Volume V – Performance Floodwall and Levee Performance Analysis

Interagency Performance Evaluation Task Force (IPET)

NRC Meeting

May 15, 2006

Purpose - The 5 Questions

1. The Flood Protection System: What were the design criteria for the pre-Katrina hurricane protection system, and did the design, as-built construction, and maintained condition meet these criteria?

2. The Storm: What were the storm surges and waves used as the basis of design, and how do these compare to the storm surges and waves generated by Hurricane Katrina?

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

4. The Consequences: What have been the societal-related consequences of the Katrina-related damage?

5. The Risk: Following the immediate repairs, what will be the quantifiable risk to New Orleans and vicinity from future hurricanes and tropical storms?

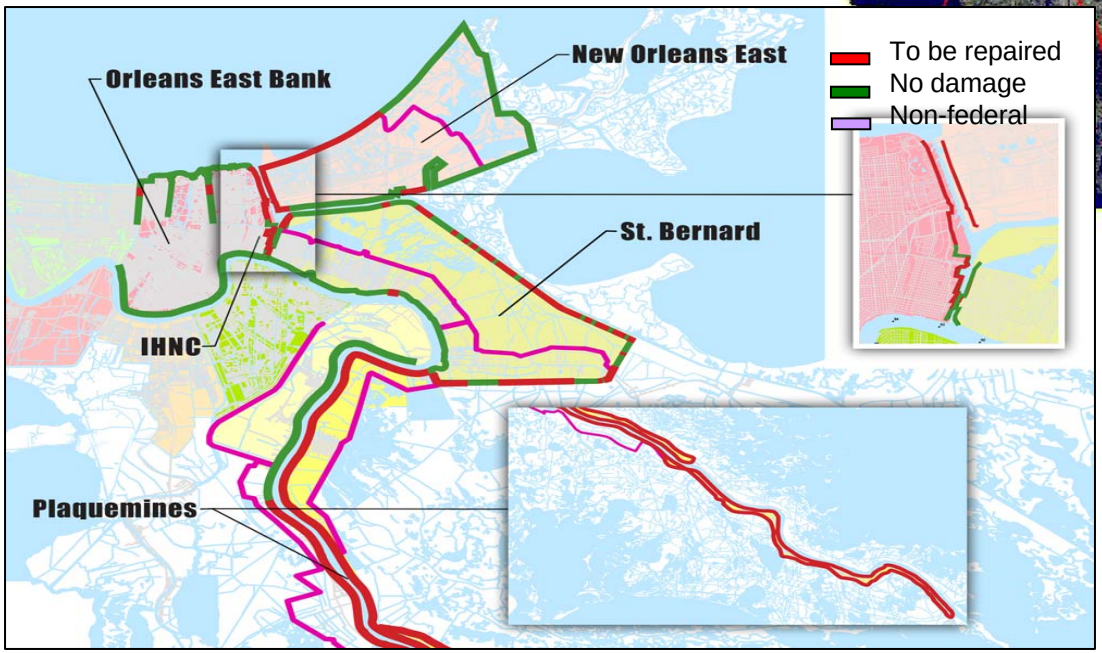
Performance

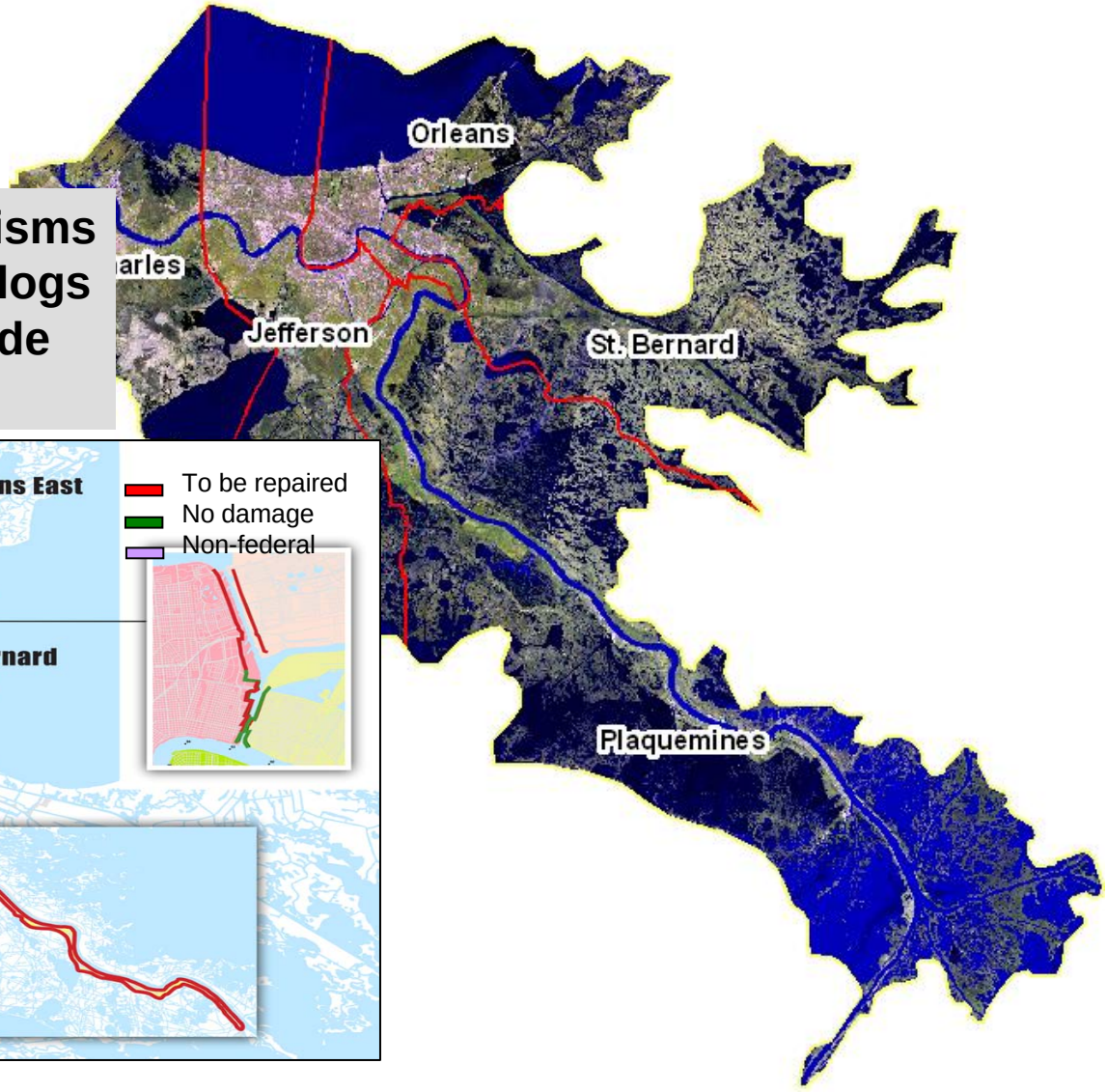
Performance

How did the structures perform and why?

System-Wide Strategy

- Understand breach mechanisms
- Understand non-breach analogs
- Extend to assess system-wide integrity





Floodwall and Levee Performance Analysis Team

- **Reed Mosher** – ERDC/GSL, Co-Lead
- **Mike Duncan** –Virginia Tech, Co-lead
- **George Sills** – ERDC/GSL, Geotechnical
- **Noah Vroman** – ERDC/GSL, Geotechnical
- **Joe Dunbar** – ERDC/GSL, Geologist
- **Ron Wahl** – ERDC/GSL, Geotechnical Modeling
- **Maureen Corcoran** - ERDC/GSL, Geologist
- **Robert Ebeling** – ERDC/ITL, Geotechnical Modeling
- **Don Yule** – ERDC/GSL, Geotechnical Modeling
- **Ellen Glynn** - ERDC/GSL, Geotechnical
- **Tom Lee** – ERDC/GSL, Geotechnical
- **Paul Mlakar** – ERDC/GSL, Structural
- **Joe Padula** - ERDC/GSL, Structural
- **Kevin Abraham** – ERDC/ITL, Geotechnical Modeling
- **Mike Pace** – ERDC/ITL, Geotechnical Modeling
- **Benita Abraham** – ERDC/GSL, Data Support
- **Tony Young** – MVD
- **Ken Klaus** – MVD
- **Richard Pinner** – MVN
- **Pete Cali** – MVN
- **Tom Brandon** – Virginia Tech - Geotechnical
- **Geomatrix** – FLAC Analysis
- **Steve Wright** – UT – Slope Stability
- **Allen Marr** – GeoComp- PLAXIS Analysis, Soil Testing
- Others TBD

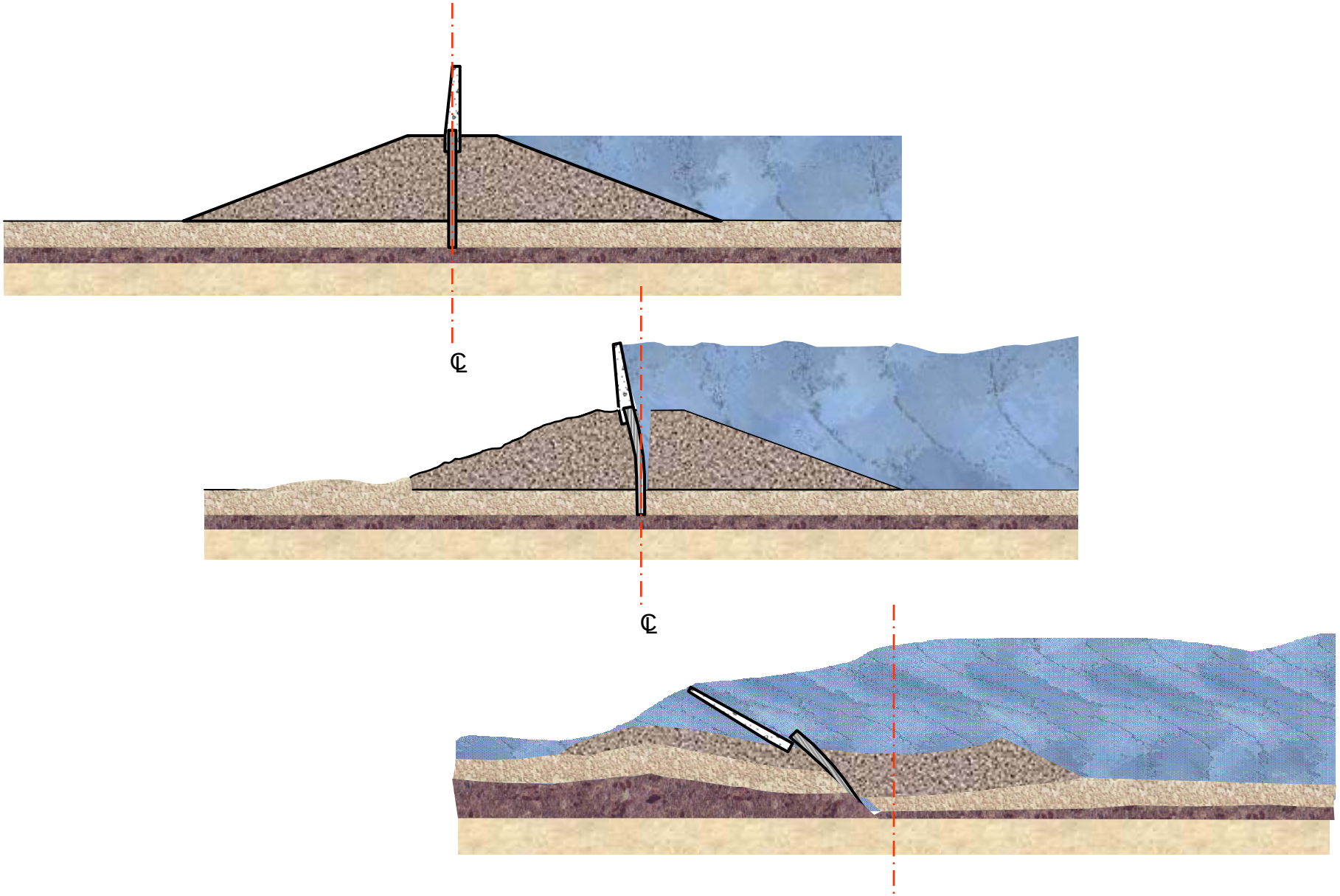
Agenda

- **Overview**
- **17th Street Canal Breach**
- **London Avenue Canal Breaches**
- **Orleans Avenue Canal Assessment**
- **IHNC Breaches**
- **Erosion Assessment**
- **Findings and Lessons Learned**

Scope of Study

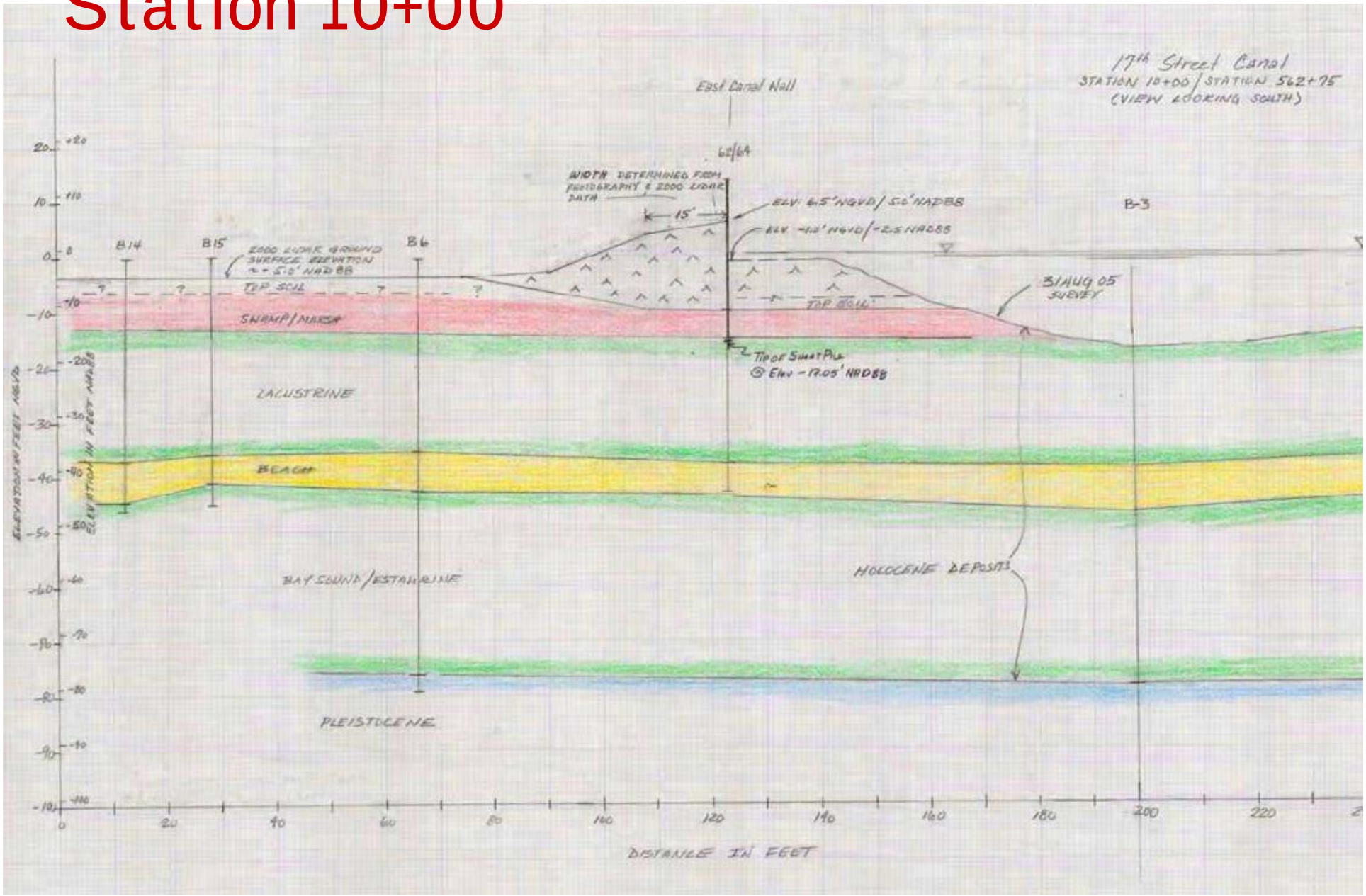
Project	Limit Equilibrium	PhysicalModel	FE Analysis	Other
17th Street Canal Breach	X	X	X	
London Ave Canal – North Breach	X	X	X	
London Ave Canal – South Breach	X	X	X	
Orleans Ave Canal – North Breach	X	X	X	
Orleans Ave Canal – South Breach	X	X		
Inner Harbor Navigation Canal	X			
New Orleans East				X
St. Bernard Parish				X
Plaquemines Parish				X
Michoud Canal	X			

