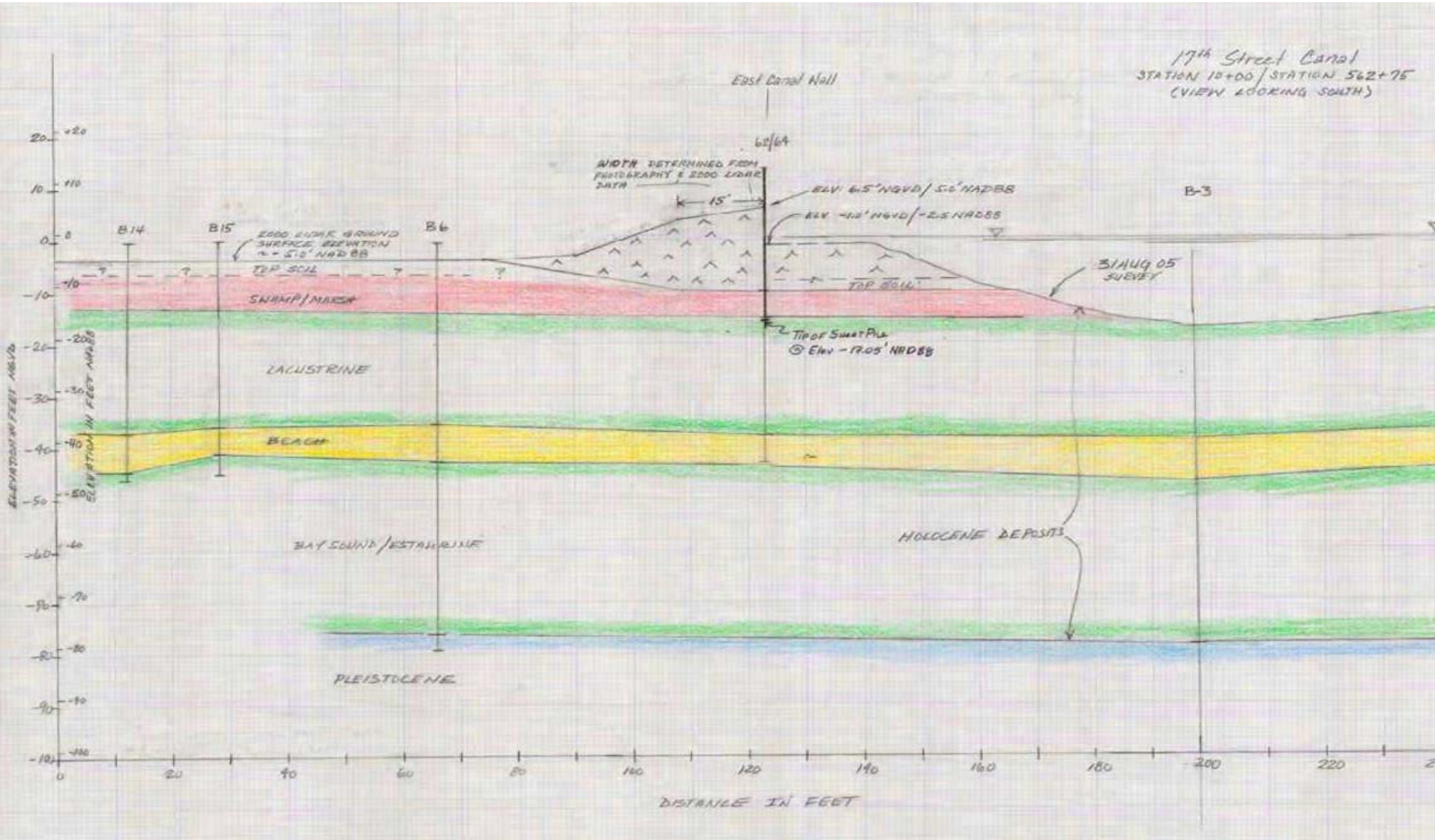
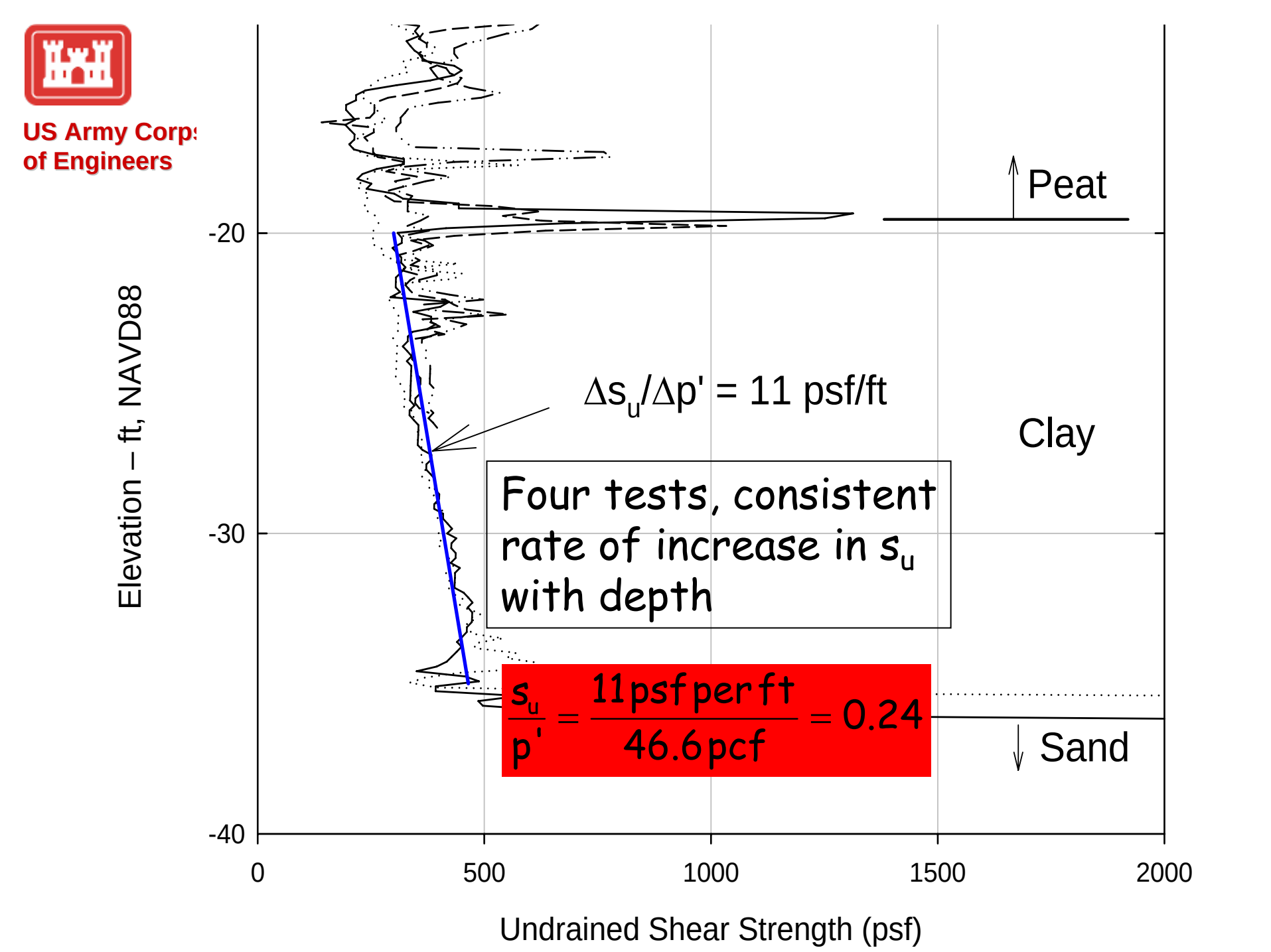
Station 10+00