Failures of walls that were not overtopped



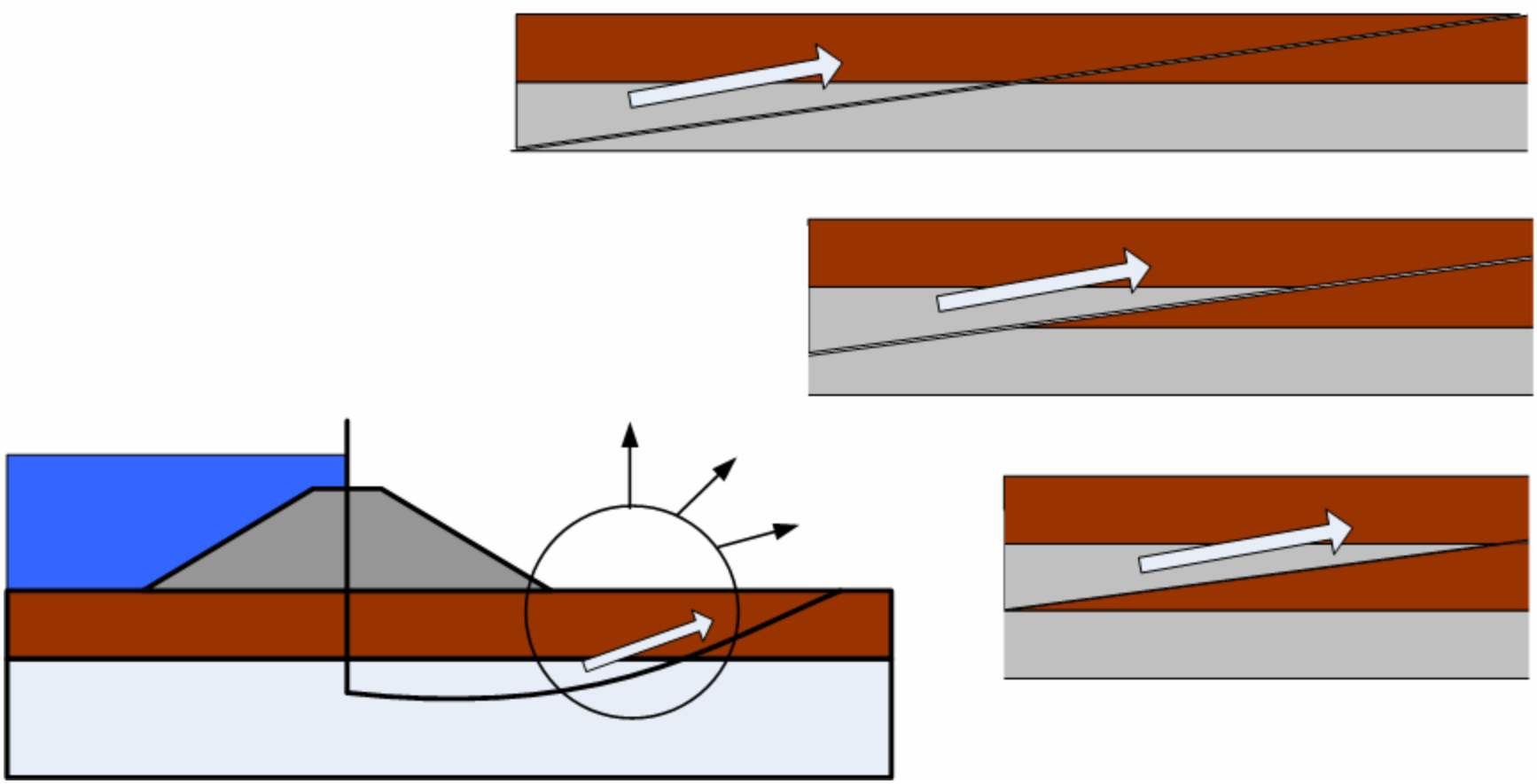
17th Street Canal breach

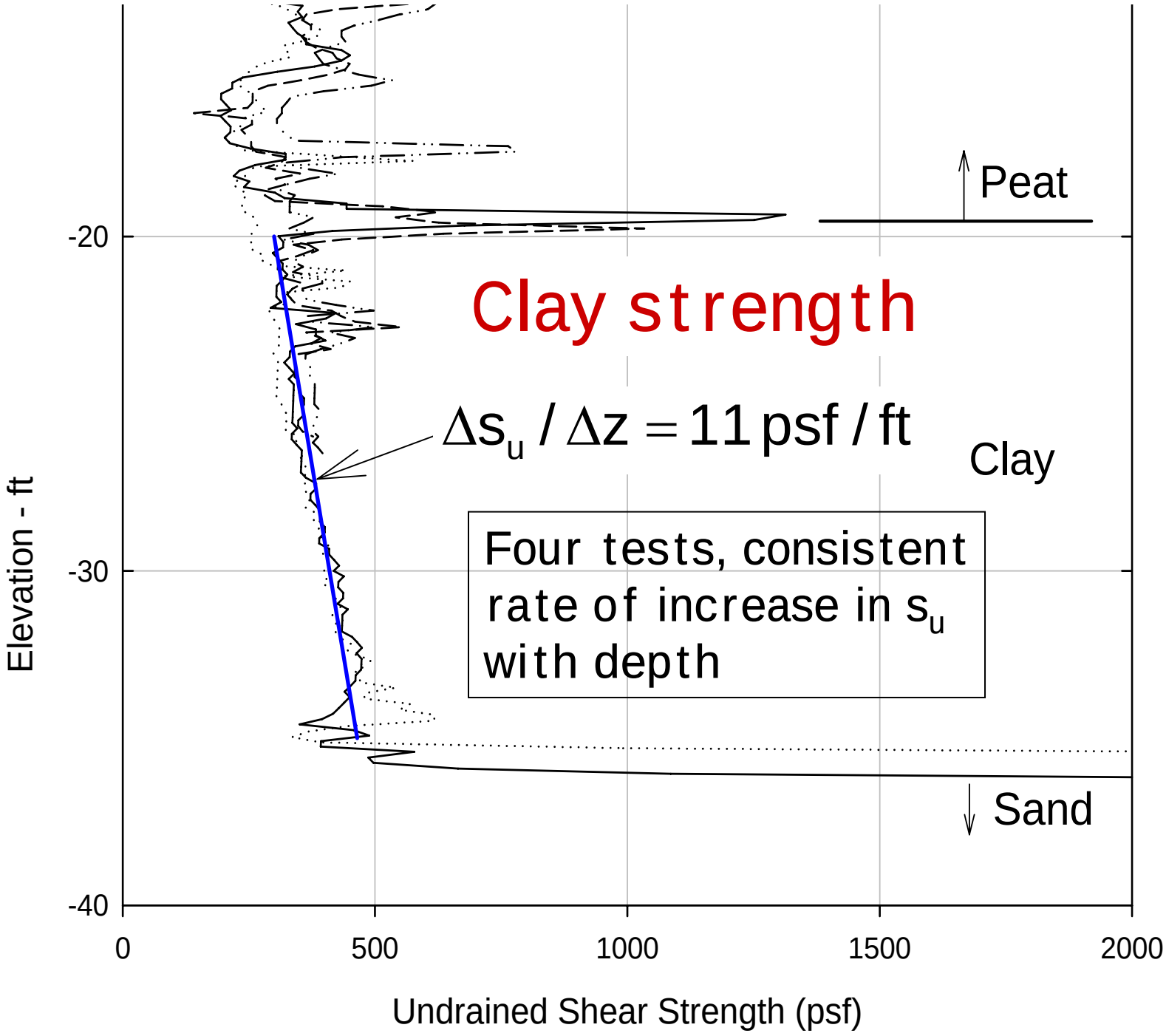
Station 10+00



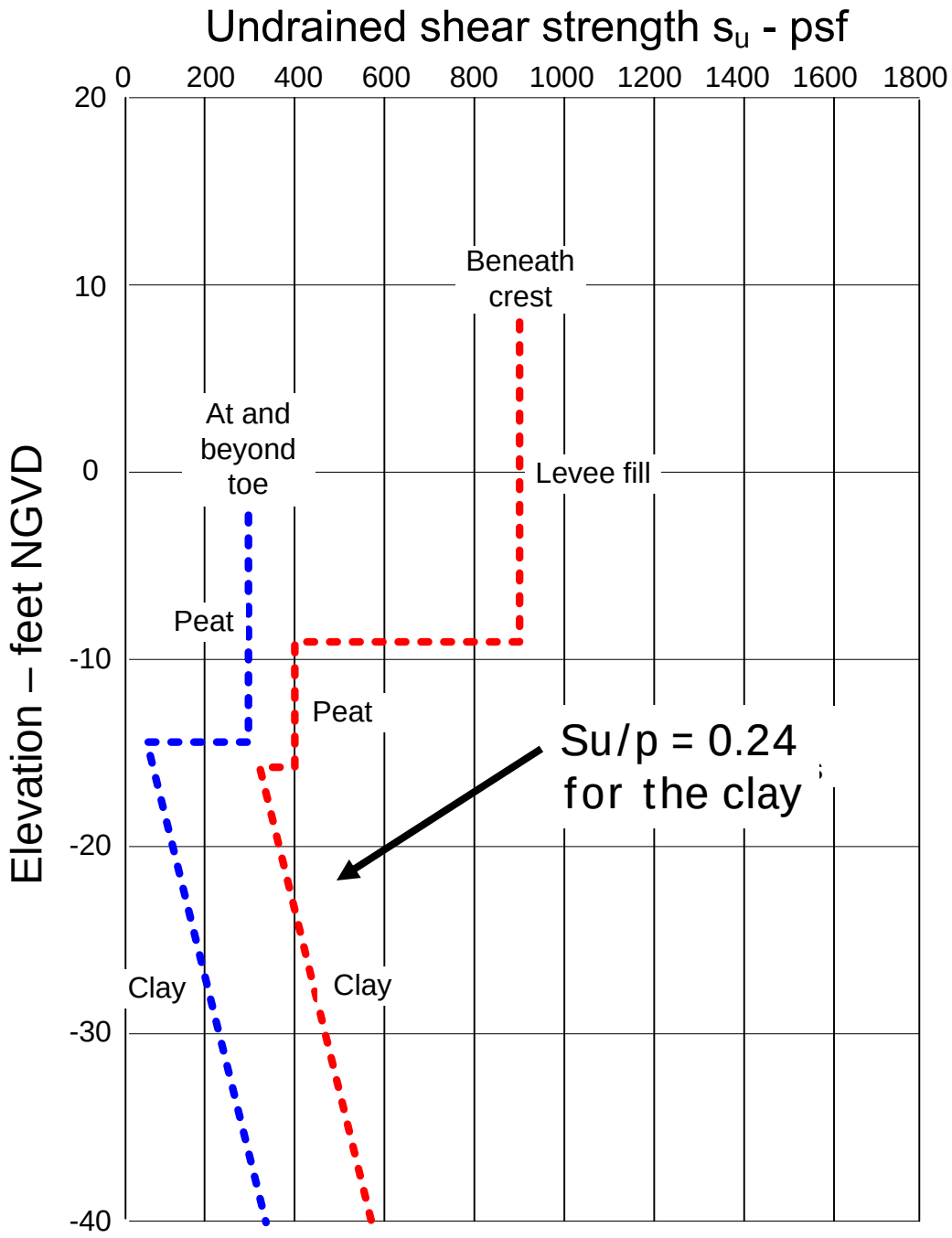
17th Street slide block

Failure mechanism

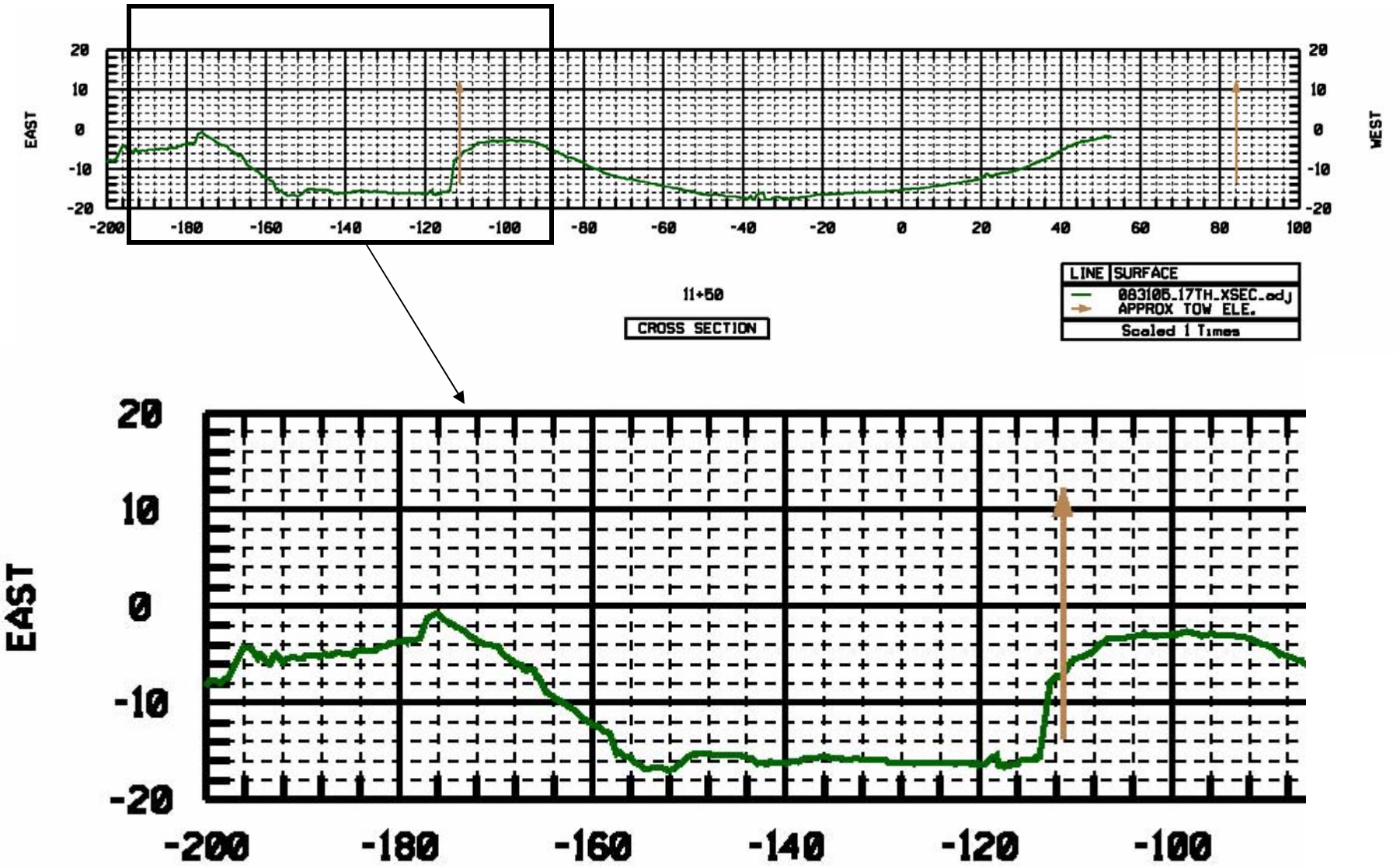



Peat
Clay strength
$\Delta s_u / \Delta z = 11$ psf / ft
Clay
Four tests, consistent rate of increase in s_u with depth
Sand
-20
-30
-40
0
500
1000
1500
2000
Elevation - ft
Undrained Shear Strength (psf)

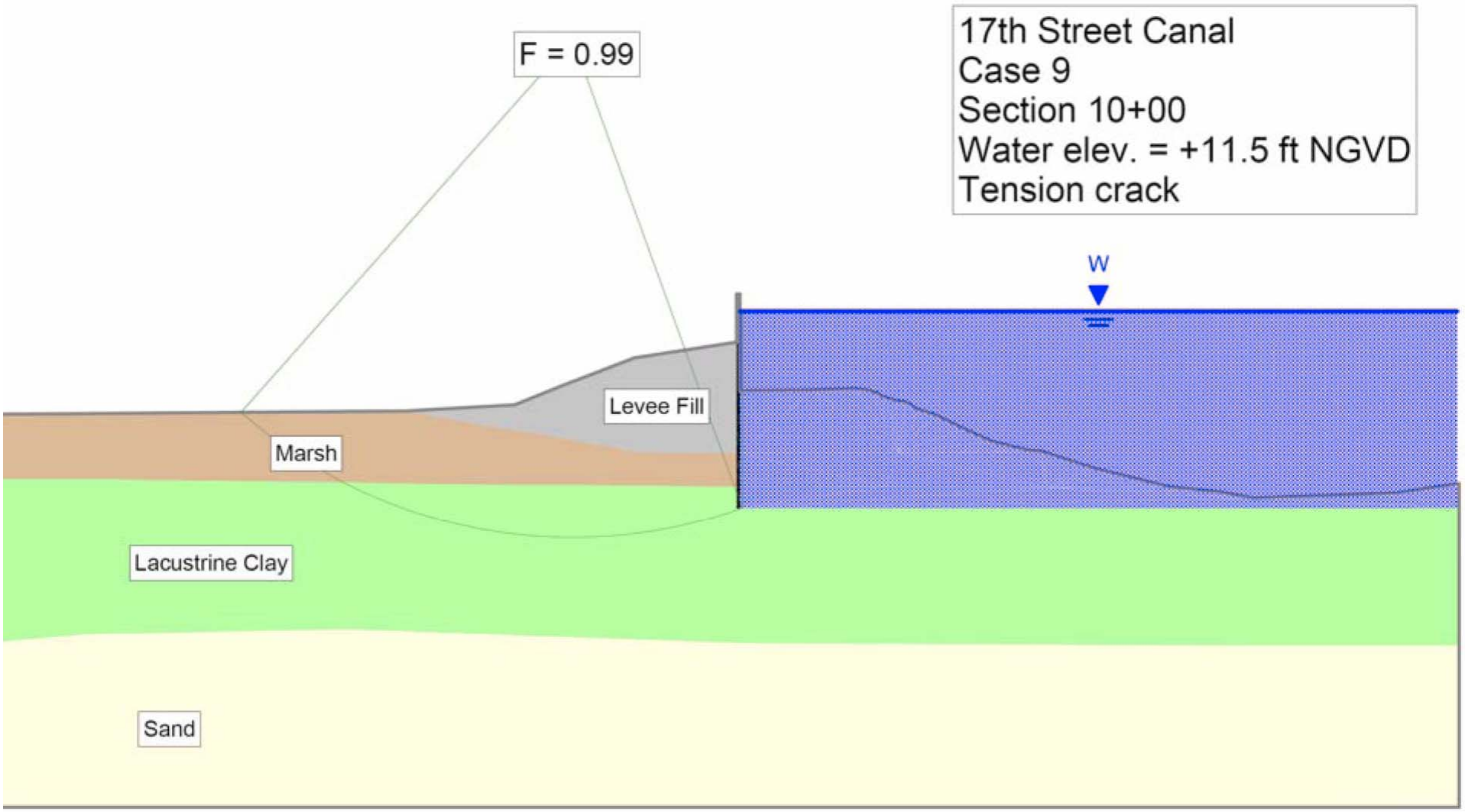
IPET strengths



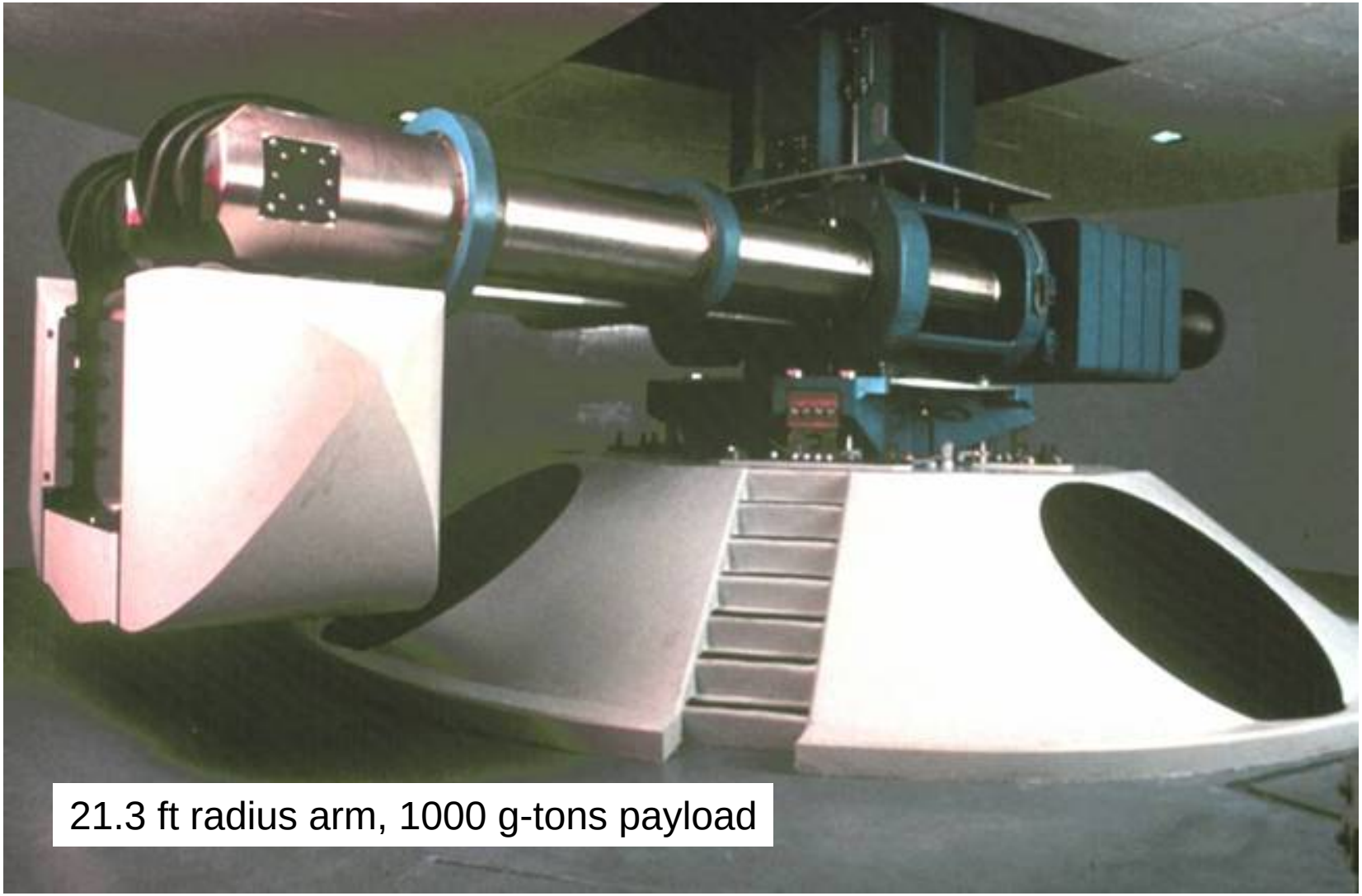
17th Street Canal after failure



Stability analysis

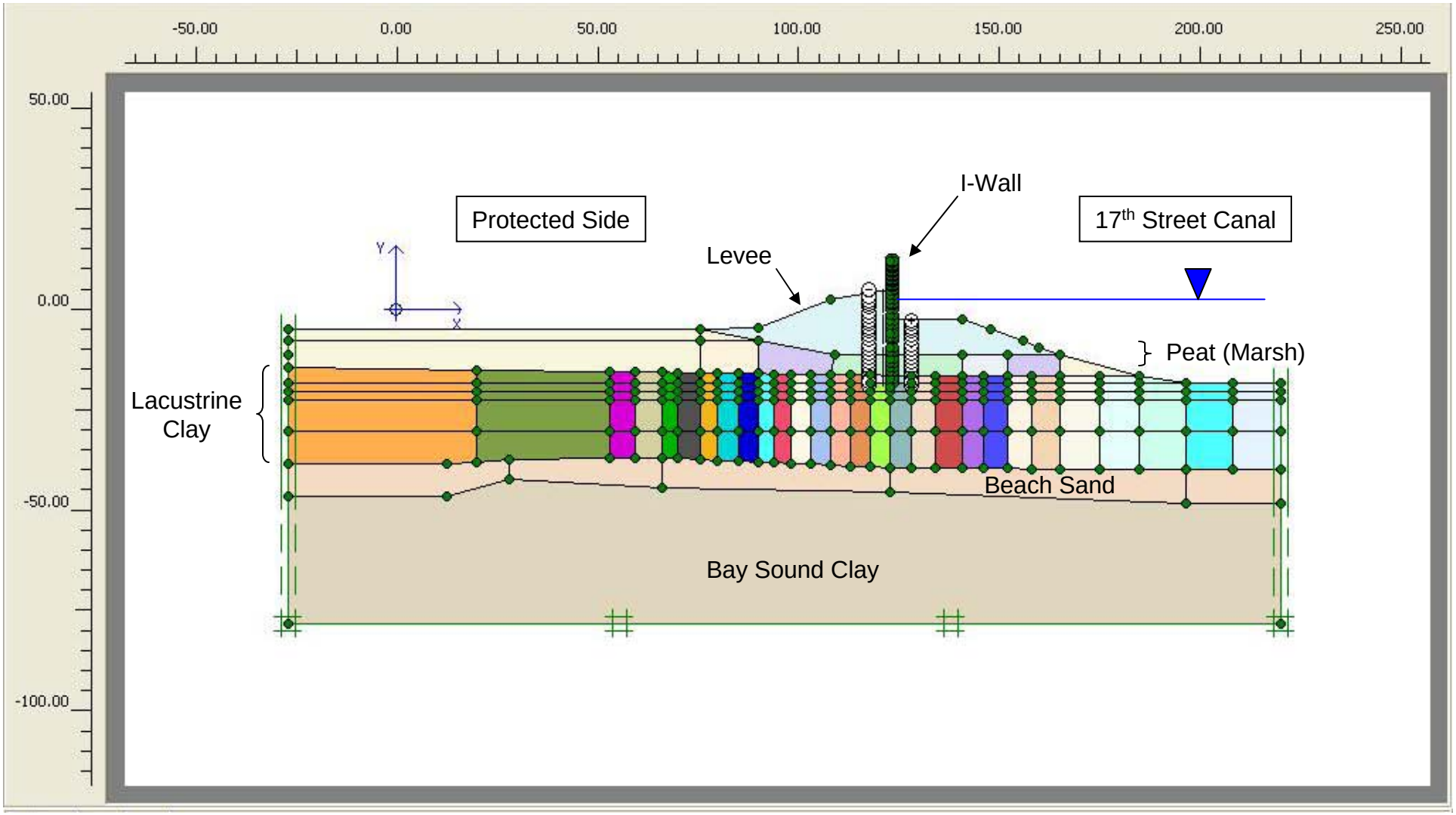


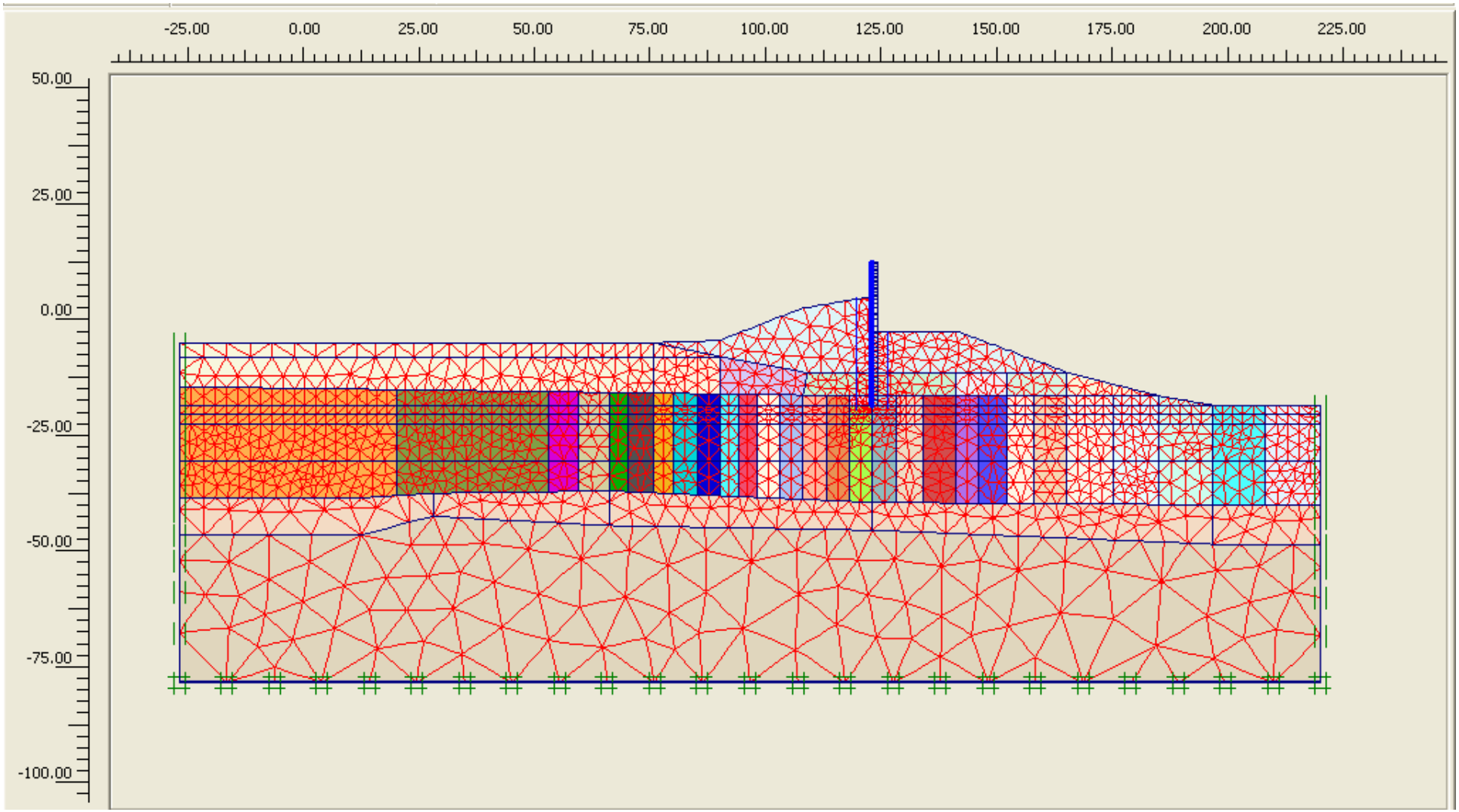
Centrifuge tests to study failure mechnism

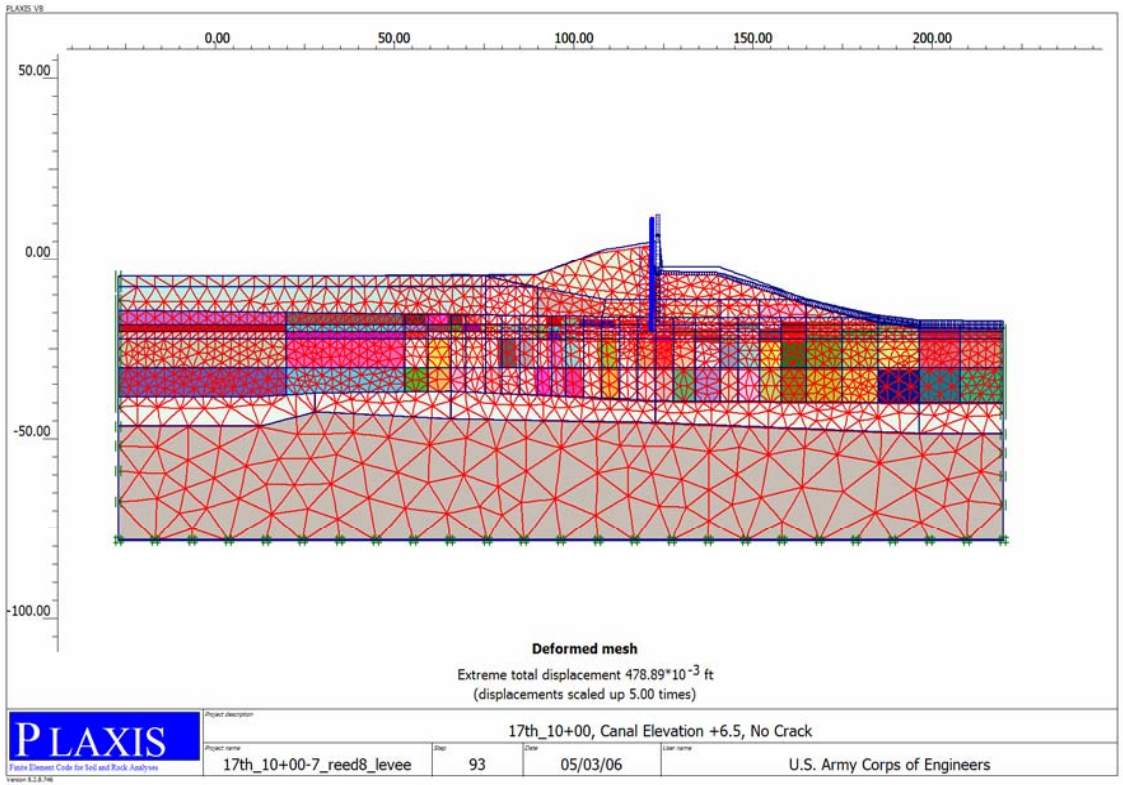


21.3 ft radius arm, 1000 g-tons payload

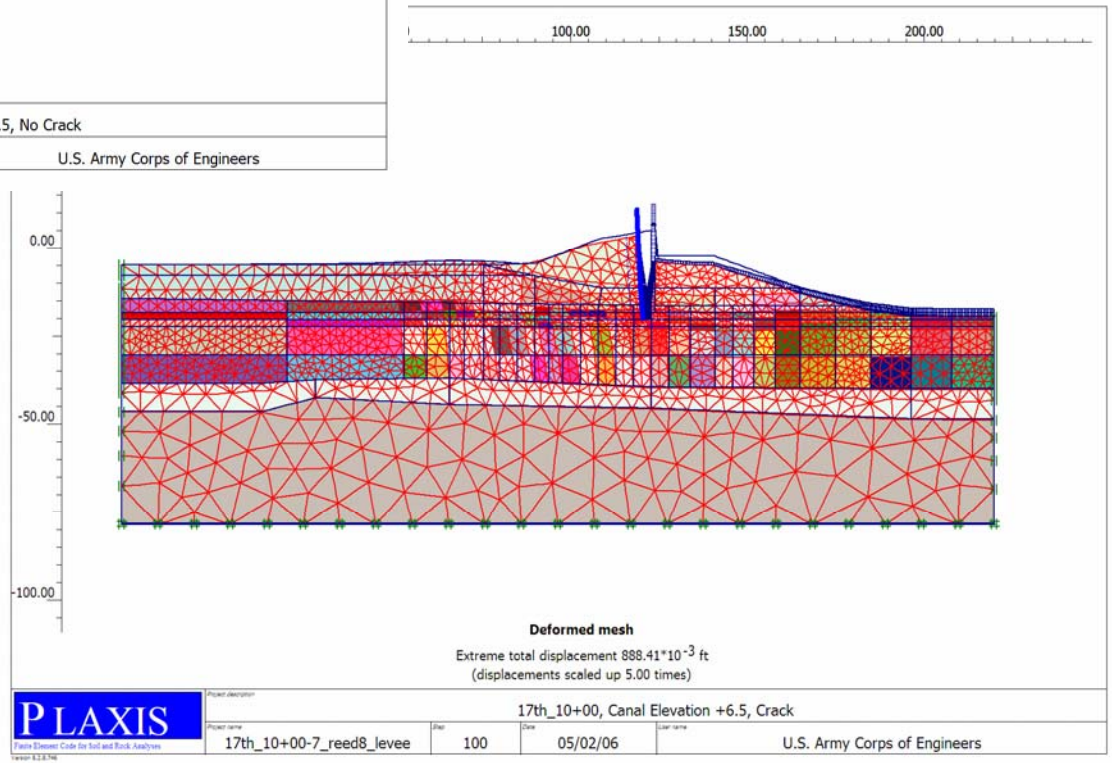
17th Street Canal
Finite Element Analysis


-50.00
0.00
50.00
100.00
150.00
200.00
250.00
50.00
0.00
-50.00
-100.00
Protected Side
I-Wall
17th Street Canal
Levee
Peat (Marsh)
Lacustrine Clay
Beach Sand
Bay Sound Clay

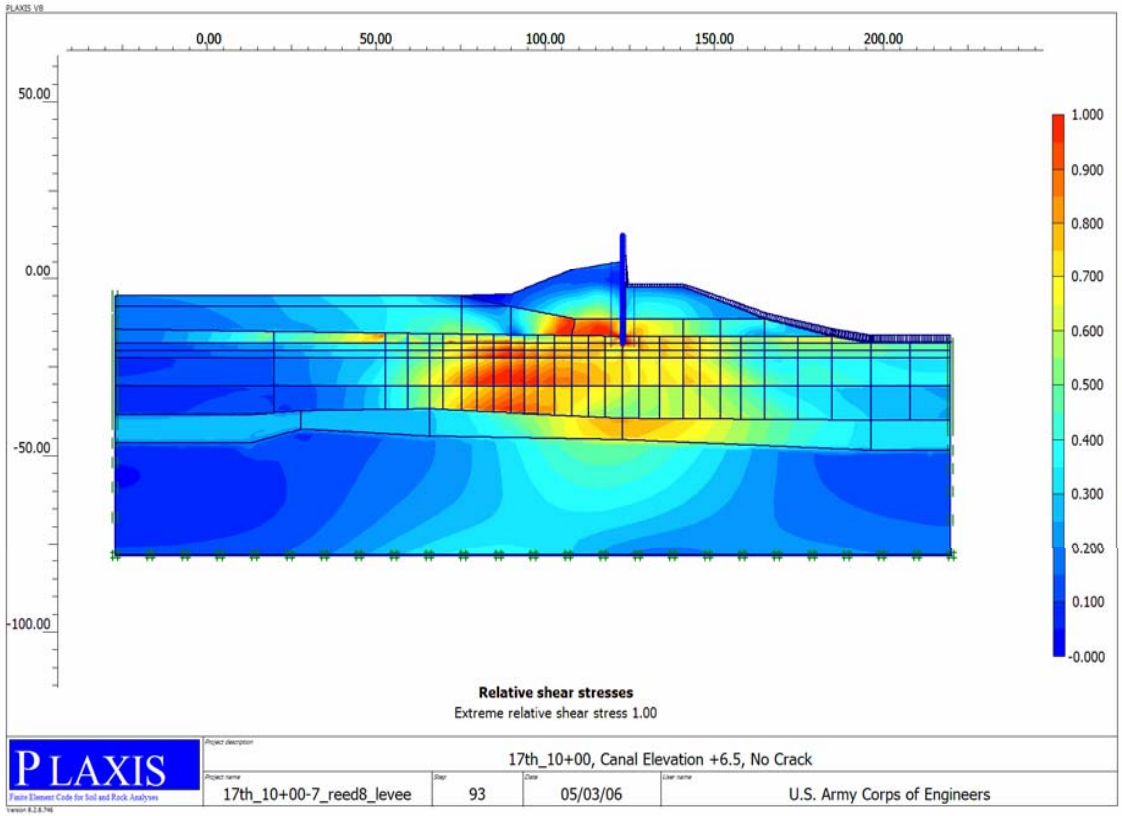

-25.00
0.00
25.00
50.00
75.00
100.00
125.00
150.00
175.00
200.00
225.00
50.00
25.00
0.00
-25.00
-50.00
-75.00
-100.00