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Peat
Clay
Sand
$\Delta s_u/\Delta p' = 11$ psf/ft
Four tests, consistent rate of increase in s_u with depth
$\frac{s_u}{p'} = \frac{11\,\text{psf per ft}}{46.6\,\text{pcf}} = 0.24$
Elevation – ft, NAVD88
-20
-30
-40
0
500
1000
1500
2000
Undrained Shear Strength (psf)

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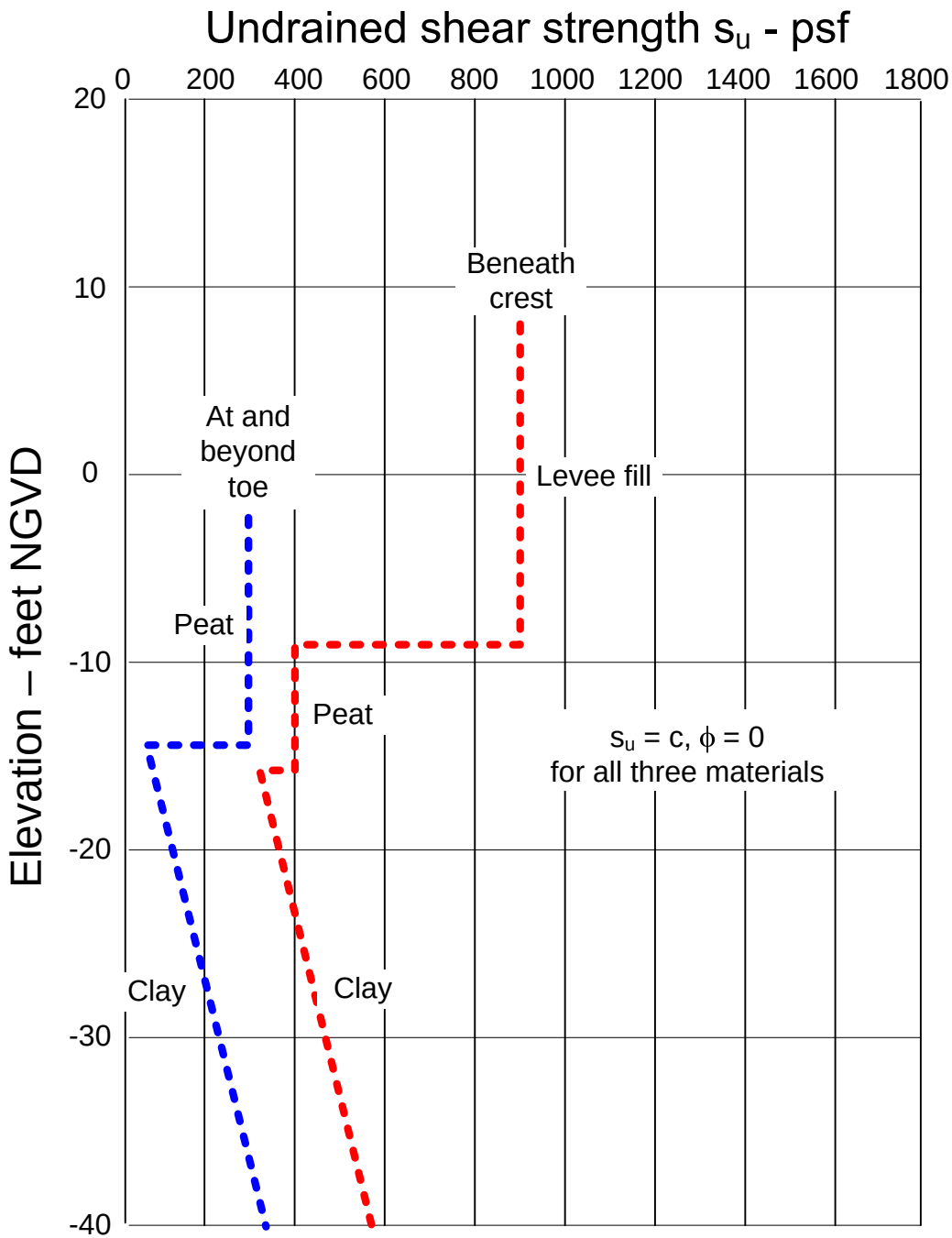
IPET shear strength model



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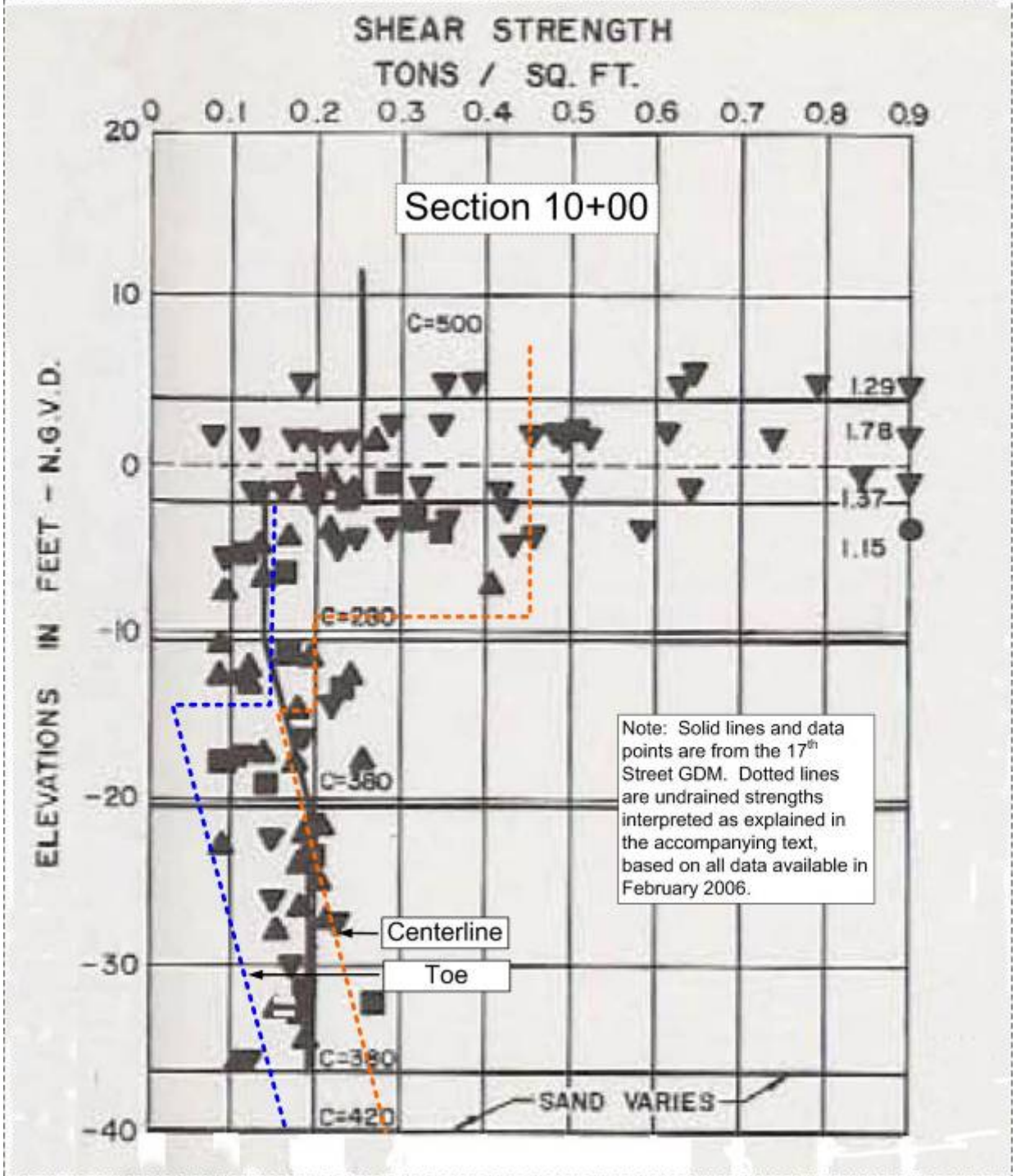
Comparison of IPET shear strength model with design shear strengths



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Clay Strengths in Breach and Adjacent Areas

- Data are sparse and scattered
- Based on five UC and one UU-1 tests from two borings in the breach area, the average s_u is 260 psf
- Based on three UC, three UU, and one UU-1 tests from two borings north of the breach area, the average s_u is 335 psf (30%)
- Based on nine UC, two UU, and one UU-1 tests from three borings south of the breach, s_u 318 psf (20%)

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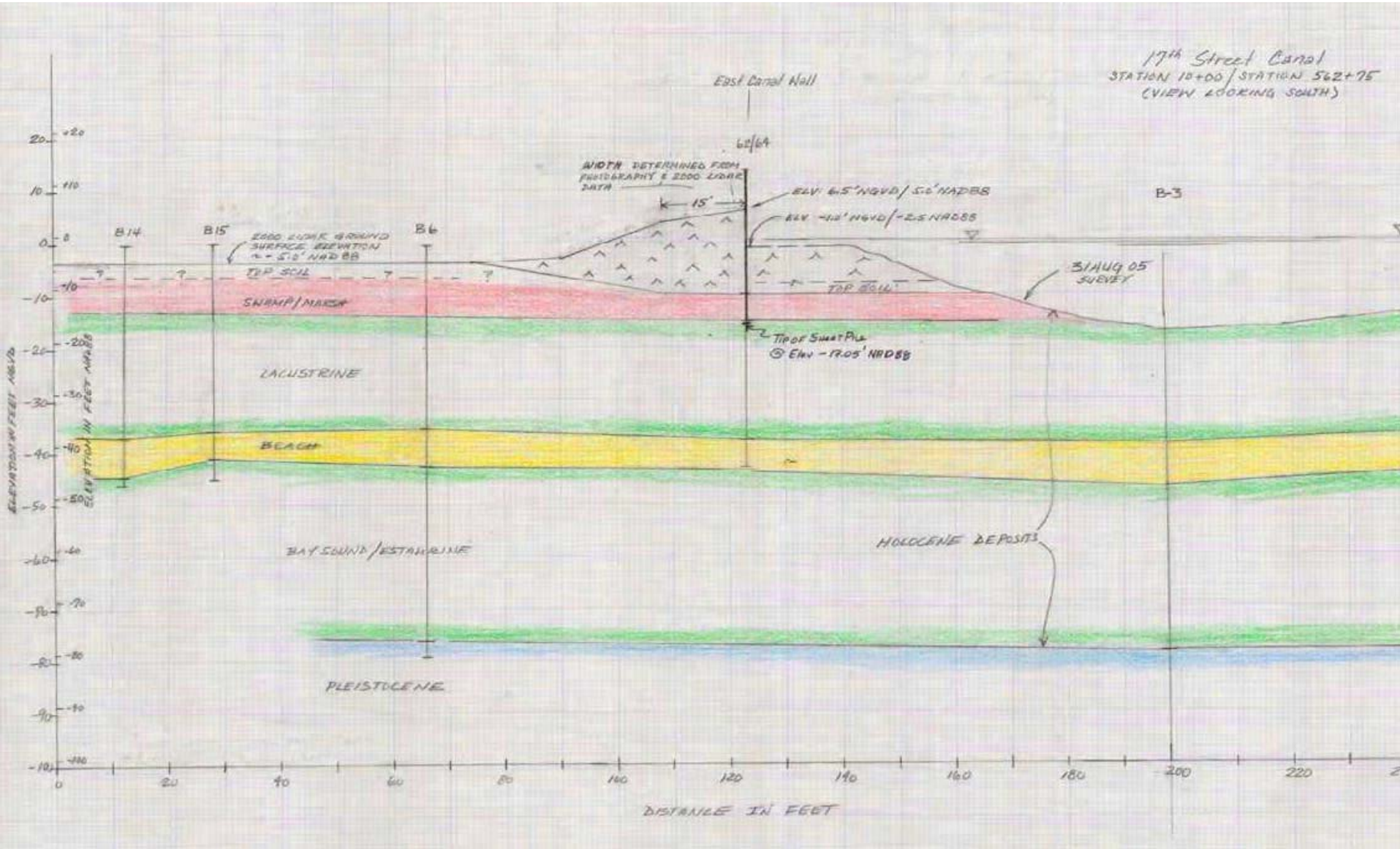
Station 10+00