No Crack

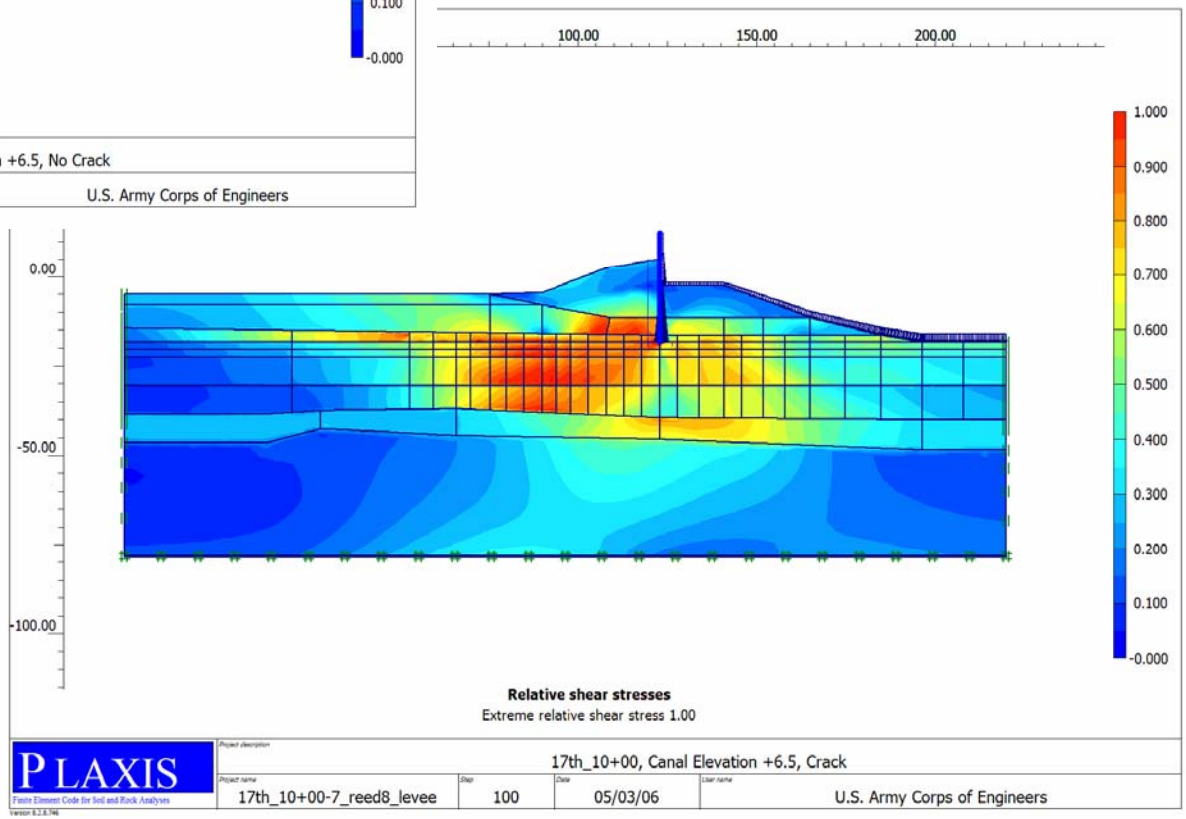


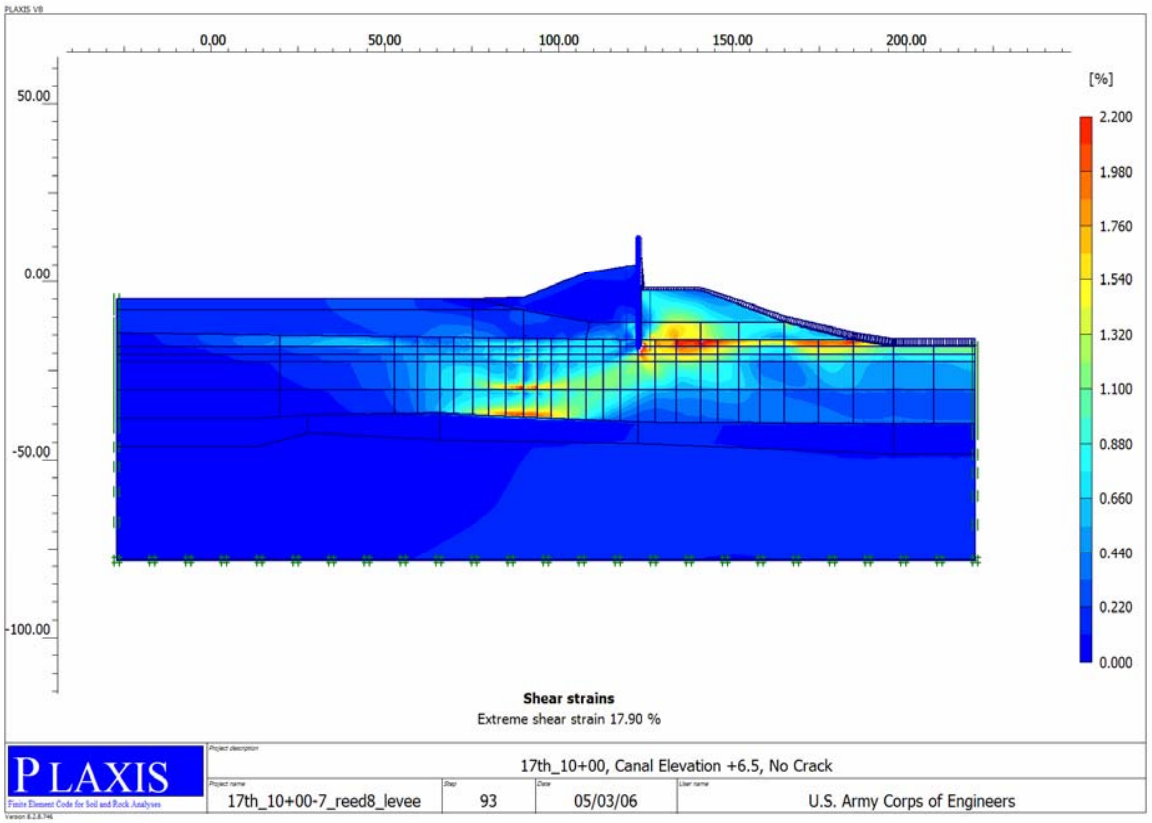
Crack



No Crack

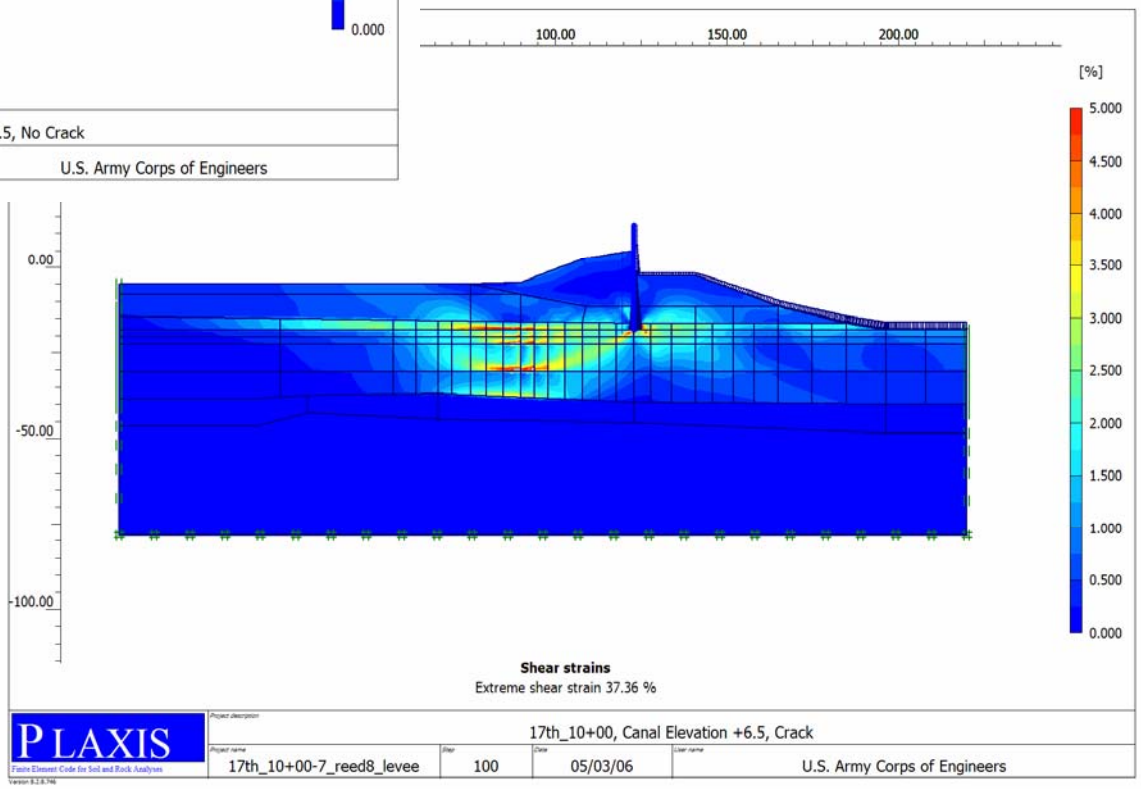
Crack



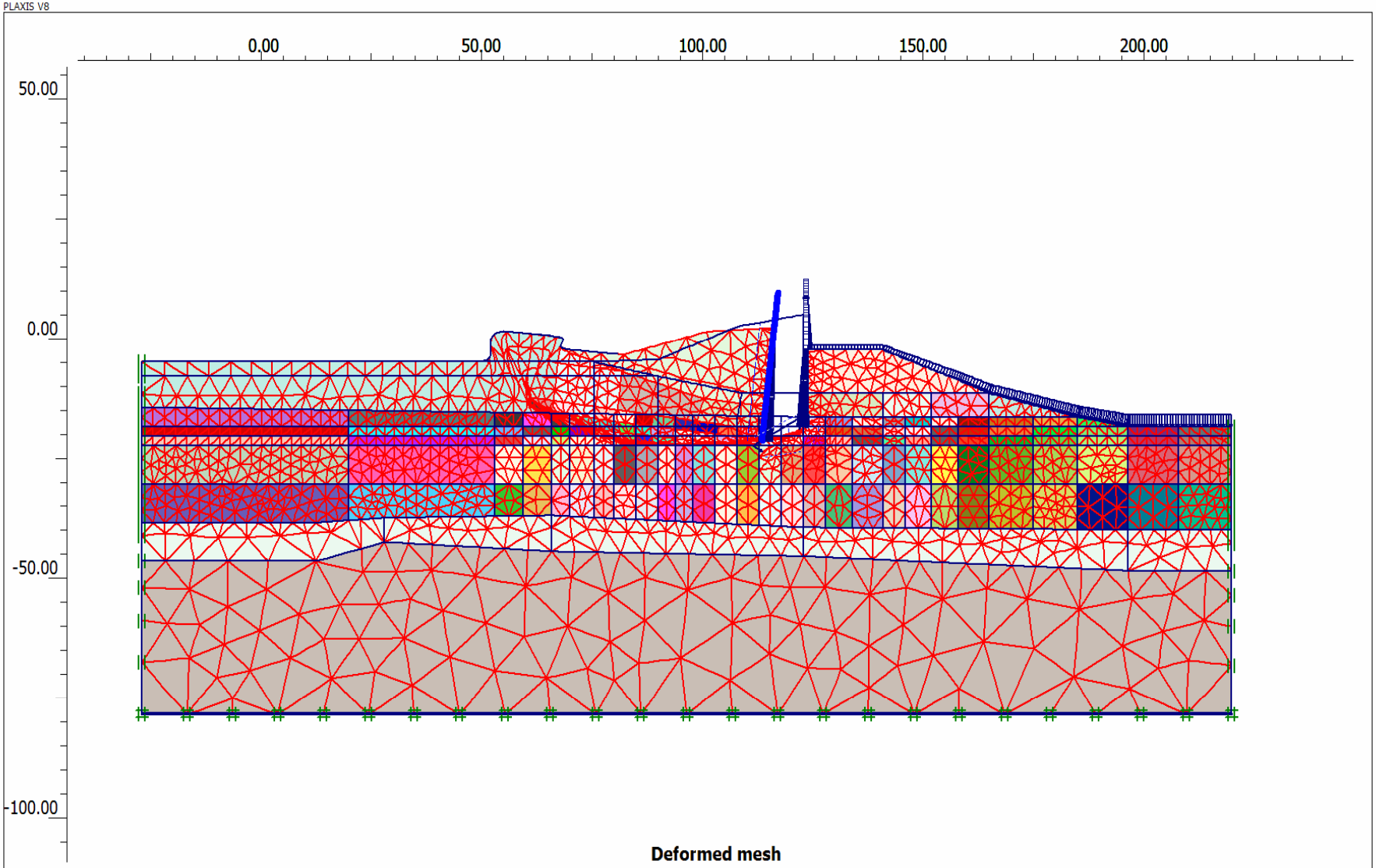


No Crack

Crack



PLAXIS V8



Deformed mesh

Extreme total displacement $53.74*10^{3}$ ft

(displacements scaled up $200.00*10^{-6}$ times)

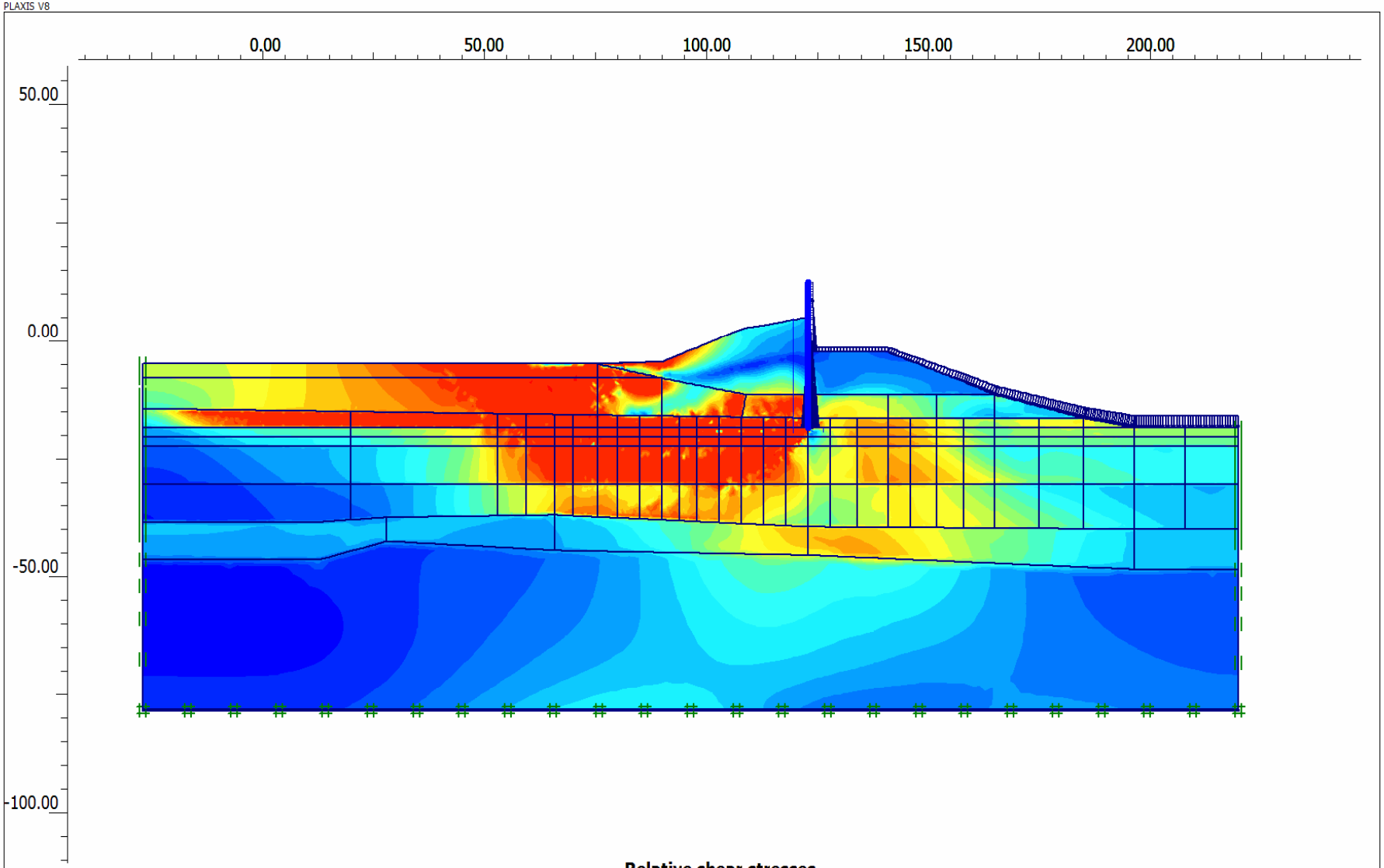
PLAXIS

Finite Element Code for Soil and Rock Analyses

Version 8.2.8.746

Project description			
17th_10+00, Canal Elevation +8.5, Crack, Phi-C Reduction			
Project name	**Step**	**Date**	**User name**
17th_10+00-7_reed8_levee	526	05/03/06	U.S. Army Corps of Engineers

PLAXIS V8



Relative shear stresses

Extreme relative shear stress 1.00

PLAXIS

Finite Element Code for Soil and Rock Analyses

Version 8.2.8.746

Project description			
17th_10+00, Canal Elevation +8.5, Crack, Phi-C Reduction			
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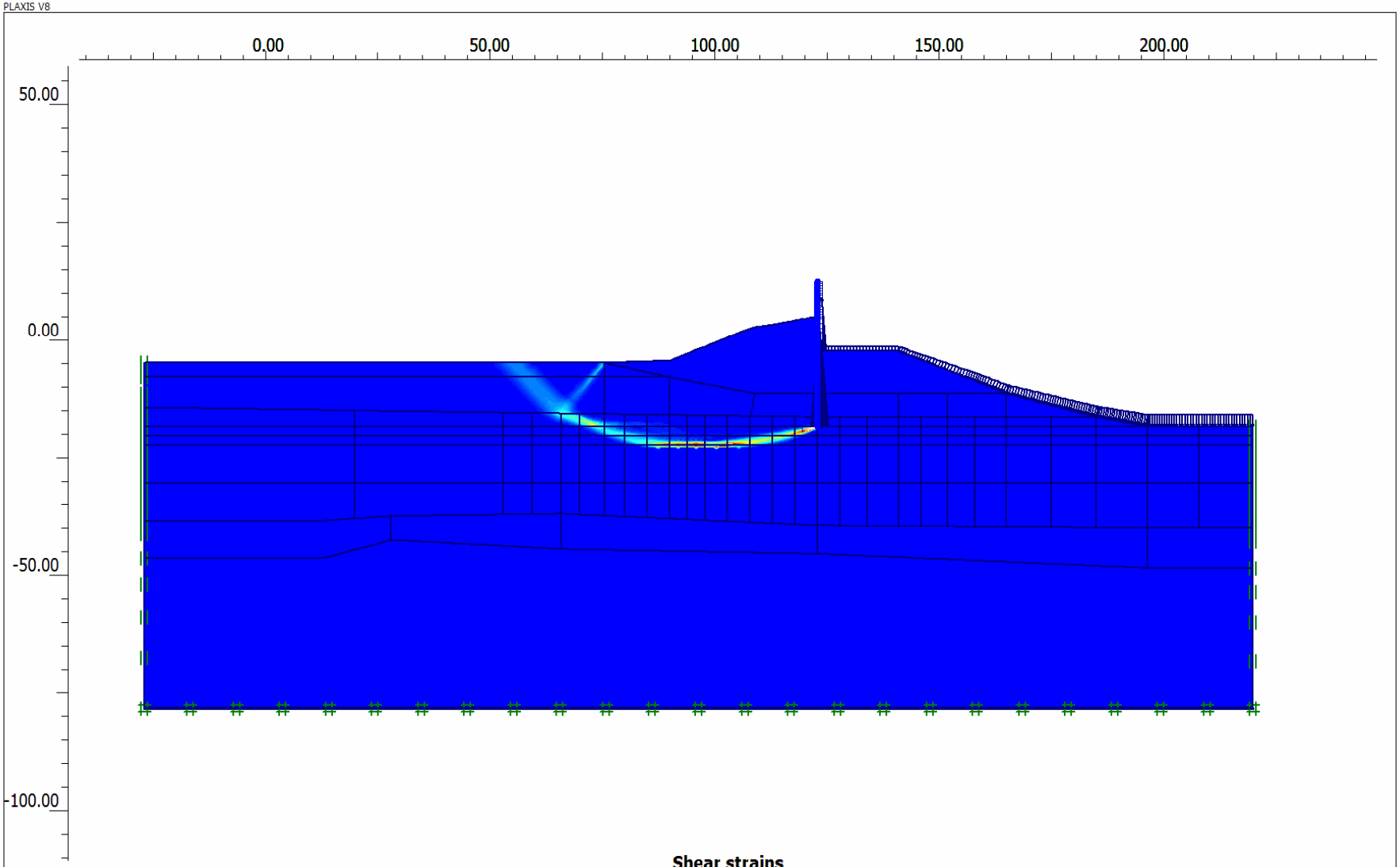
PLAXIS V8



Shear strains

Extreme shear strain $32.28*10^{6}$ %

PLAXIS
Finite Element Code for Soil and Rock Analyses

Project description			
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Project name	**Step**	**Date**	**User name**
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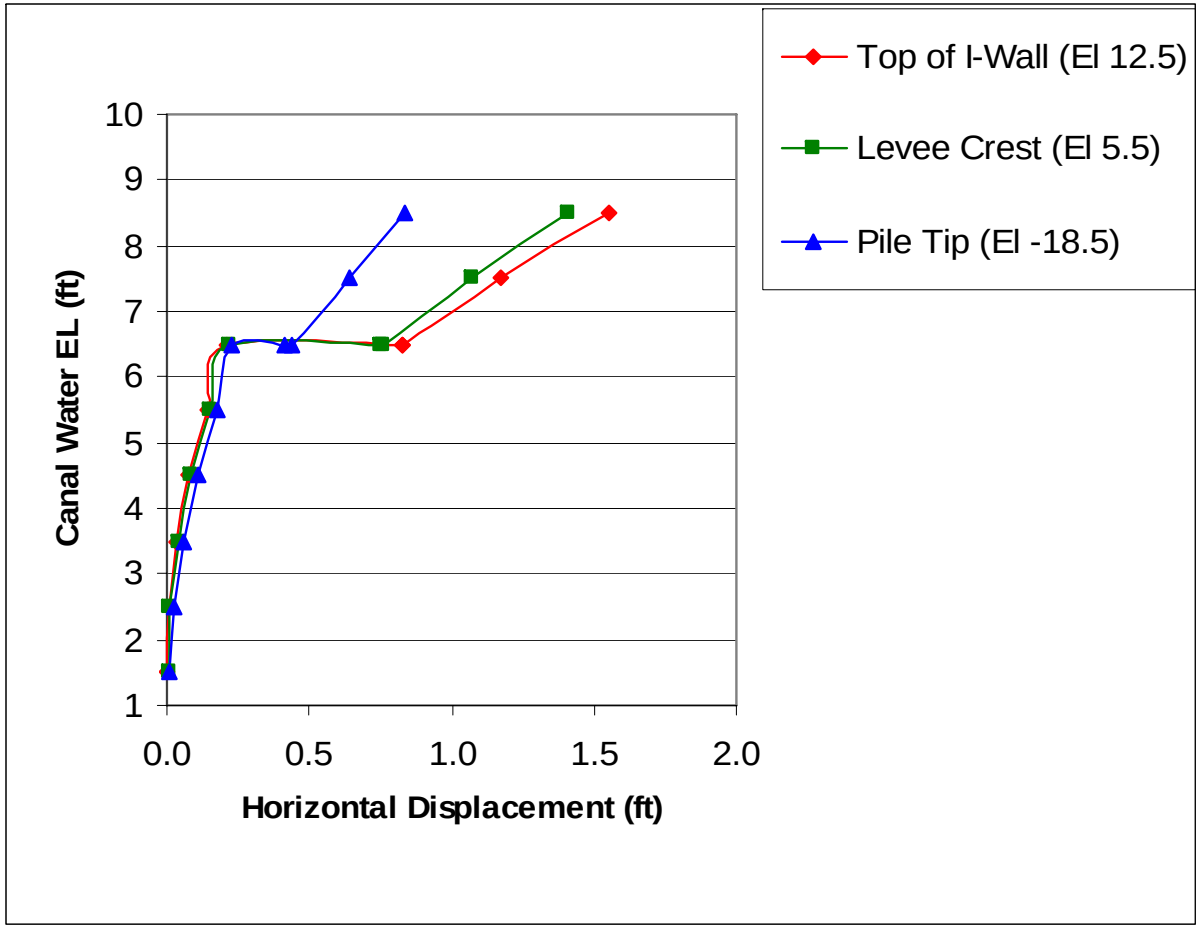

Top of I-Wall (El 12.5)
Levee Crest (El 5.5)
Pile Tip (El -18.5)
Canal Water EL (ft)
10
9
8
7
6
5
4
3
2
1
0.0
0.5
1.0
1.5
2.0
Horizontal Displacement (ft)


Safety Factor
Crack
10
8
6
4
2
0
Canal Water Elevation
1.8
1.6
1.4
1.2
1
0.8
SF

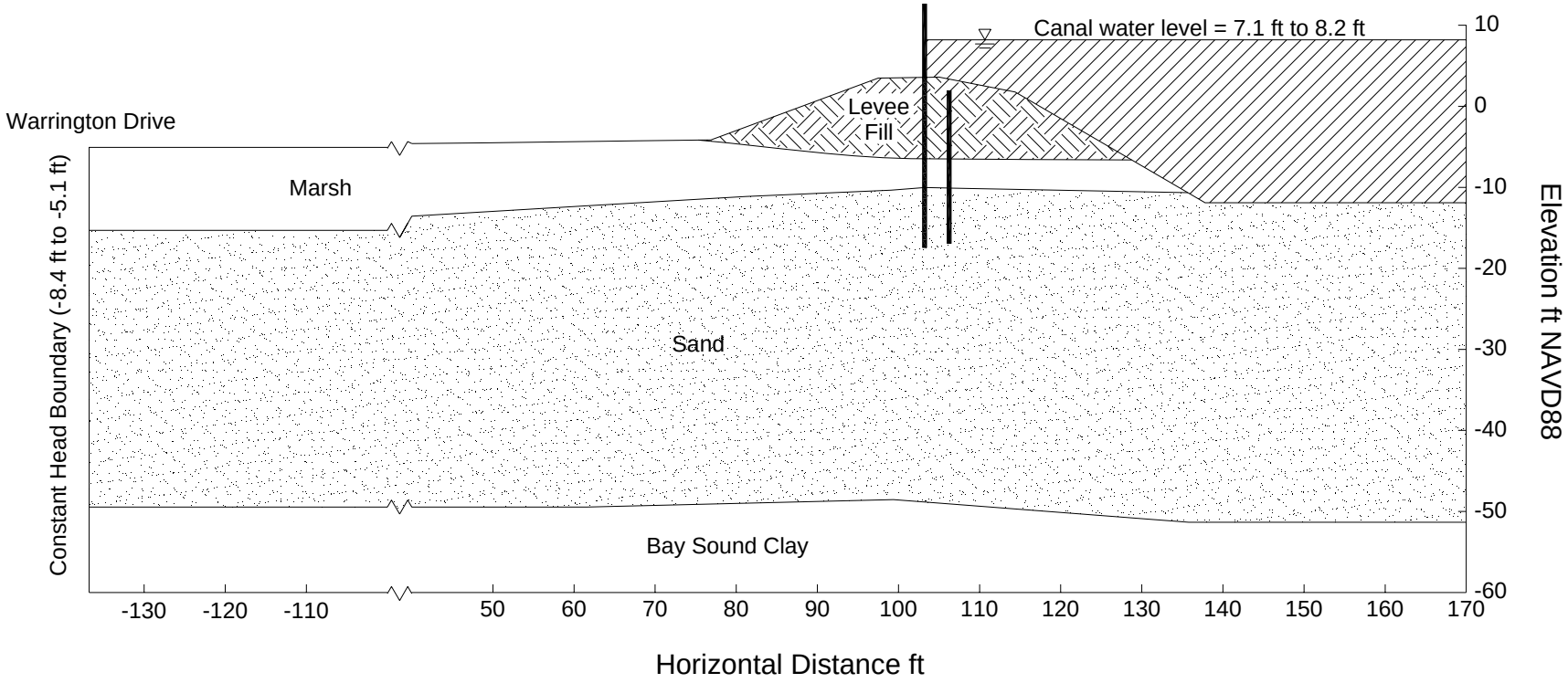
Study of London Avenue Canal Breach Mechanisms