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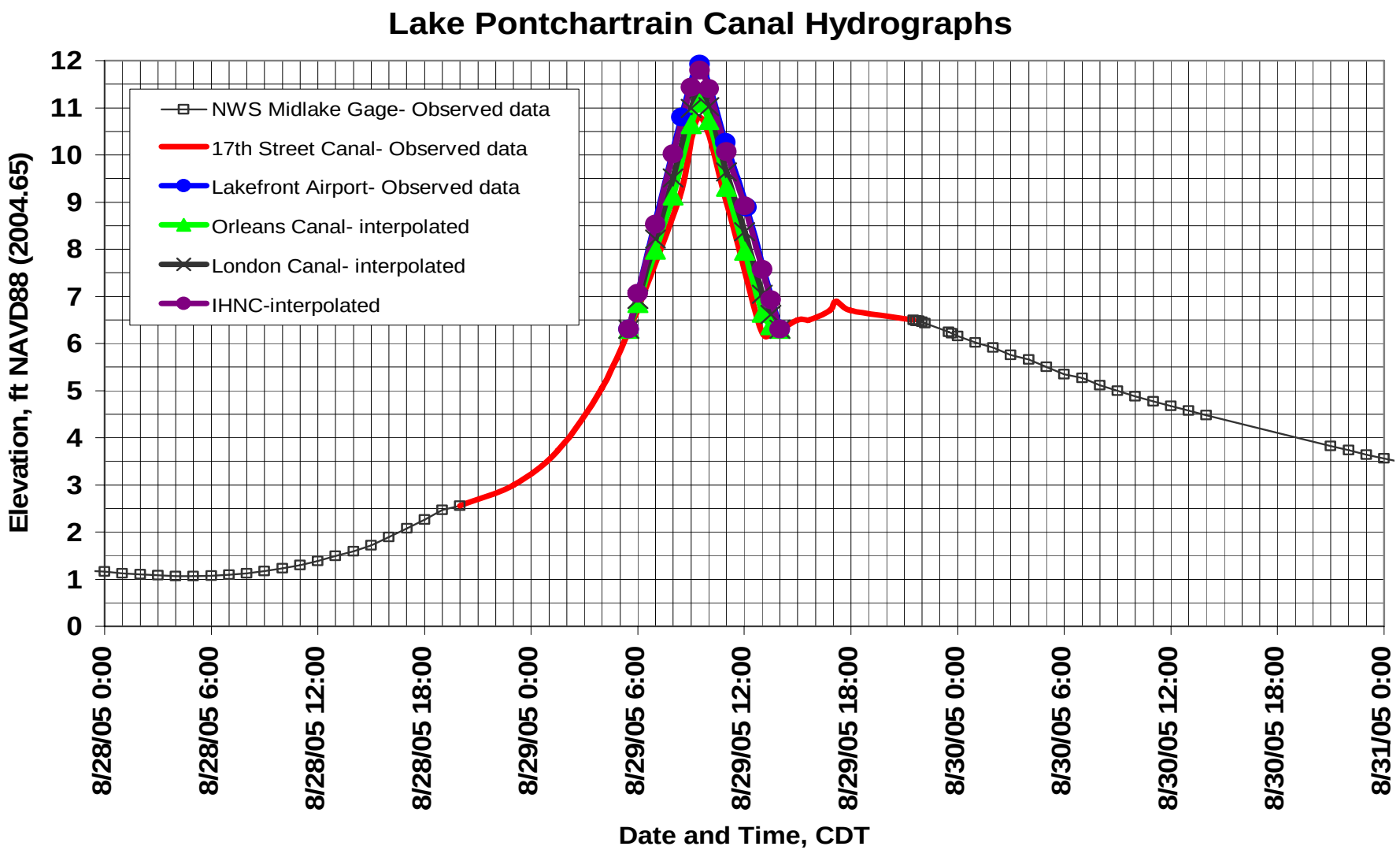
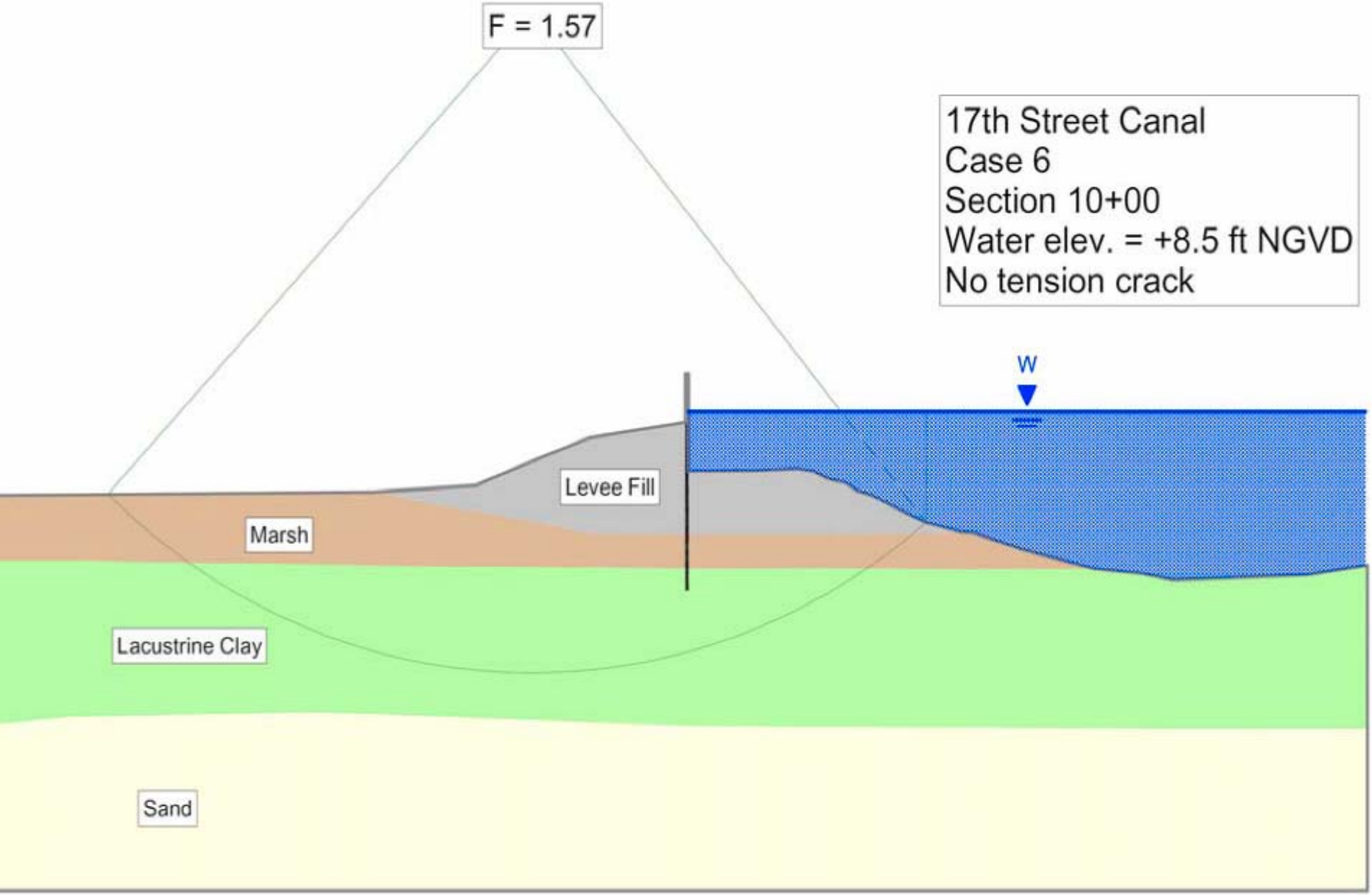
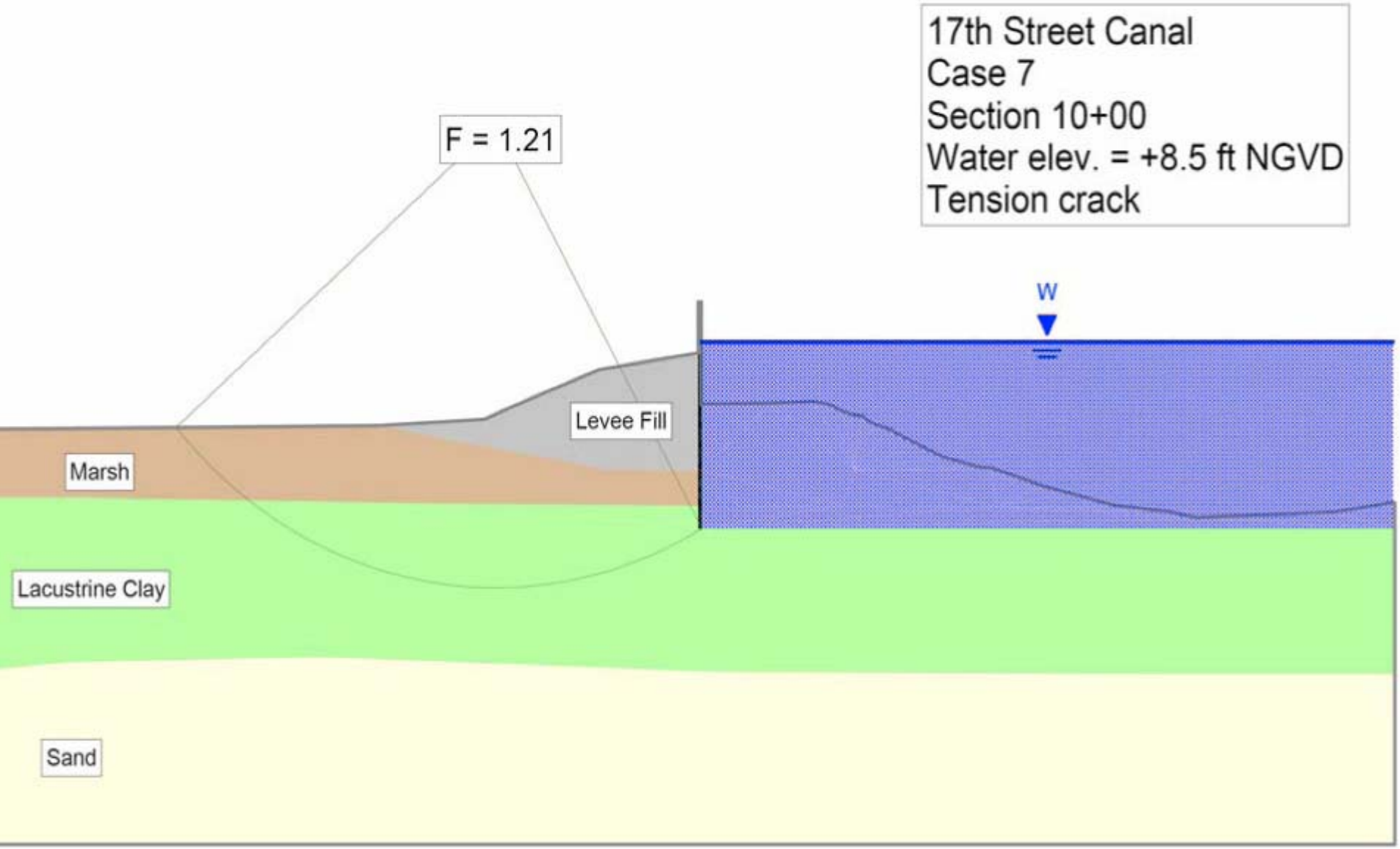
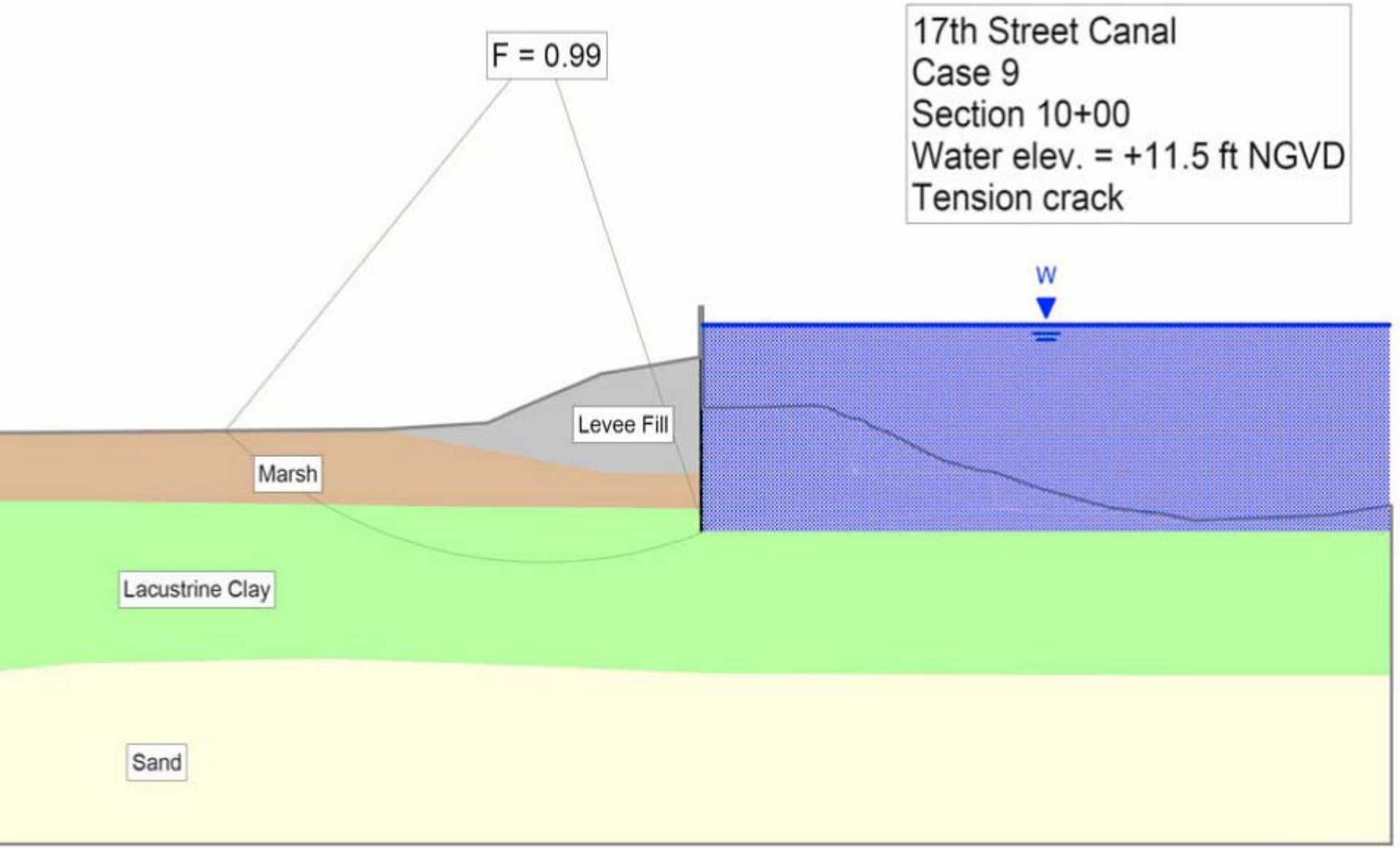
17th Street Canal Hydrograph




F = 1.57
17th Street Canal
Case 6
Section 10+00
Water elev. = +8.5 ft NGVD
No tension crack
W
Levee Fill
Marsh
Lacustrine Clay
Sand


17th Street Canal
Case 7
Section 10+00
Water elev. = +8.5 ft NGVD
Tension crack
F = 1.21
W
Levee Fill
Marsh
Lacustrine Clay
Sand


F = 0.99
17th Street Canal
Case 9
Section 10+00
Water elev. = +11.5 ft NGVD
Tension crack
W
Levee Fill
Marsh
Lacustrine Clay
Sand

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Water levels (NGVD)

- W. L. = 11.3 ft, with crack, F = 1.00
- W. L. was 7.5 ft to 9.5 ft, plus wave effects, at time of failure
- Wave effects may be + 1.0 ft
- W. L. for F = 1.0 is one to two feet higher than estimated effective water level at time of failure

Design Cross Section for Breach a Area

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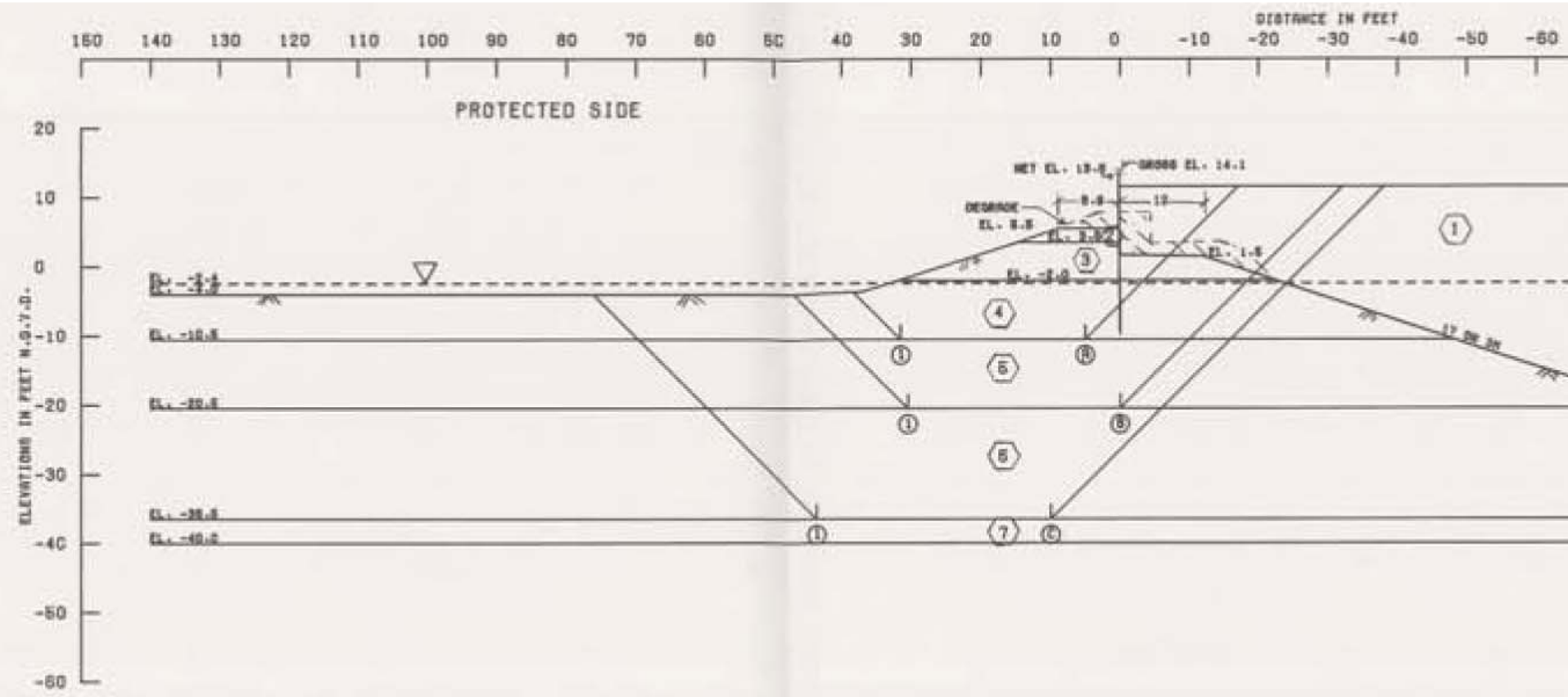
W. L. = 11.5 NGVD
No crack
Method of planes F = 1.30