New Orleans IPET/ERP meeting

May 4 - 5, 2006

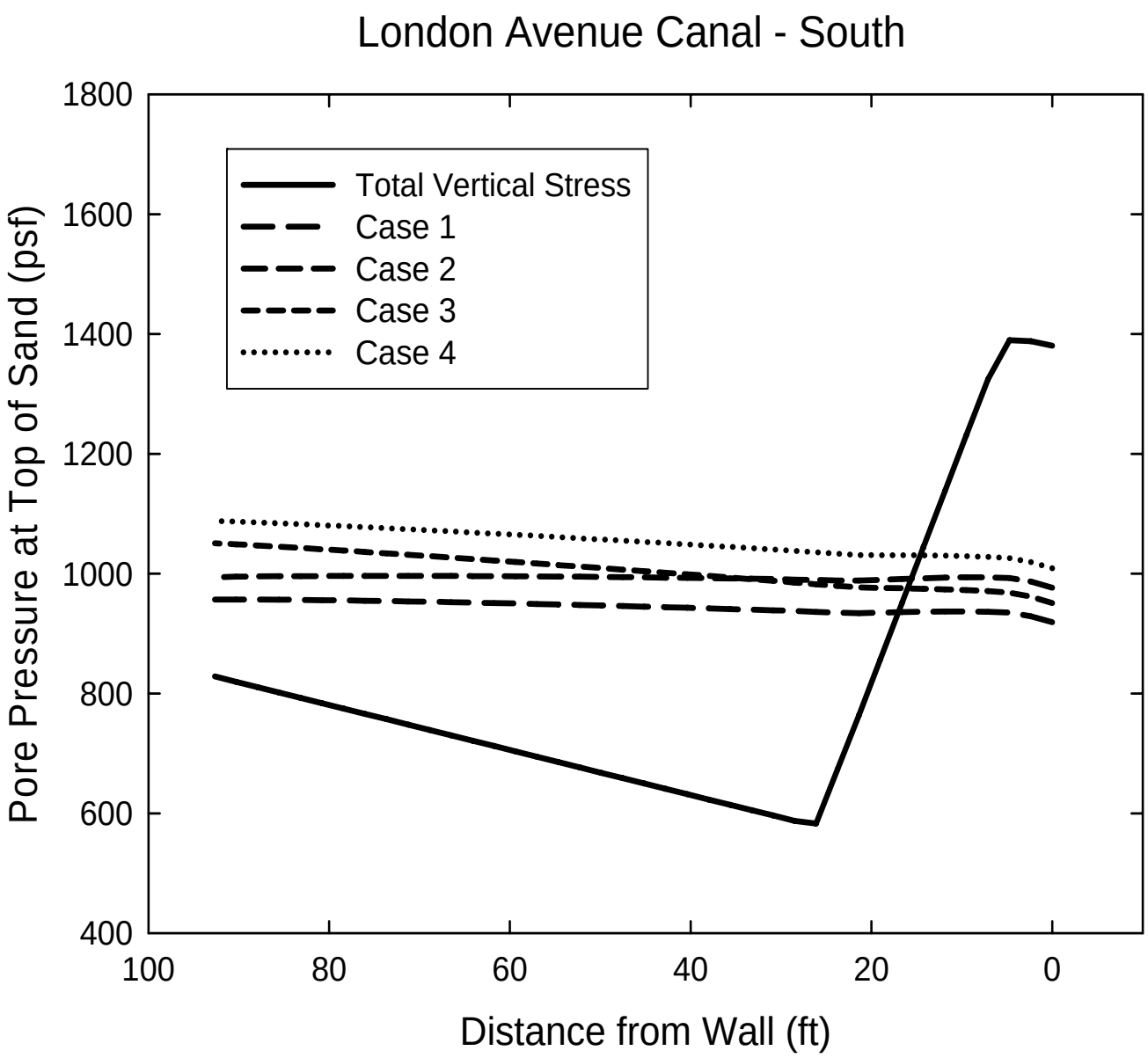
London Avenue south breach – about 60 ft wide – much sand washed through the breach into the neighborhood

London Avenue Canal - South
Station 53+00/75+00
East I-Wall



Permeability values

- Sand – 1.5 x 10^{-2} cm/sec based on pumping test
- Marsh – 1 x 10^{-5} cm/sec
- Levee fill – 1 x 10^{-7} cm/sec


London Avenue Canal - South
Pore Pressure at Top of Sand (psf)
Distance from Wall (ft)
Total Vertical Stress
Case 1
Case 2
Case 3
Case 4
1800
1600
1400
1200
1000
800
600
400
100
80
60
40
20
0

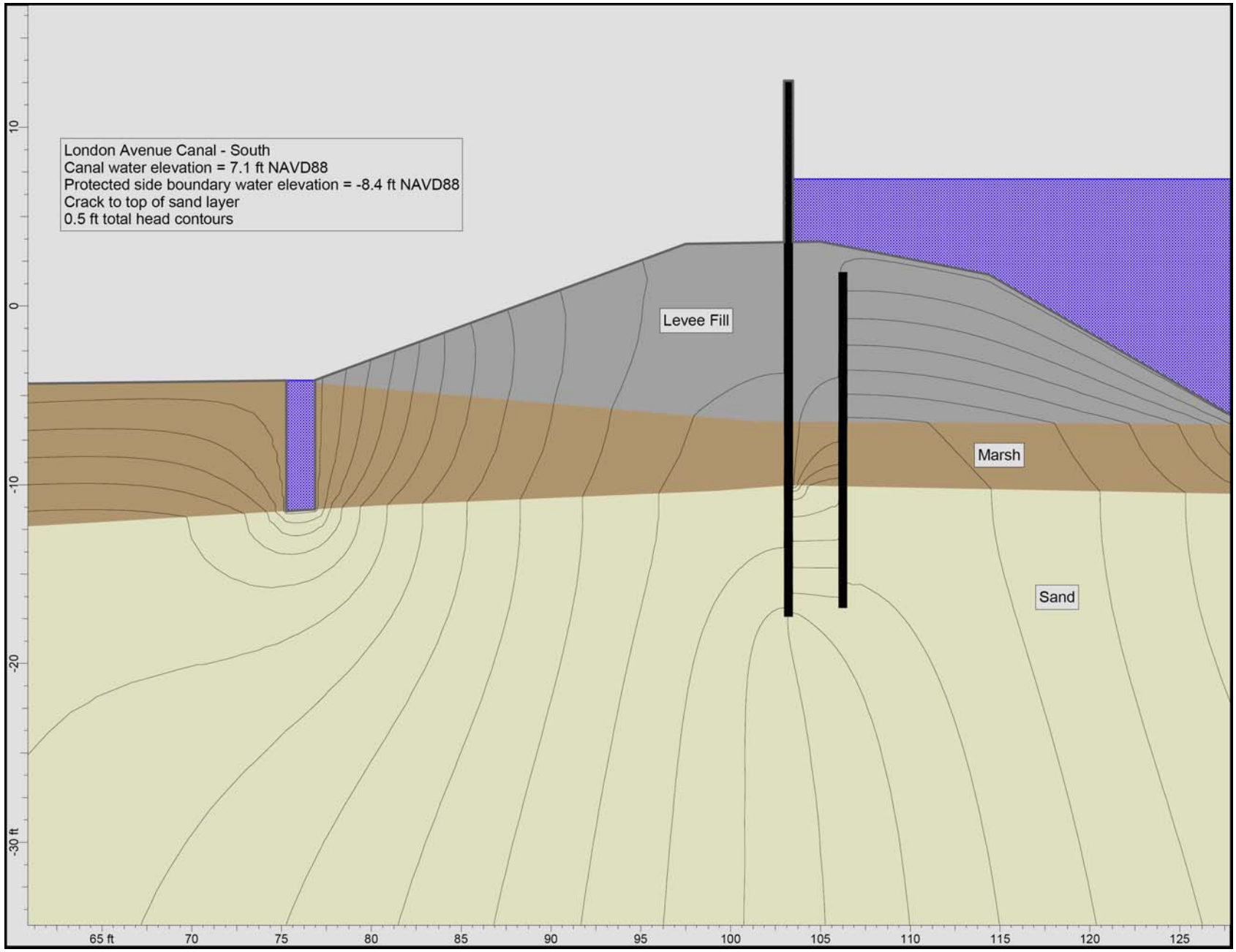
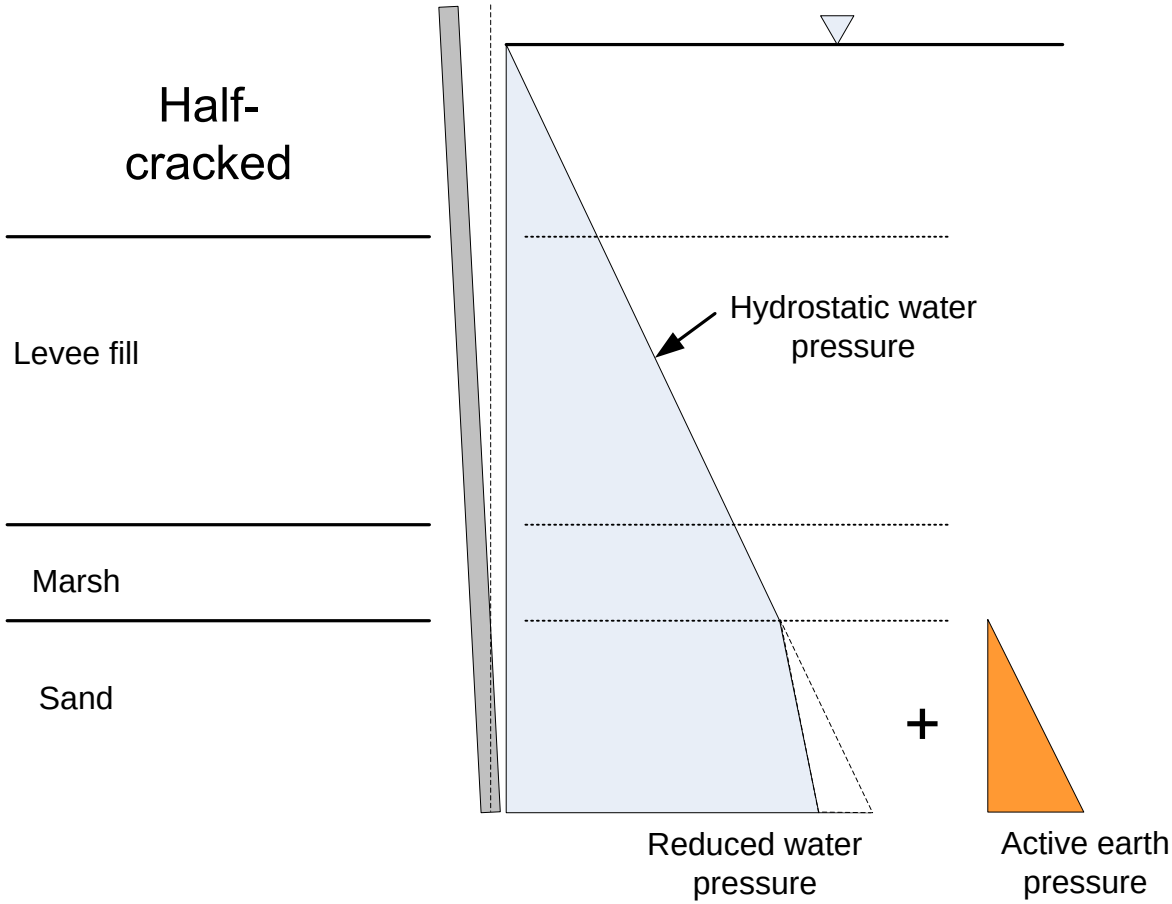

London Avenue Canal - South
Canal water elevation = 7.1 ft NAVD88
Protected side boundary water elevation = -8.4 ft NAVD88
Crack to top of sand layer
0.5 ft total head contours
Levee Fill
Marsh
Sand
10
0
-10
-20
-30 ft
65 ft
70
75
80
85
90
95
100
105
110
115
120
125

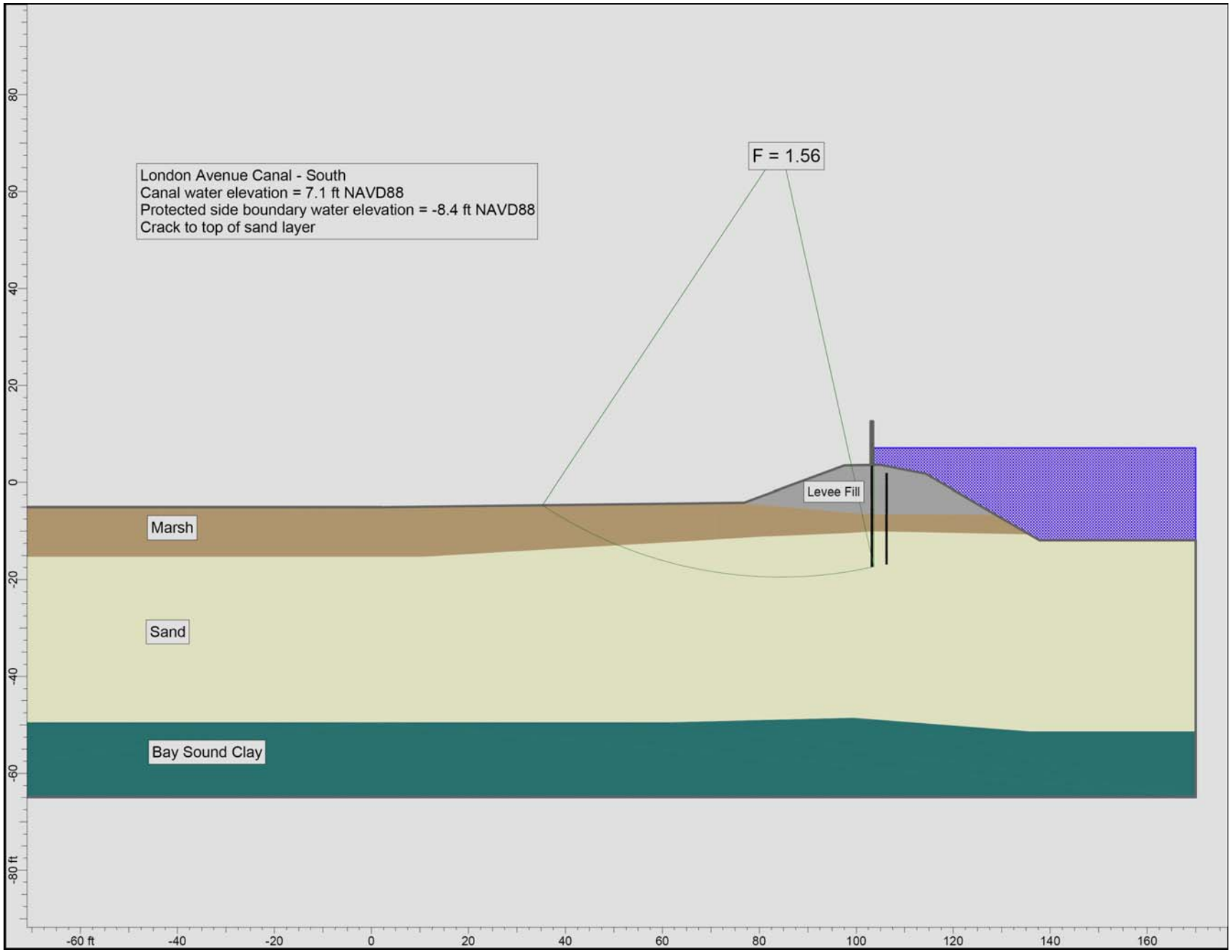
Table 3. Calculated probabilities of erosion – London Avenue south breach

Canal water level	F_{MLV} *	COV_F **	Probability of erosion
7.1 ft	0.84	5%	> 99%
8.2 ft	0.77	4%	> 99%

* F_{MLV} taken as the average for high and low positions of LWL

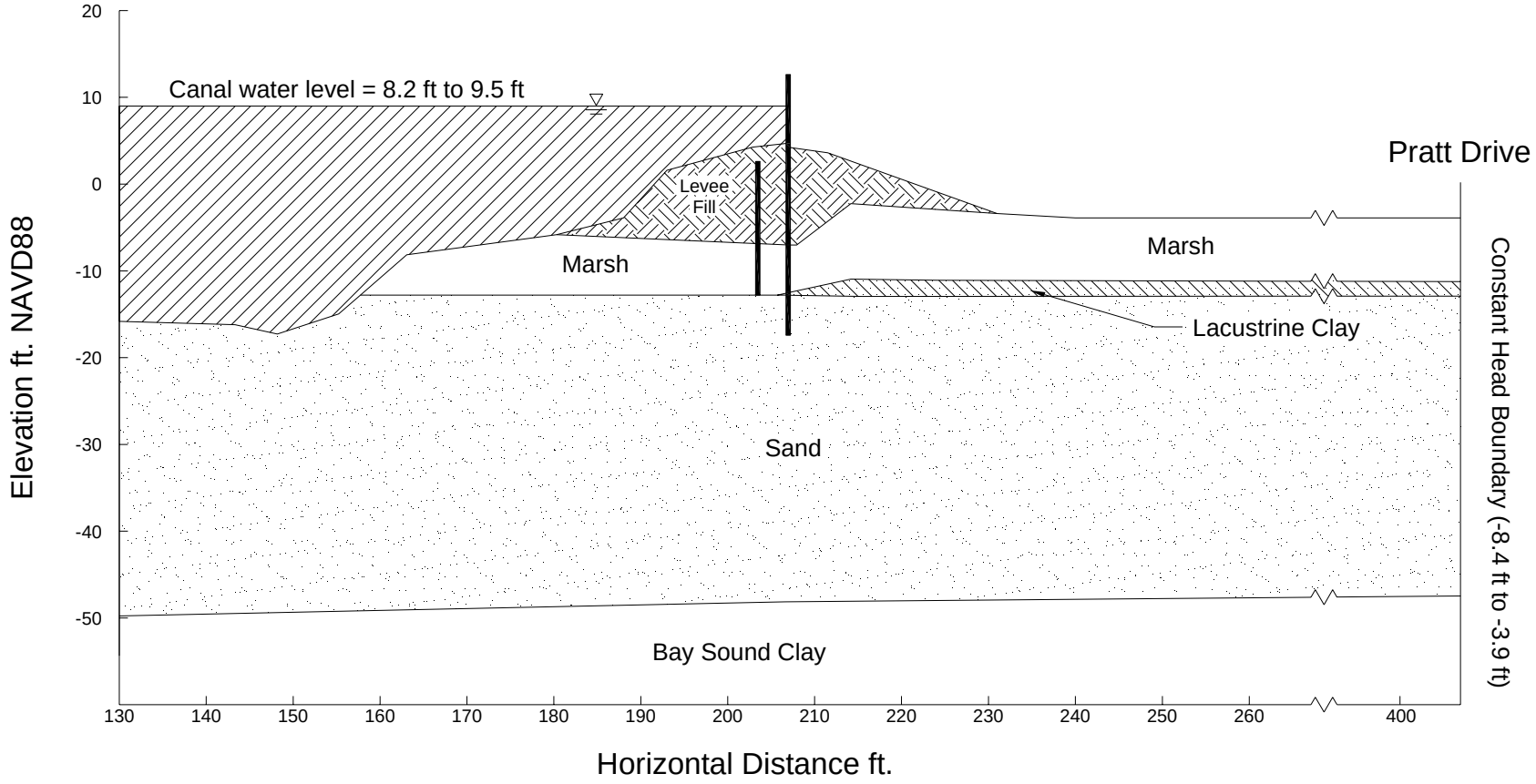
** Reflects ΔF due to variations in LWL

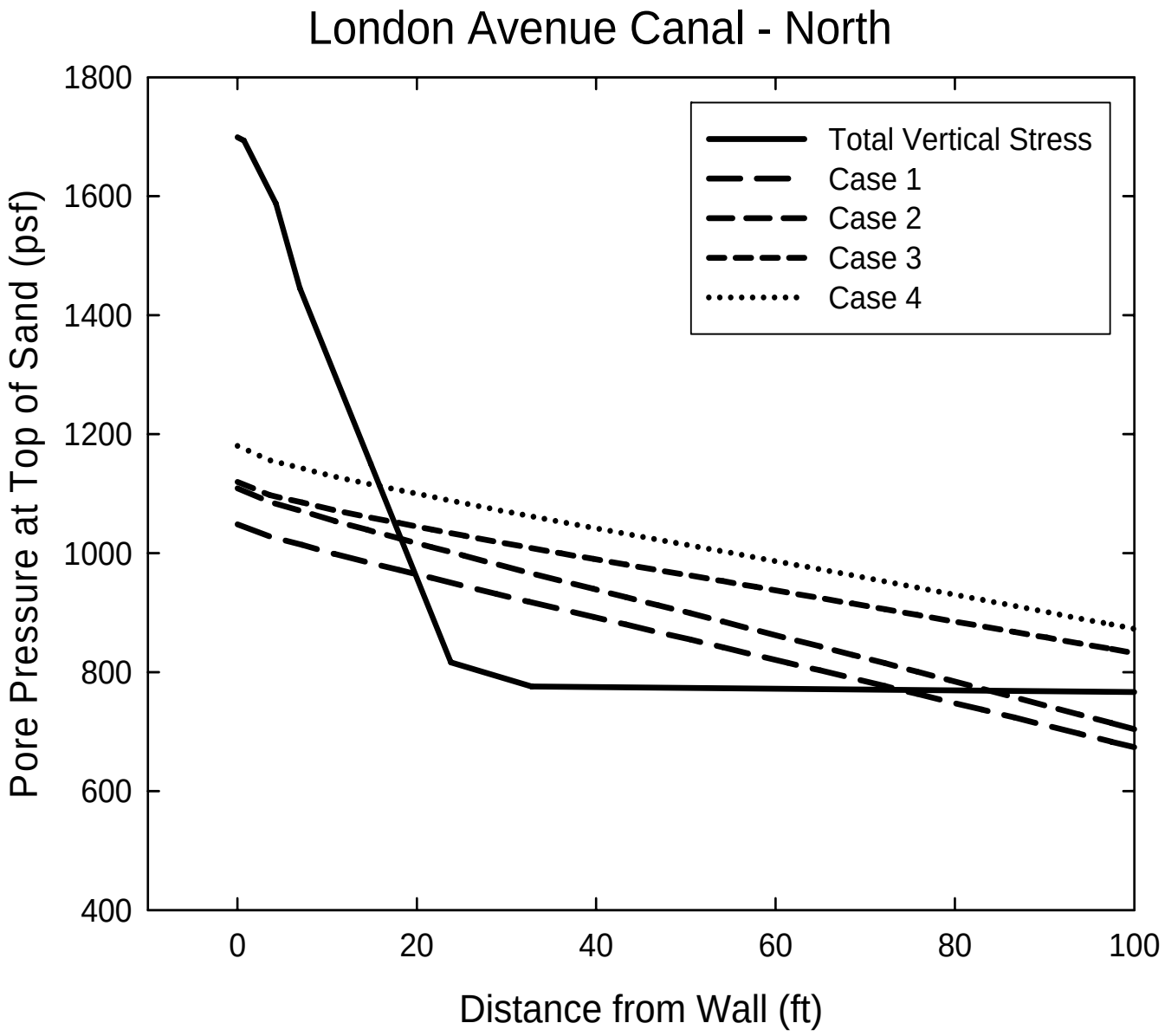

Half-
cracked
Levee fill
Marsh
Sand
Hydrostatic water
pressure
+
Reduced water
pressure
Active earth
pressure