Design Cross Section for Breach a Area

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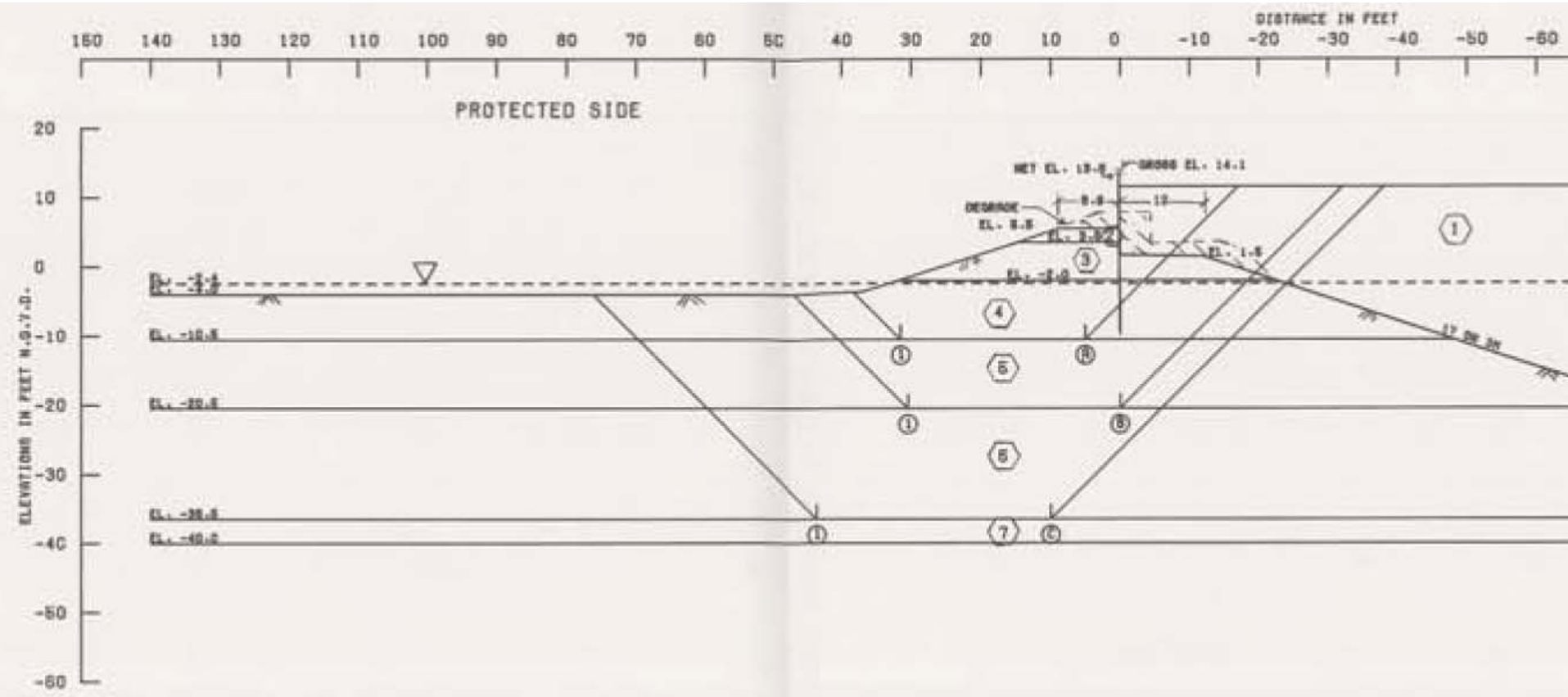
W. L. = 11.5 NGVD
No crack
Spencer's method F = 1.45



Design cross section and strength

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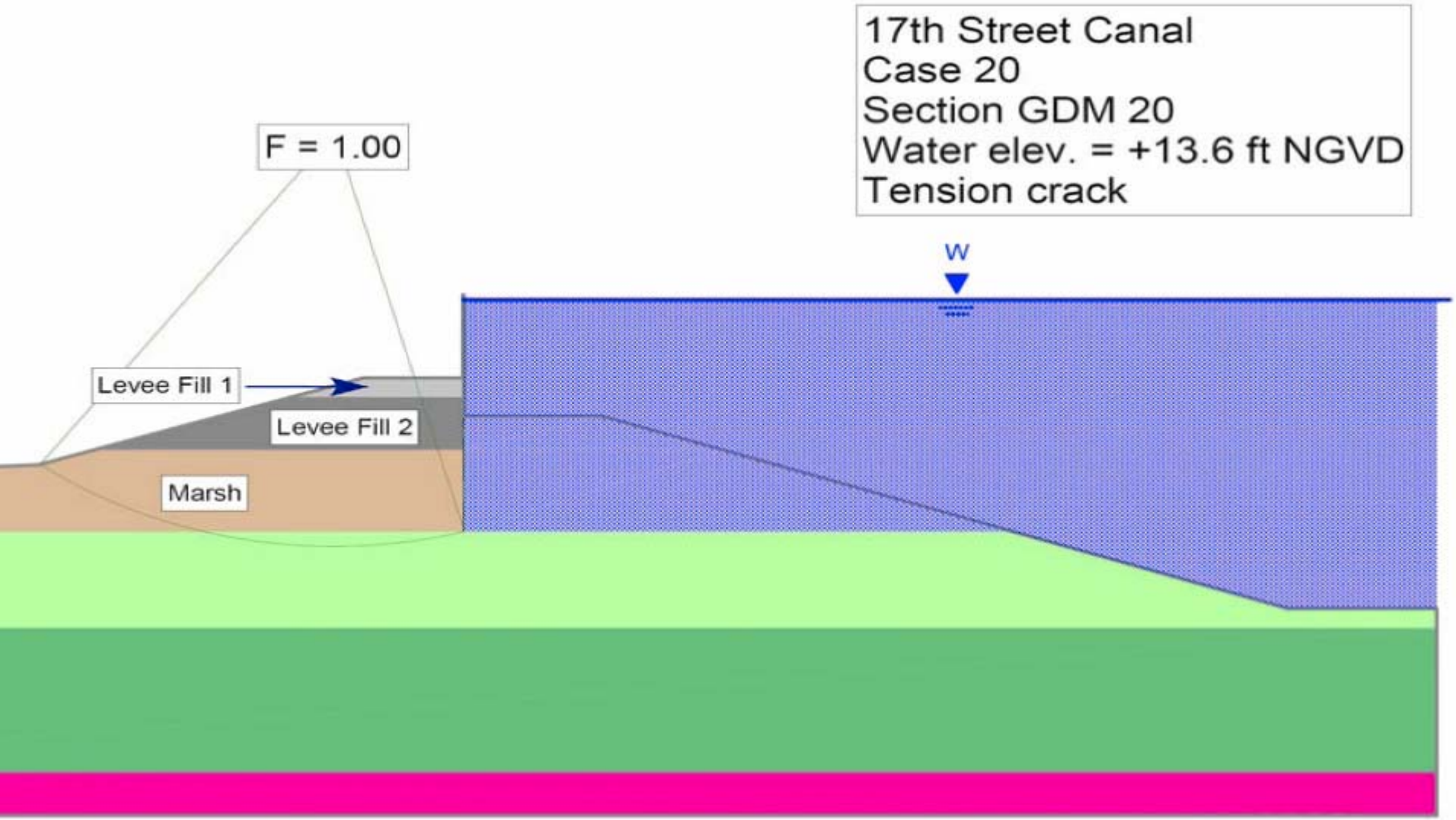
W. L. = 13.6 NGVD, with crack for F = 1.00 using Spencer's method



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Probabilities of failure

Probabilities of failure (in yellow)				
			COV_F	
Area	WL	F_{MLV}	15%	30%
Breach	11.5 ft	0.99	56%	57%
Adjacent	11.5 ft	1.15	19%	37%

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Summary

- The peat is not the weak link
- The peat is stronger than the clay beneath the peat
- The strength of the clay increases markedly with depth

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Summary

- **Strengths are lower beneath levee slope and beyond toe than beneath crest**
- **GDM 20 strengths were the same beneath the levee crest, slope and beyond the toe**
- **Strengths are about 20% higher to the south of the breach and 30% higher to the north**
- **Factor of safety are about 15% higher for adjacent areas than for the breach area**

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Summary

- **Factors of safety are about 25% lower for the cracked condition than for uncracked condition**

- **Development of a crack on the canal side of the wall is an important factor in the mechanism of failure**

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Summary

- Water level = 11.3 ft required for F = 1.00
- These water levels are higher than the eyewitness water level at time of failure
- Differences may be due to:
  - Wave effects
  - IPET shear strengths higher than actual
  - Circular slip surfaces give factors of safety that are higher by about 3%, and water levels for F = 1.0 that are about 1.2 ft higher than noncircular surfaces

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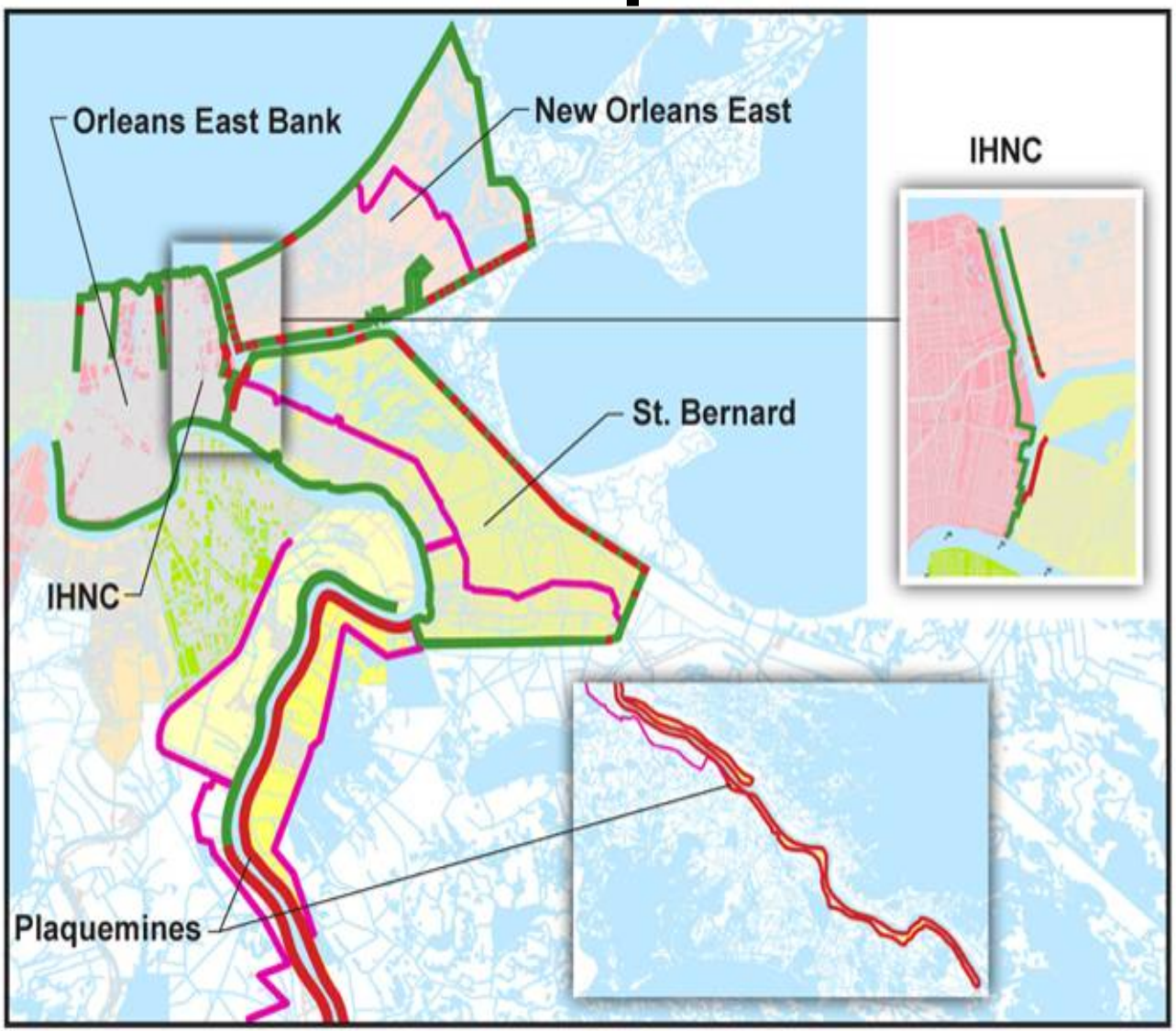
System-Wide Assessment

Impacted Area



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New Orleans District

Local Authorities
- Louisiana DOTD
- Port of New Orleans
- Lake Borgne Basin Levee District
- N.O. Sewerage and Water Board
- Orleans Levee District
- Plaquemines Parish Government
- St. Bernard Parish Government

Hurricane Protection System
- 284 miles: Federal levees/floodwalls
- 71 pump stations

Damage
- 169 miles: Federal levees/floodwalls
- 34 pump stations

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Assessment of Entire System

Selection For Detailed Analysis

- Walls that failed (category WF)
- Walls that were close to failure, indicated by permanent deflection (WCF)
- Walls that are stable, with no permanent deflection (WS)
- Levees that overtopped and breached (LOB)
- Levees that overtopped and did not breach (LONB)
- Levee under seepage locations (LU)
- Failures at transitions between different types of flood protection structures (TF)