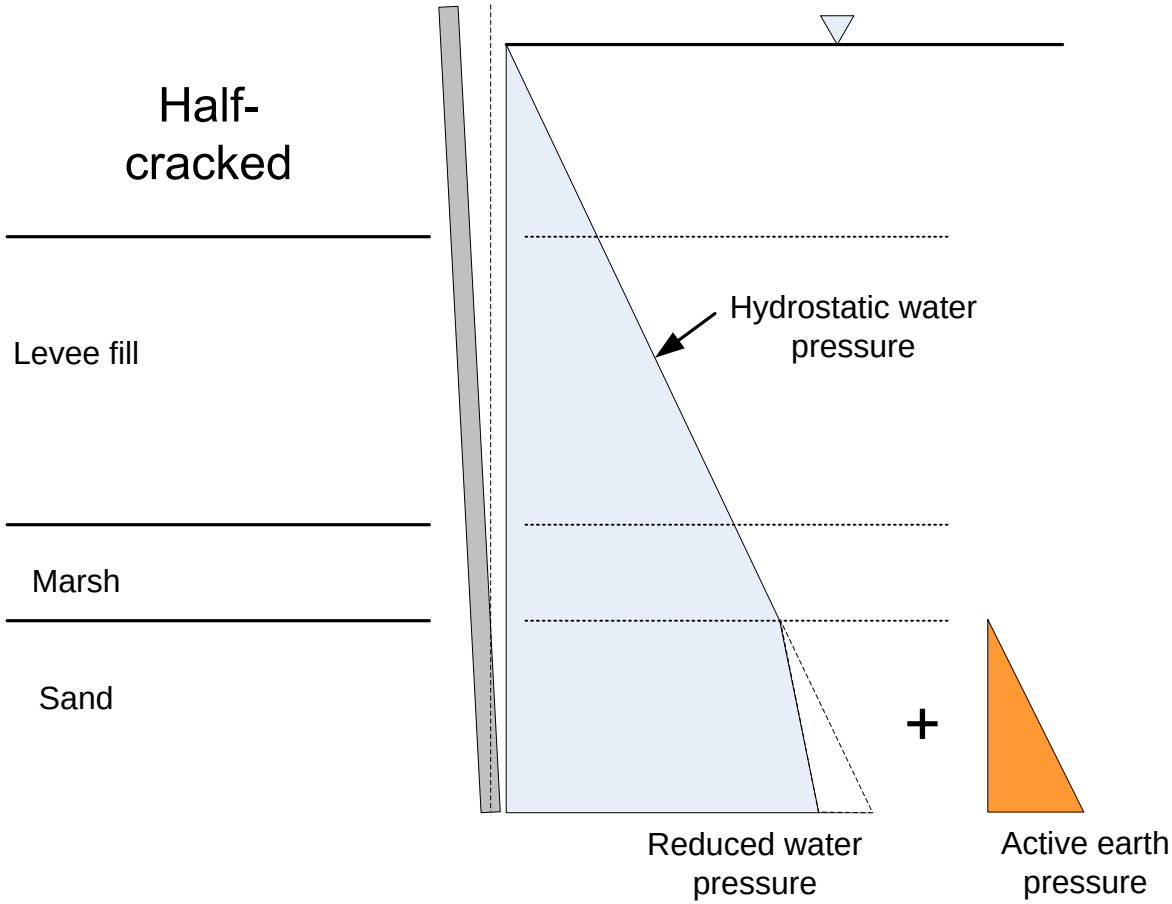

London Avenue Canal - South
Canal water elevation = 7.1 ft NAVD88
Protected side boundary water elevation = -8.4 ft NAVD88
Crack to top of sand layer
F = 1.56
Levee Fill
Marsh
Sand
Bay Sound Clay
80
60
40
20
0
-20
-40
-60
-80 ft
-60 ft
-40
-20
0
20
40
60
80
100
120
140
160

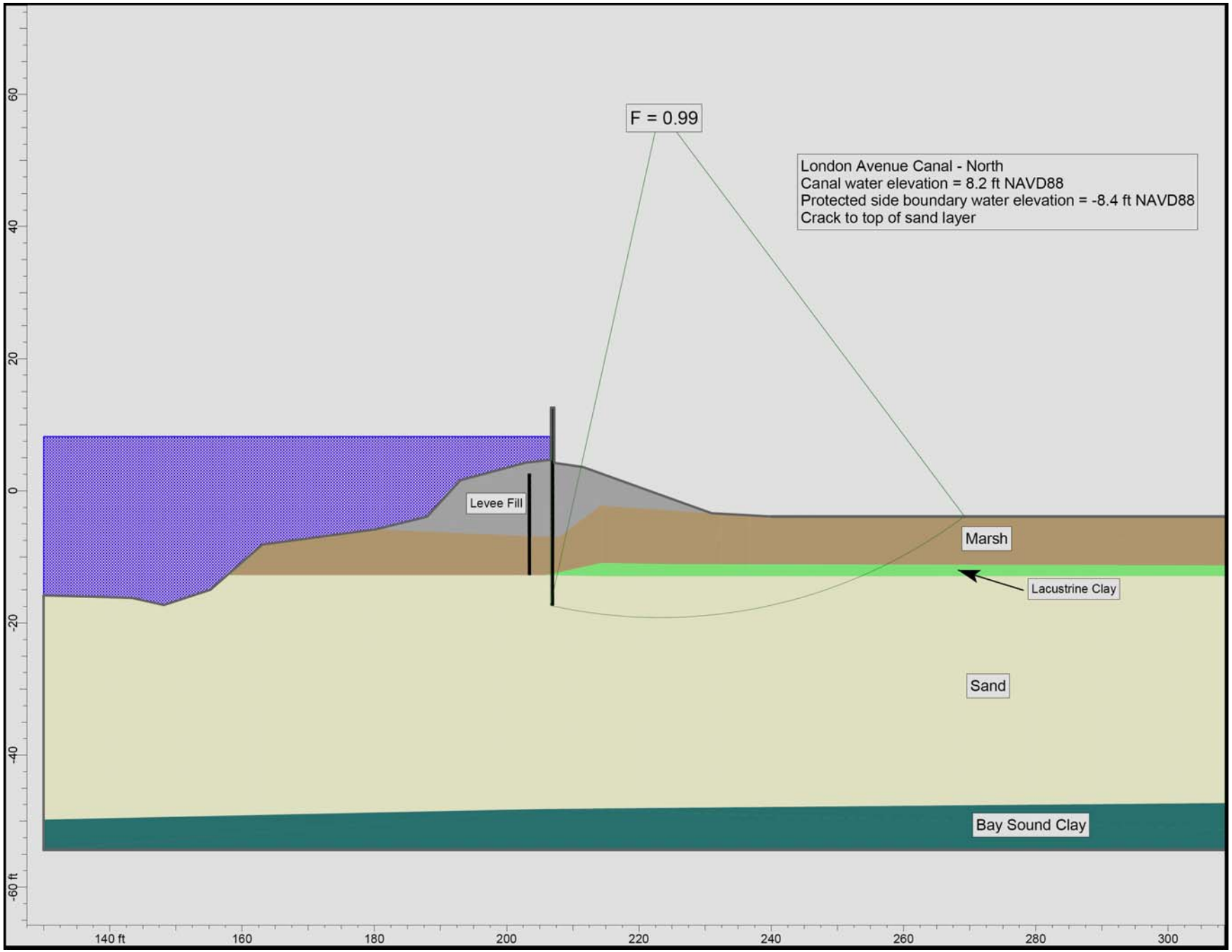
London Avenue north breach – about 410 ft wide – similar to 17th Street canal I-wall failure

London Avenue Canal - North
Station 14+00/114+75
West I-Wall




London Avenue Canal - North
Pore Pressure at Top of Sand (psf)
Distance from Wall (ft)
1800
1600
1400
1200
1000
800
600
400
0
20
40
60
80
100
Total Vertical Stress
Case 1
Case 2
Case 3
Case 4


Half-
cracked
Levee fill
Marsh
Sand
Hydrostatic water
pressure
+
Reduced water
pressure
Active earth
pressure

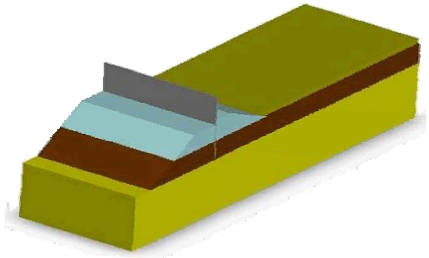

F = 0.99
London Avenue Canal - North
Canal water elevation = 8.2 ft NAVD88
Protected side boundary water elevation = -8.4 ft NAVD88
Crack to top of sand layer
Levee Fill
Marsh
Lacustrine Clay
Sand
Bay Sound Clay
60
40
20
0
-20
-40
-60 ft
140 ft
160
180
200
220
240
260
280
300

Comparison of Factor of Safety for north and south breaches

Breach	$F_{erosion}$	$F_{instability}$
South	0.74 to 0.89	1.19 to 1.56
North	0.67 to 0.88	0.72 to 0.99

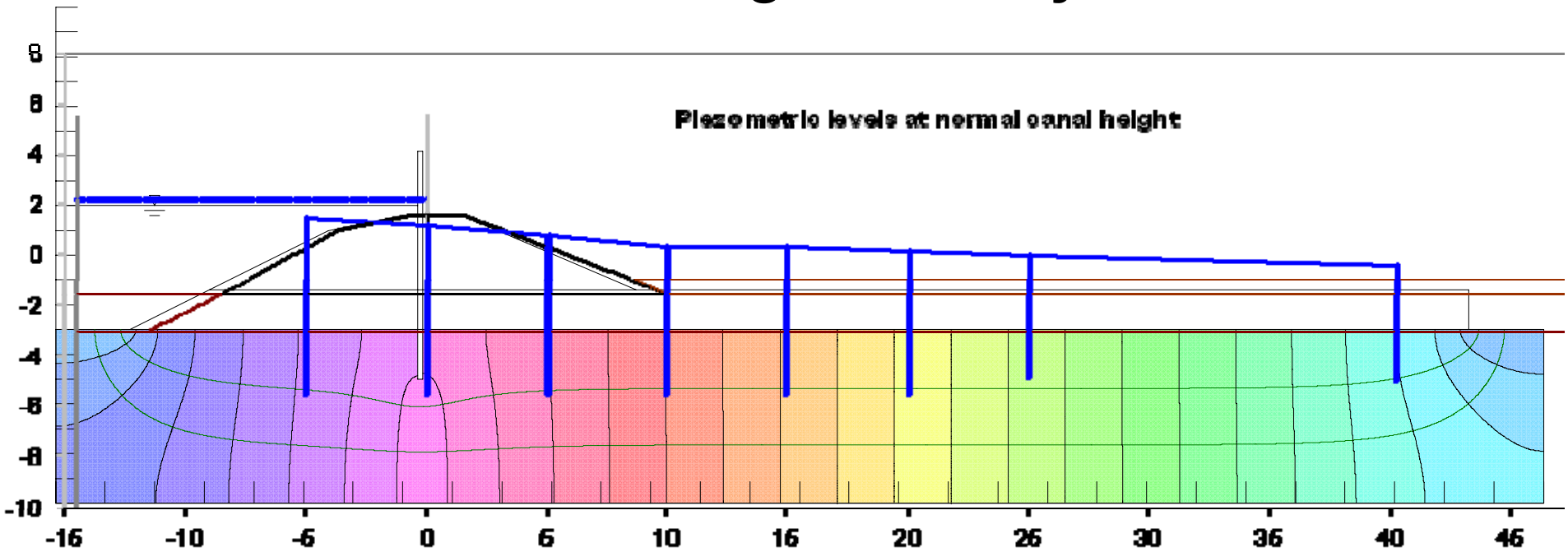
Comparison of probabilities for north and south breaches

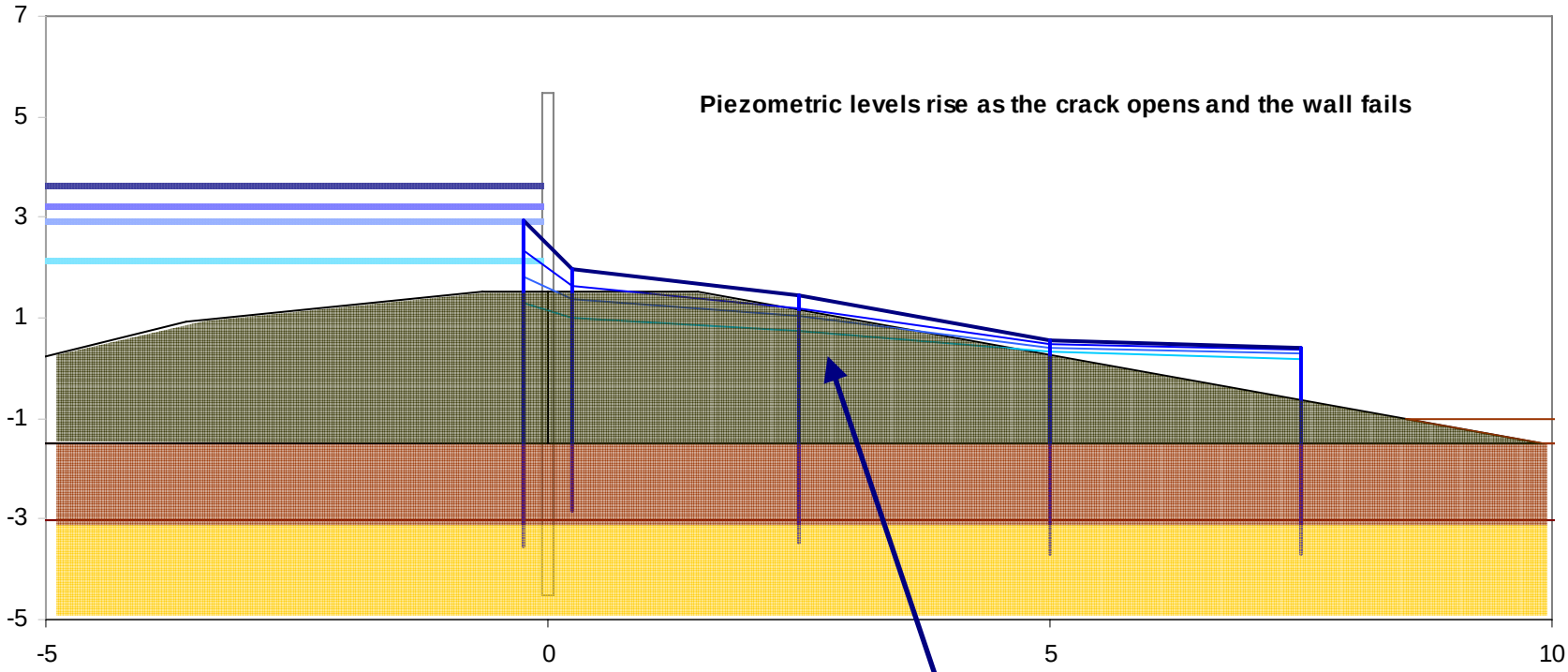
Breach	$P_{erosion}$	$P_{instability}$
South	>99%	1% to 10%
North	91% to 99%	70% to 97%