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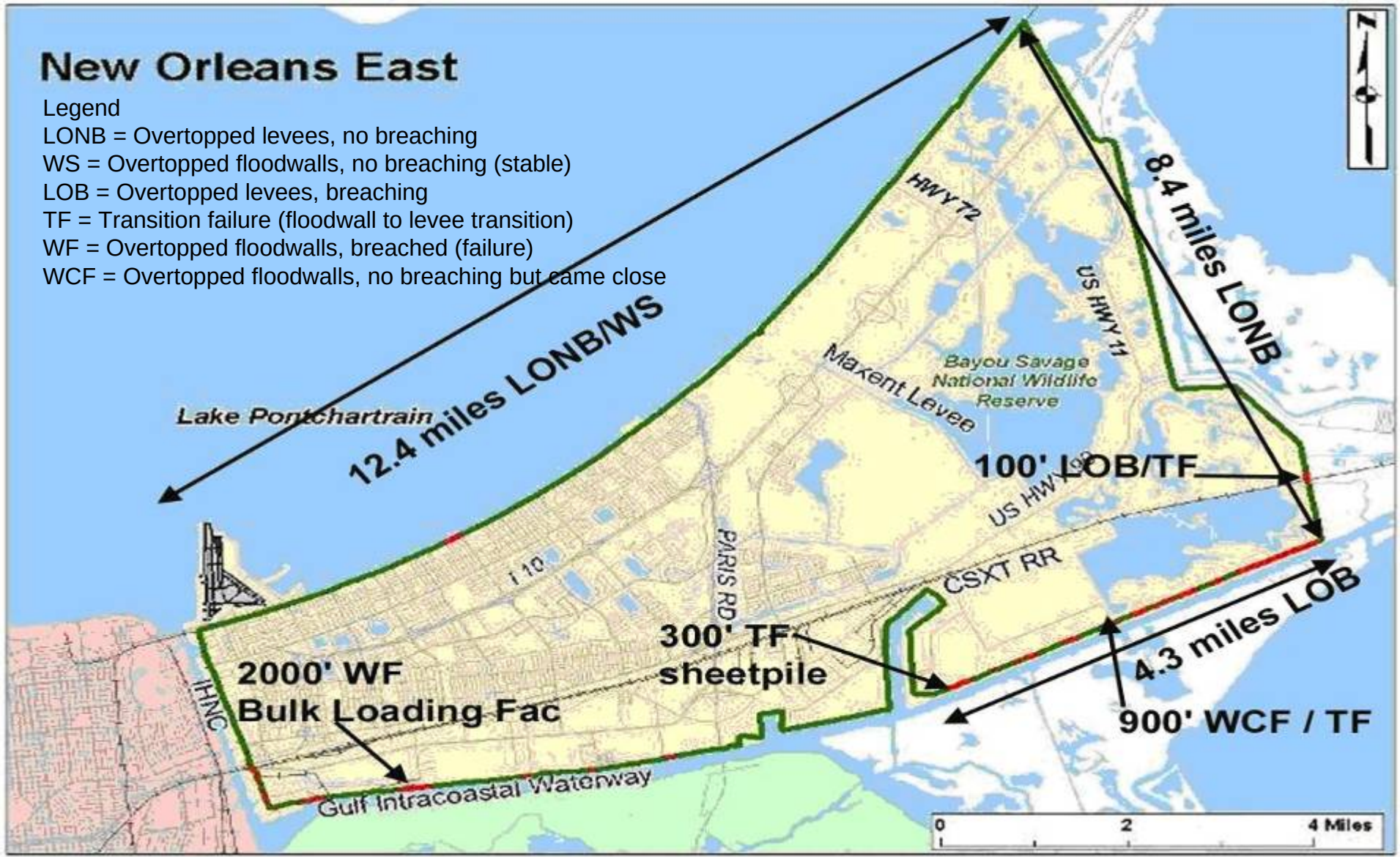
New Orleans East Basin



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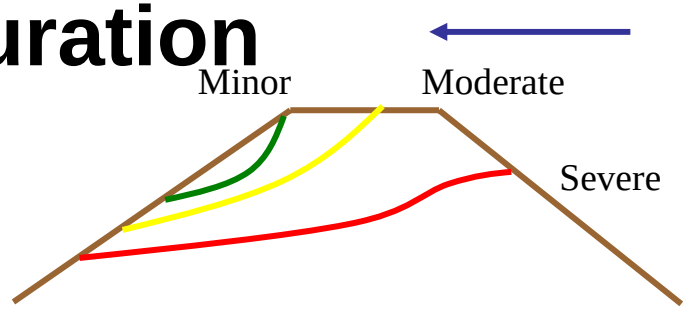
Erosion Assessment

- **Pre-Katrina and post-Katrina LIDAR surveys**
  - Determine depth and surface area of erosion
  - Categorize the severity of the erosion
- **Storm surge height and duration**
- **Wave height and duration**
- **Levee surface soil type**
- **Elevation of the levee crest**



Overtopping Erosion

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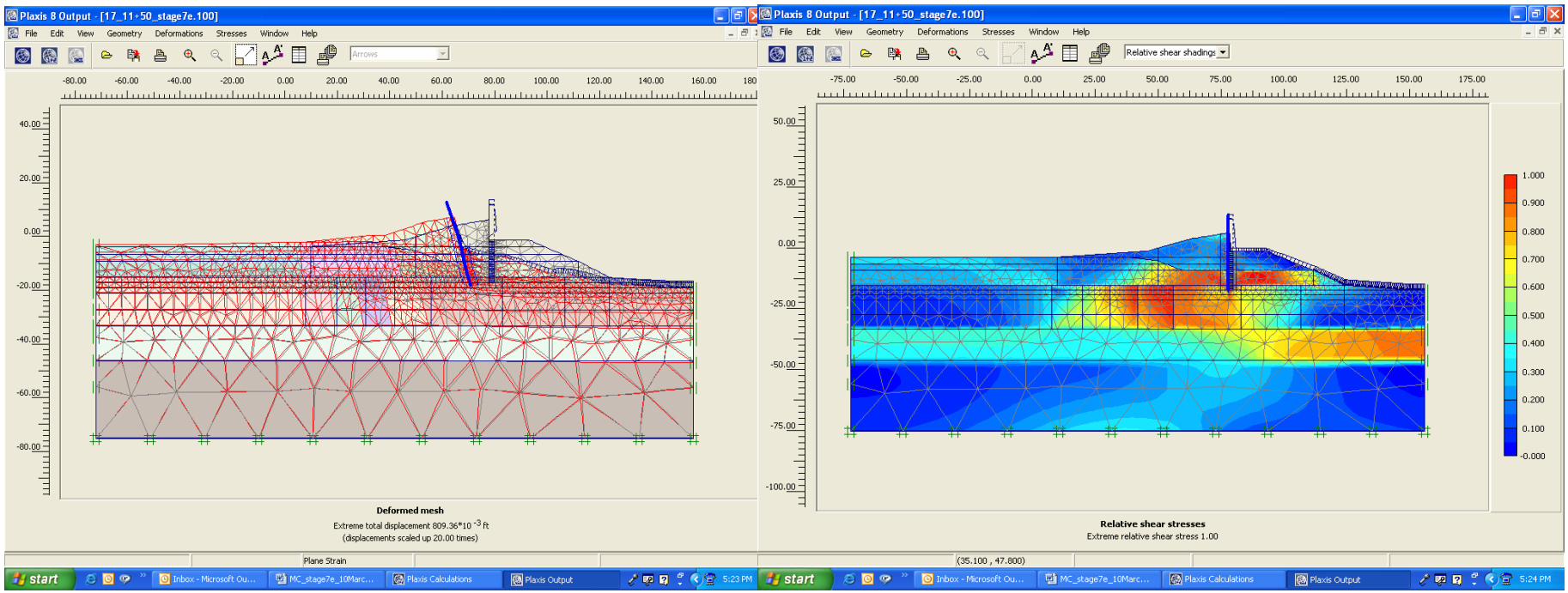
Remaining Effort

- **Additional CPTU, Vane Shear, DSS**
- **Soil-Structure Interaction Analysis**



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Remaining Effort

- London Avenue Canal
- Orleans Canal
- Inner Harbor Navigation Canal
- St. Bernard Parish
  - Mississippi River Gulf Outlet
- Plaquemines Parish