Establishing initial conditions

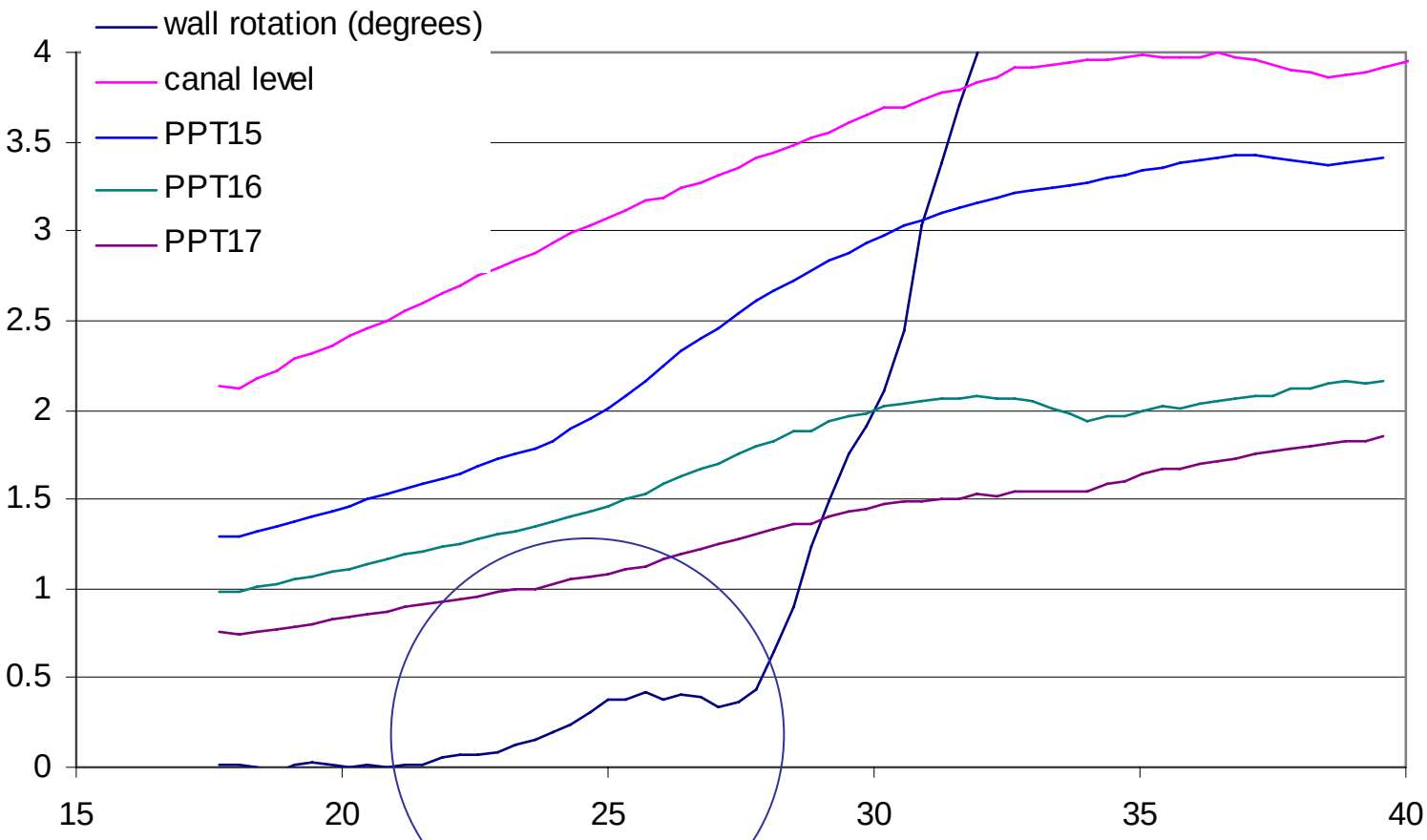
Flownet through sand layer



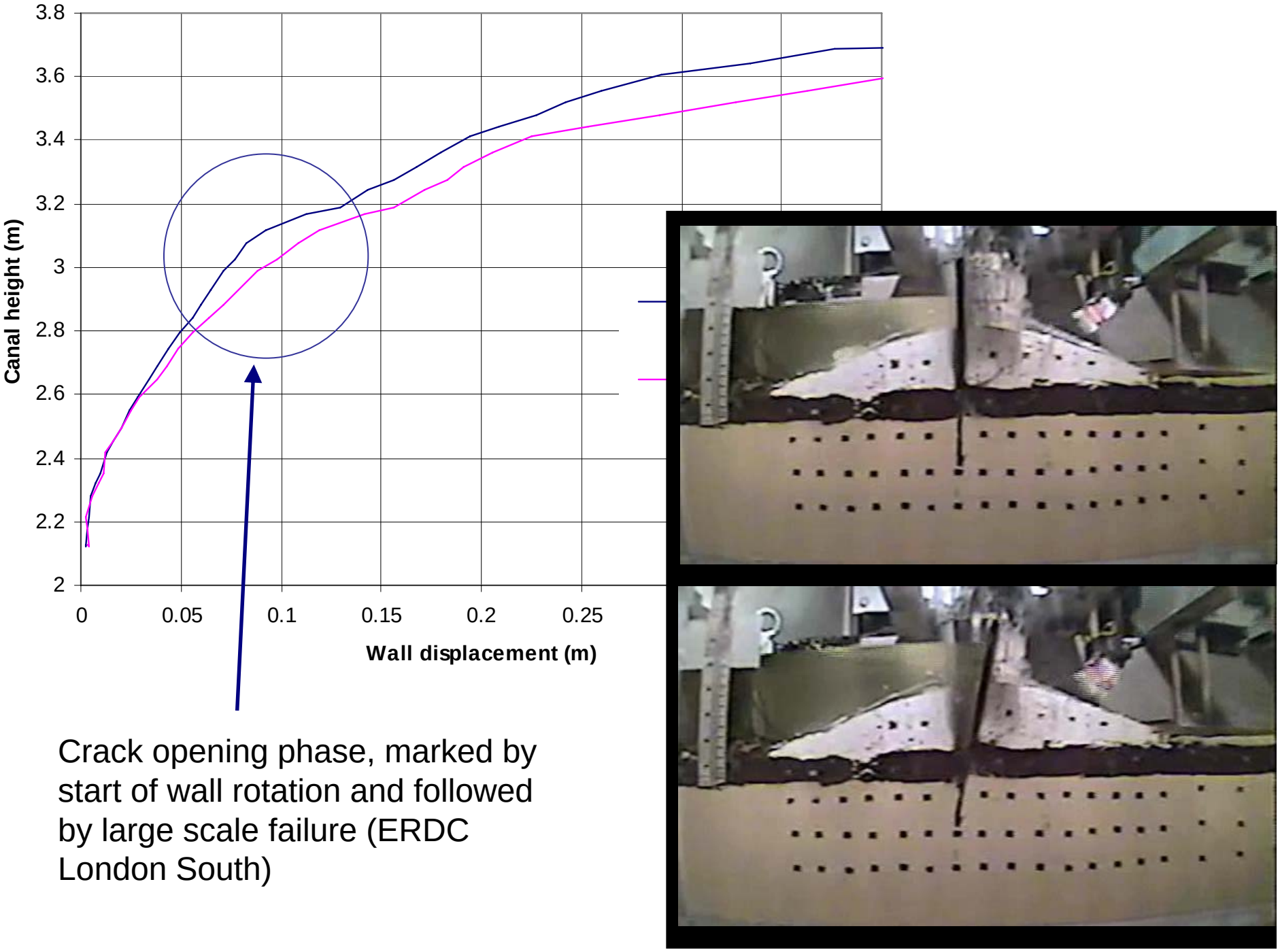


Piezometric levels under the landward levee berm rise as water rises in the canal, (ERDC London South)

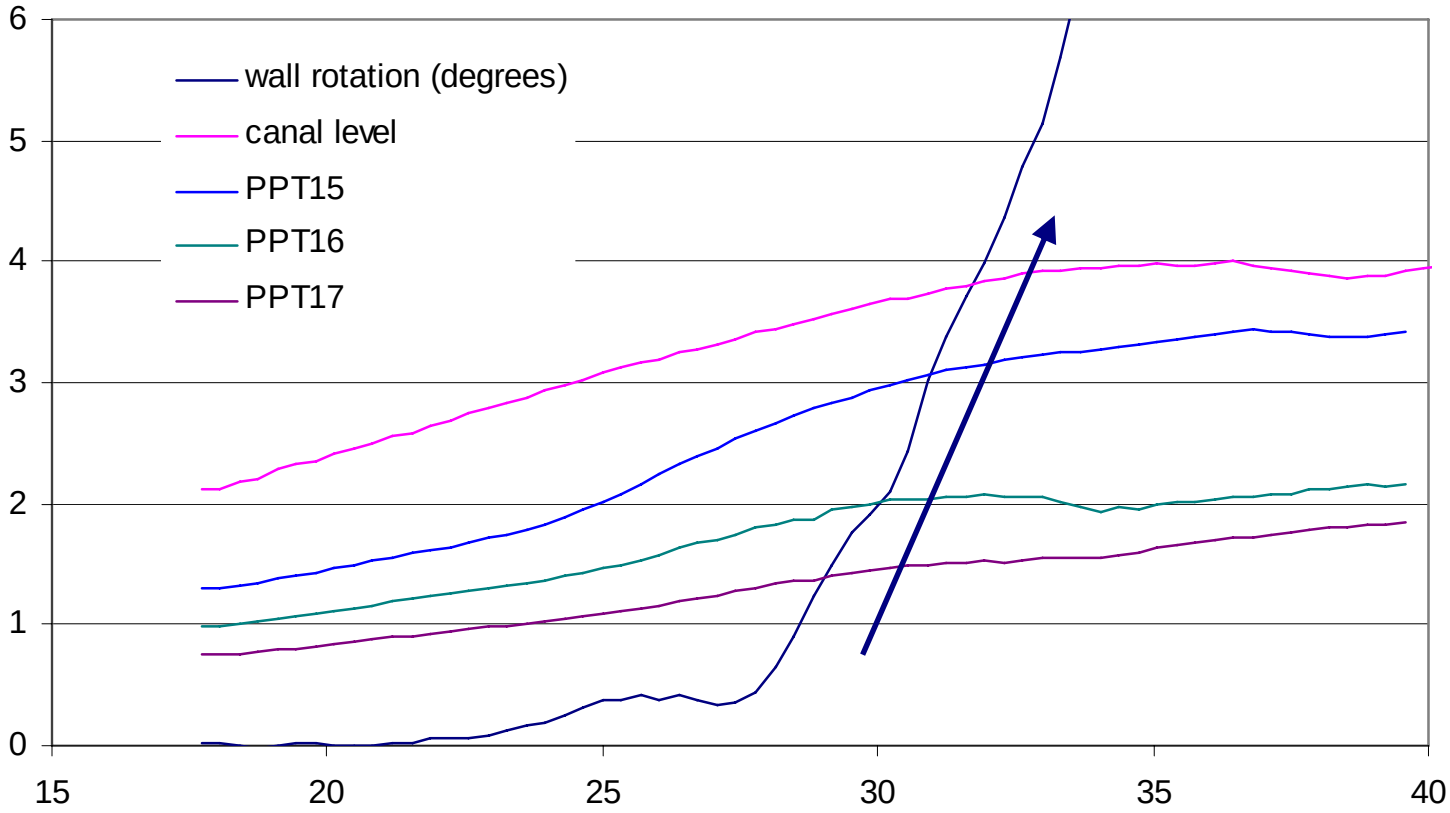
London South – sand foundation



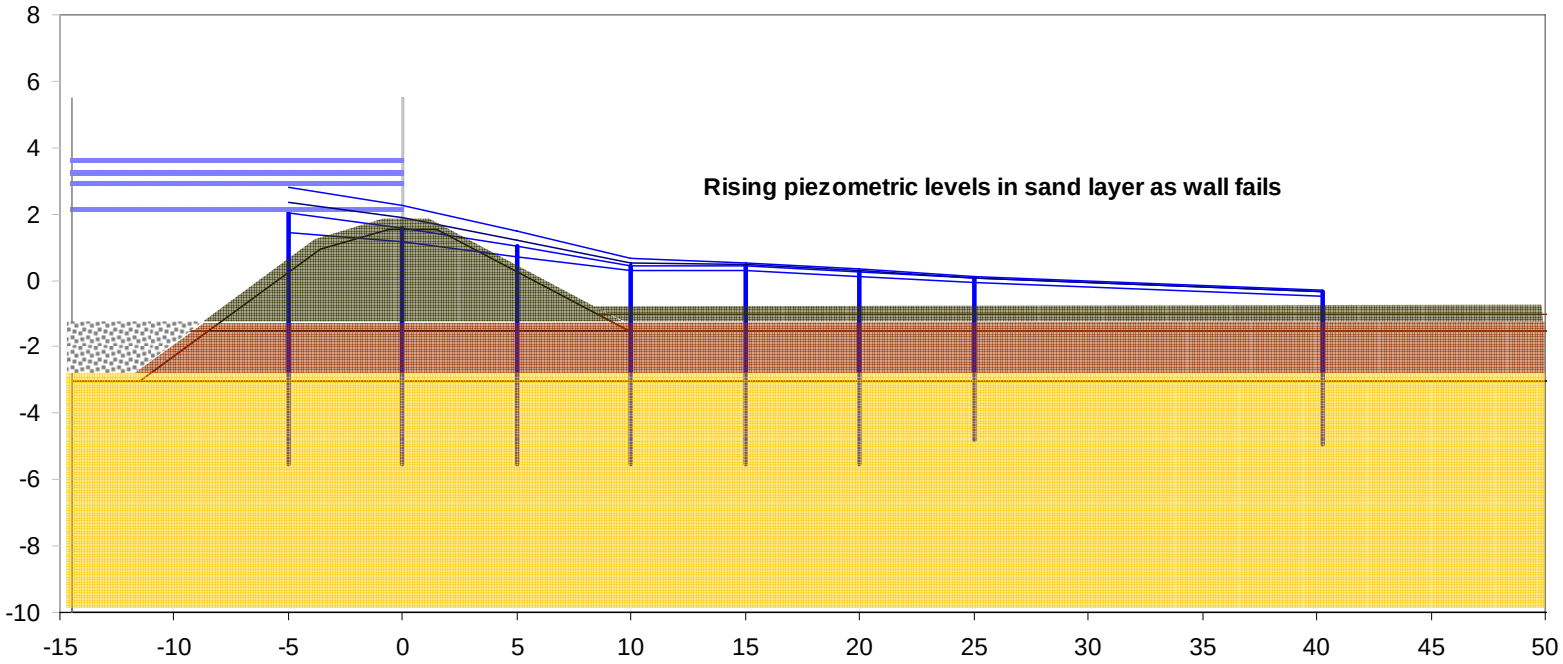
Crack opening phase, marked by start of wall rotation and pore pressure rise around the toe of the sheet pile (ERDC London South)



Crack opening phase, marked by start of wall rotation and followed by large scale failure (ERDC London South)

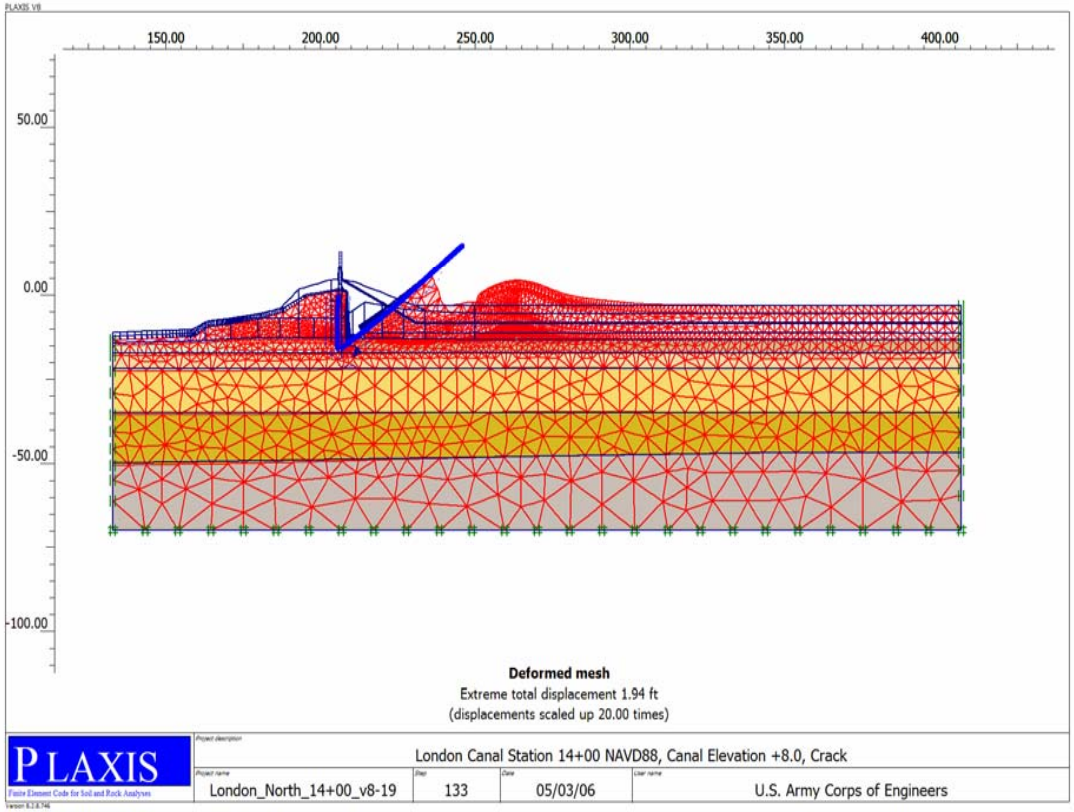


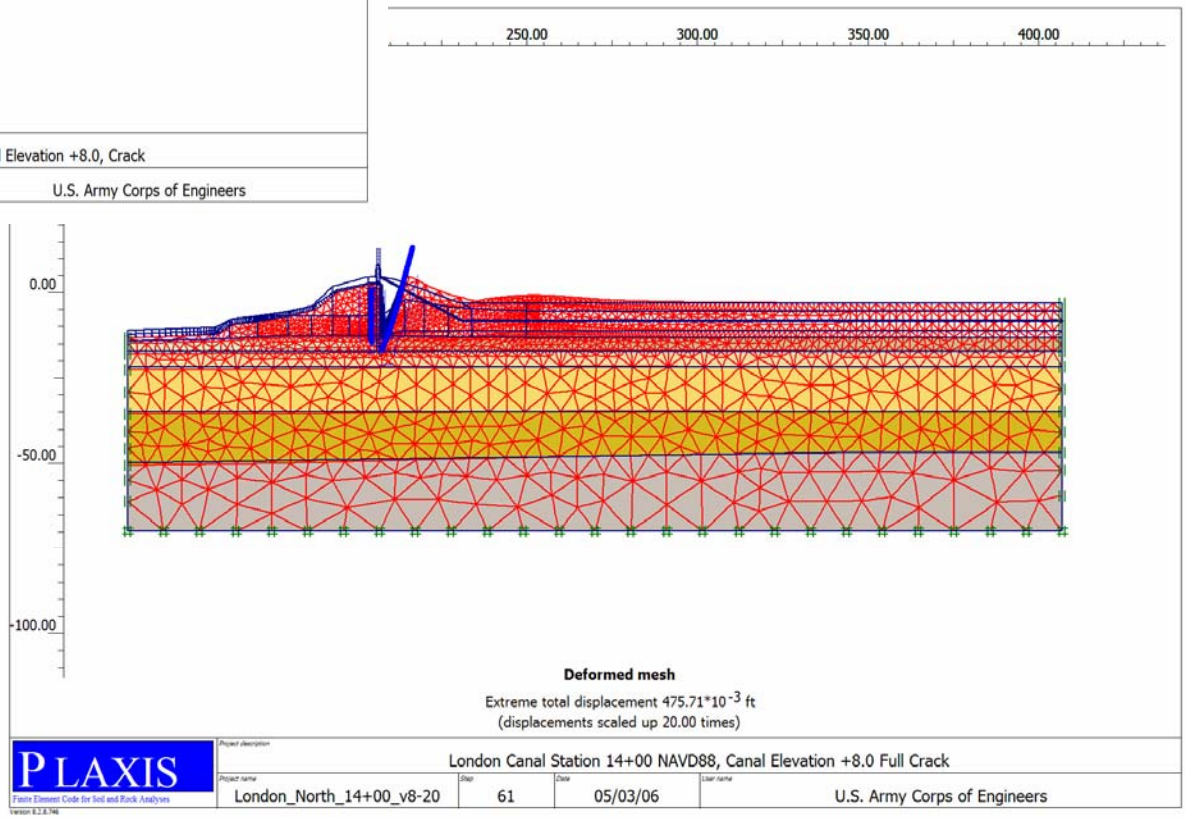
Main failure phase, ERDC London South, marked by rapid and continuing wall rotation and pore pressure rise (PPT15)

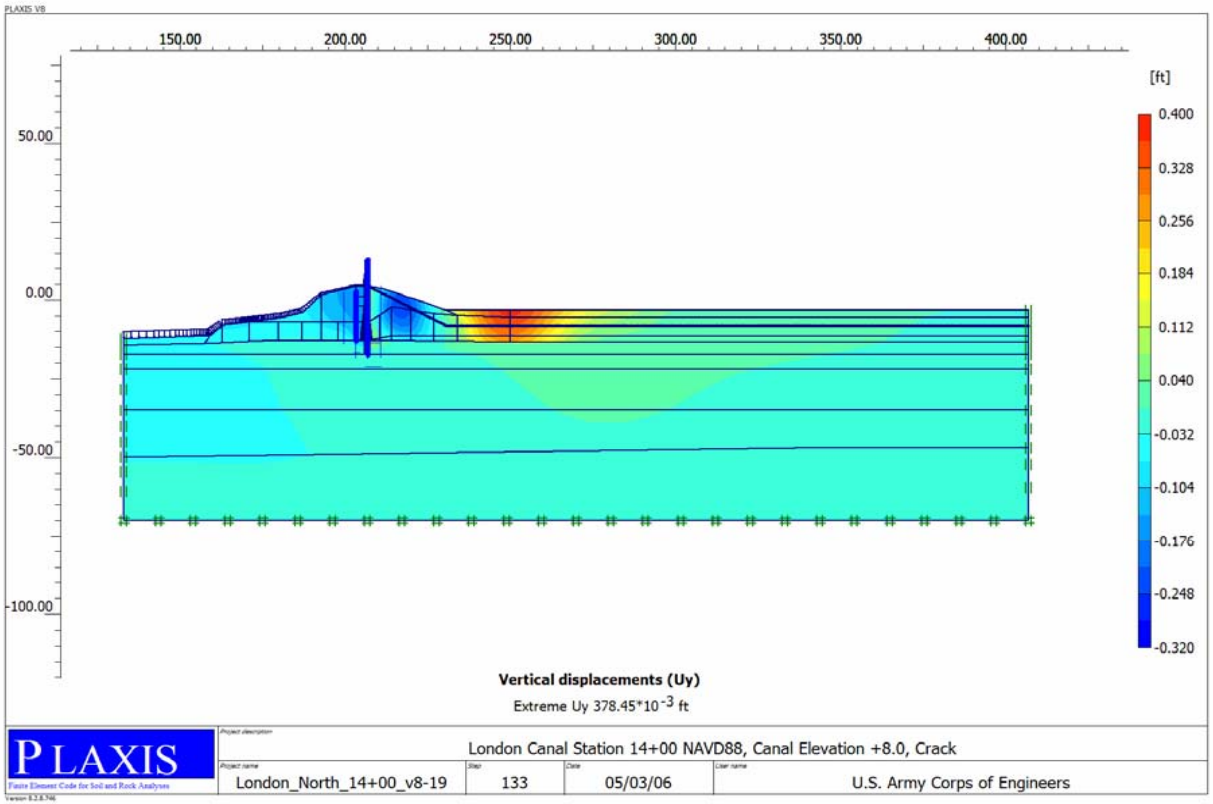


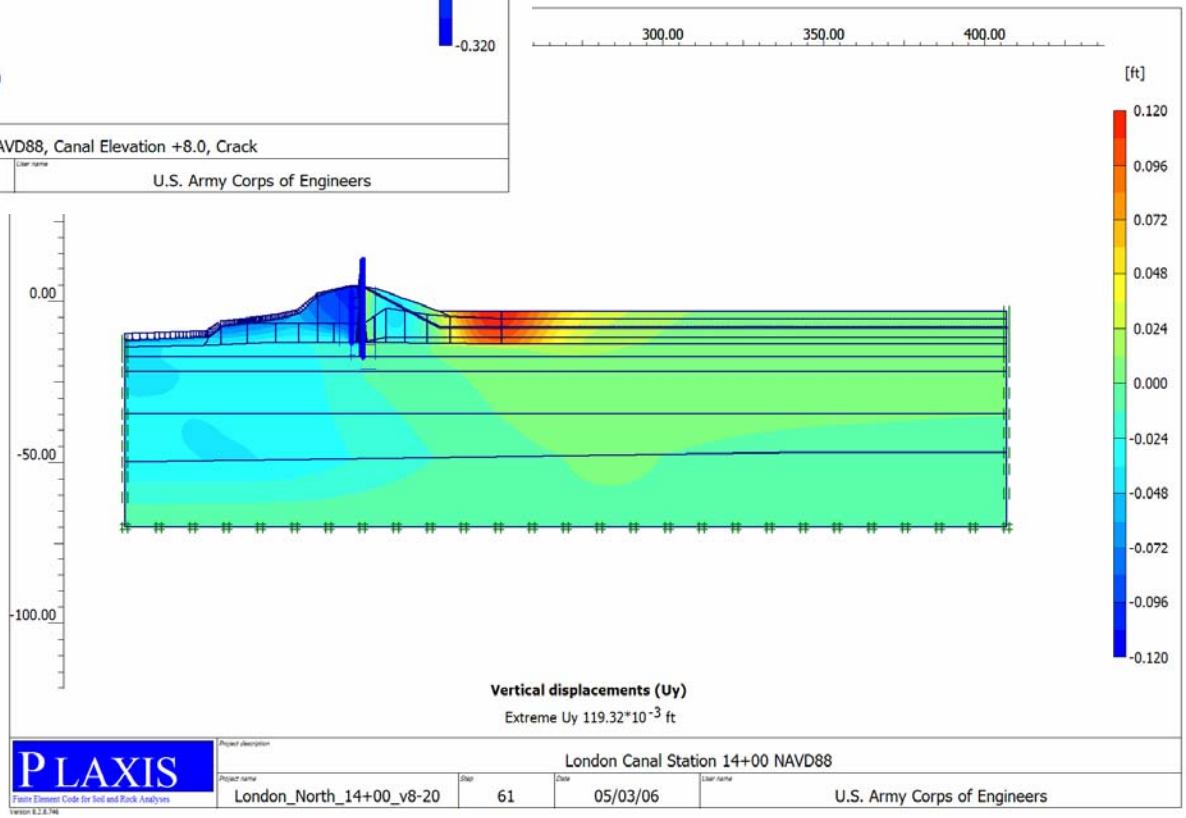
Main failure phase, beyond the levee on the landward side there is a small increase in piezometric level and water emerges from the toe of the levee (RPI London South)

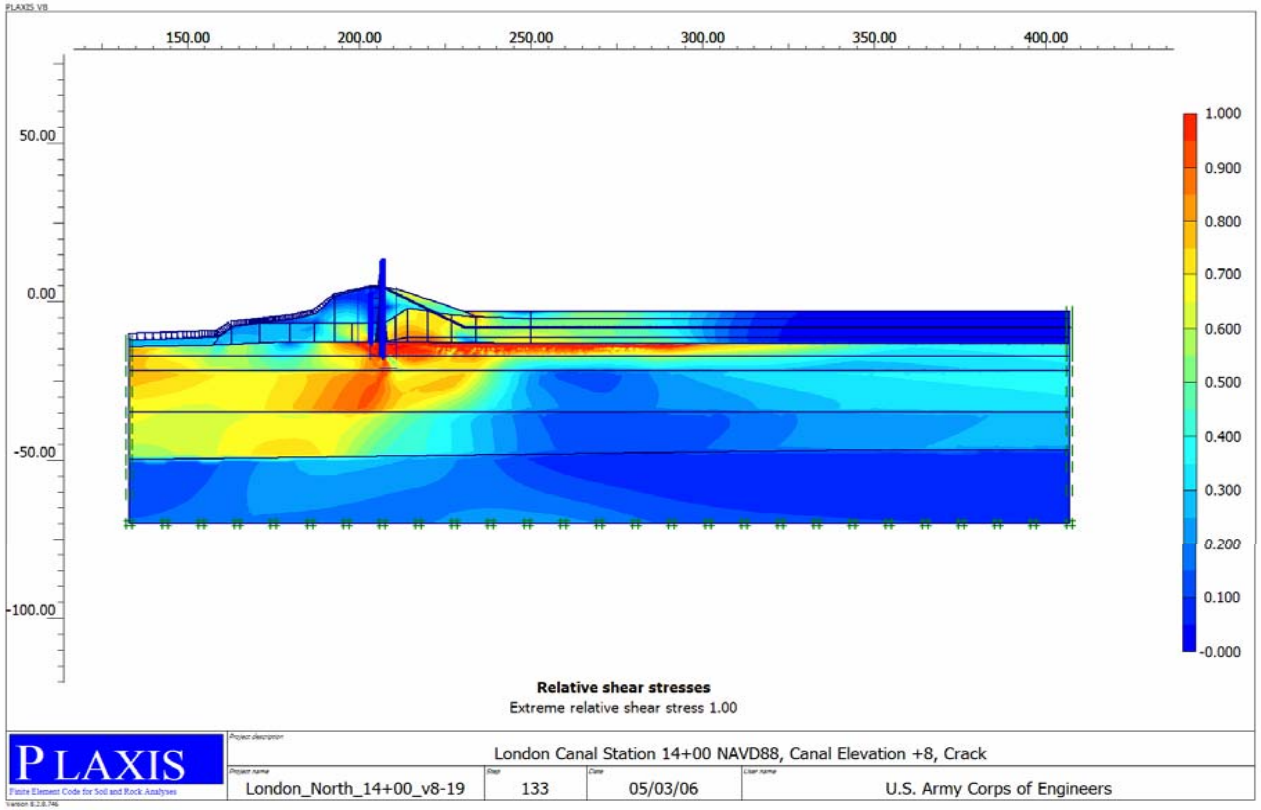
London Avenue Canal
North
Finite Element Analysis

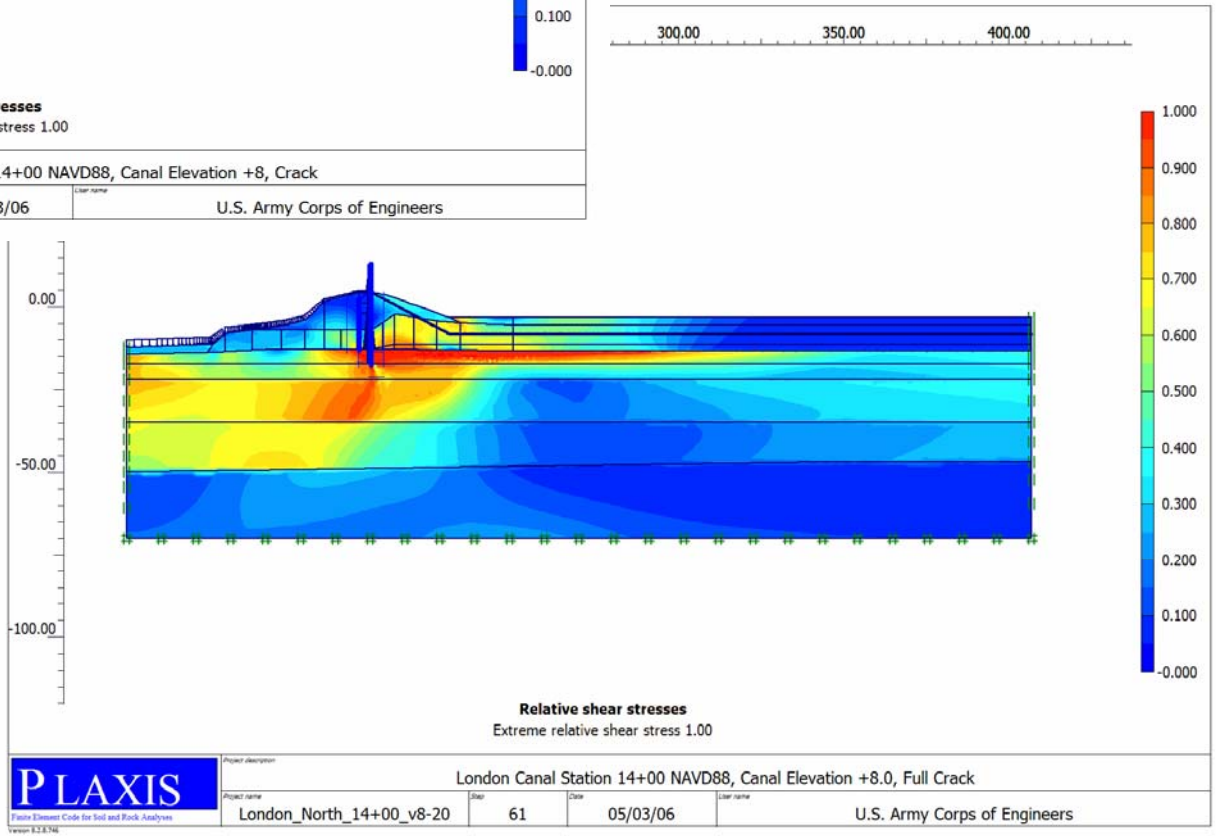

PLAXIS V8
150.00
200.00
250.00
300.00
350.00
400.00
50.00
0.00
-50.00
-100.00
Deformed mesh
Extreme total displacement 1.94 ft
(displacements scaled up 20.00 times)
PLAXIS
Finite Element Code for Soil and Rock Analyses
Project description
London Canal Station 14+00 NAVD88, Canal Elevation +8.0, Crack
Project name
London_North_14+00_v8-19
Step
133
Date
05/03/06
User name
U.S. Army Corps of Engineers

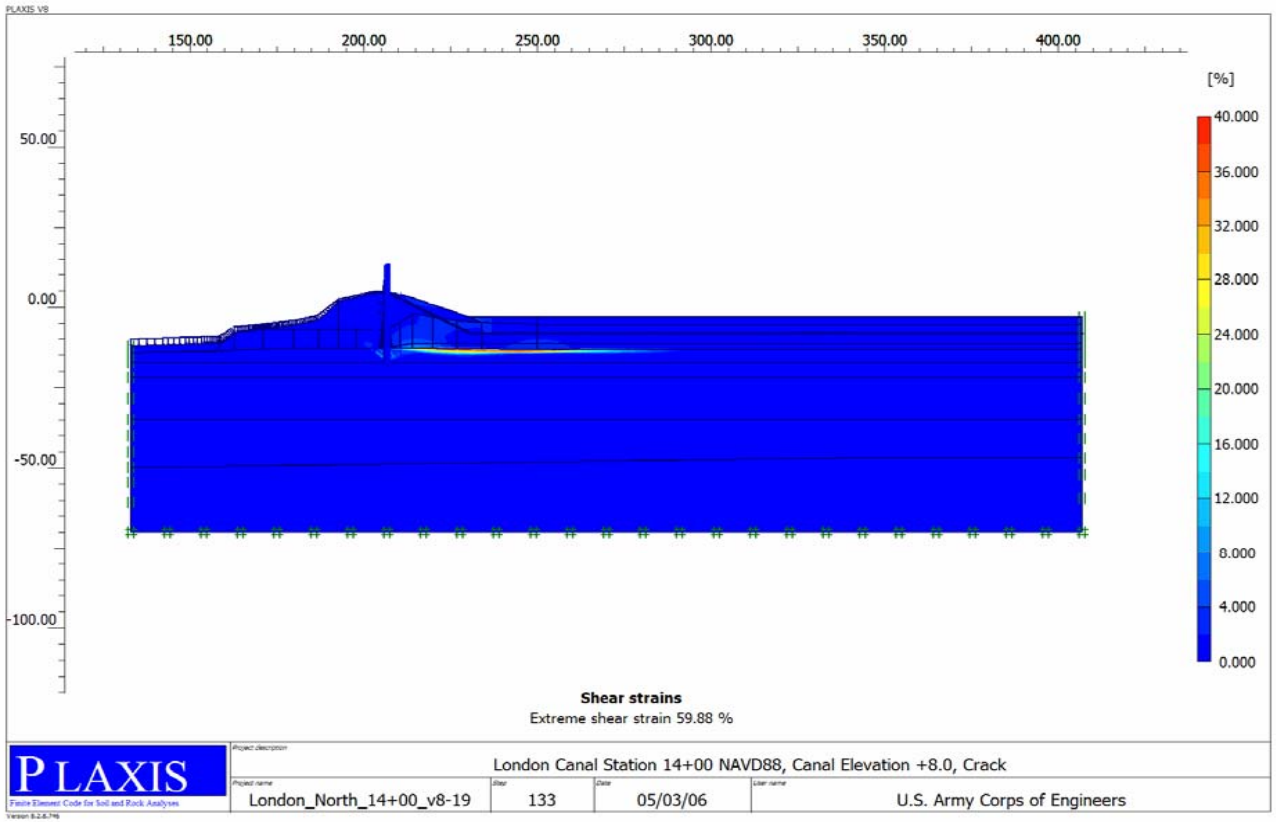

250.00
300.00
350.00
400.00
0.00
-50.00
-100.00
Deformed mesh
Extreme total displacement 475.71*10-3 ft
(displacements scaled up 20.00 times)
PLAXIS
Finite Element Code for Soil and Rock Analyses
Project description
London Canal Station 14+00 NAVD88, Canal Elevation +8.0 Full Crack
Project name
London_North_14+00_v8-20
Step
61
Date
05/03/06
User name
U.S. Army Corps of Engineers

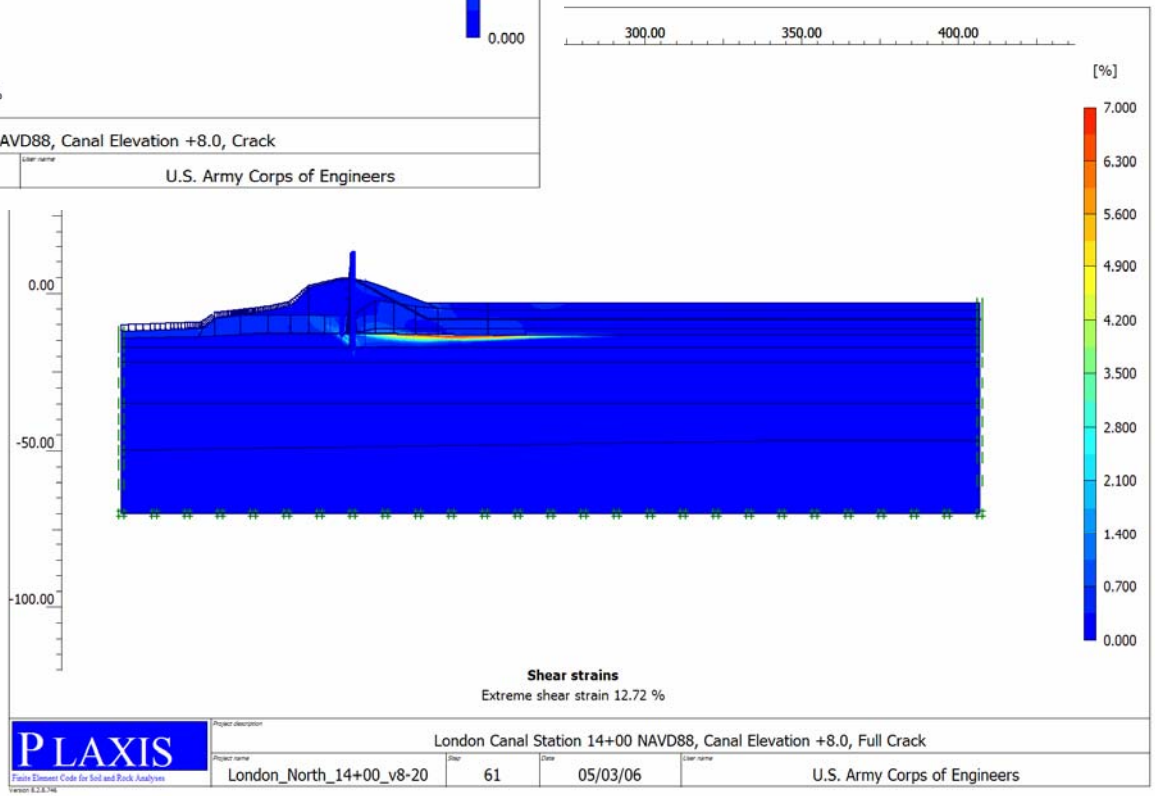

PLAXIS V8
150.00
200.00
250.00
300.00
350.00
400.00
50.00
0.00
-50.00
-100.00
[ft]
0.400
0.328
0.256
0.184
0.112
0.040
-0.032
-0.104
-0.176
-0.248
-0.320
Vertical displacements (Uy)
Extreme Uy 378.45*10-3 ft
PLAXIS
Finite Element Code for Soil and Rock Analyses
London Canal Station 14+00 NAVD88, Canal Elevation +8.0, Crack
London_North_14+00_v8-19
133
05/03/06
U.S. Army Corps of Engineers


300.00
350.00
400.00
[ft]
0.120
0.096
0.072
0.048
0.024
0.000
-0.024
-0.048
-0.072
-0.096
-0.120
0.00
-50.00
-100.00
Vertical displacements (Uy)
Extreme Uy 119.32*10-3 ft
PLAXIS
Finite Element Code for Soil and Rock Analyses
London Canal Station 14+00 NAVD88
London_North_14+00_v8-20
61
05/03/06
U.S. Army Corps of Engineers

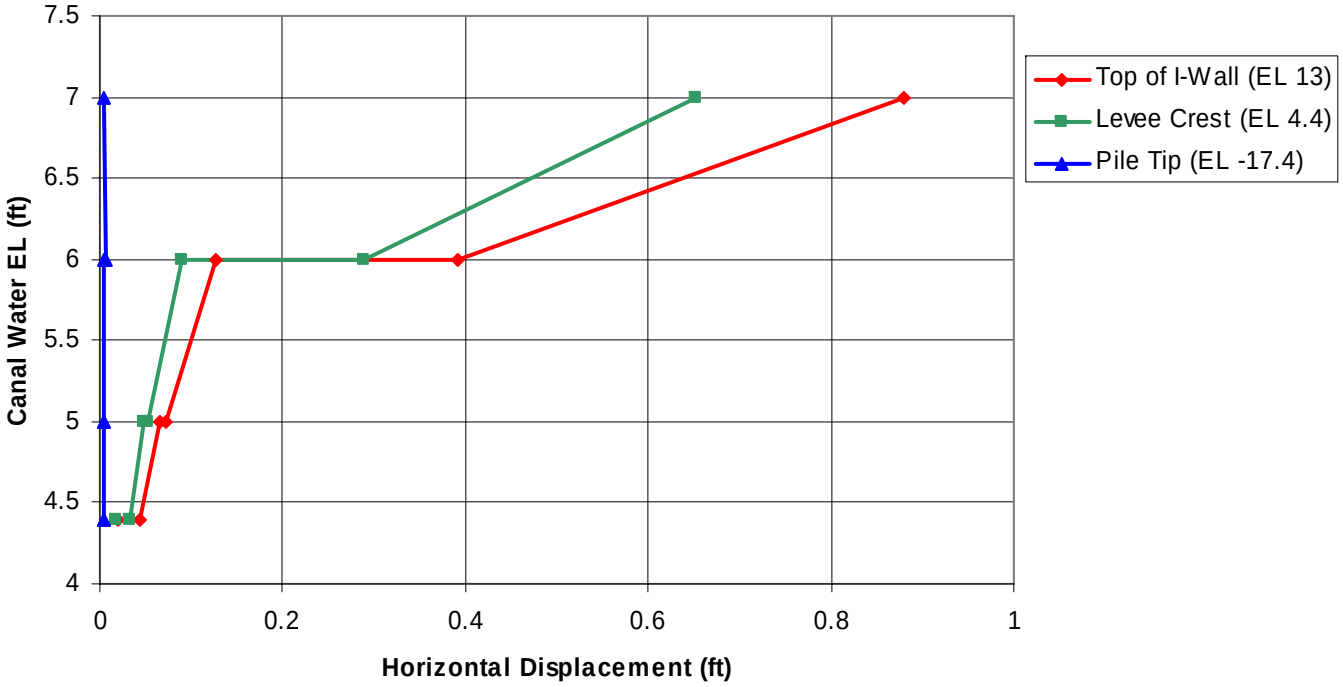

150.00
200.00
250.00
300.00
350.00
400.00
50.00
0.00
-50.00
-100.00
1.000
0.900
0.800
0.700
0.600
0.500
0.400
0.300
0.200
0.100
-0.000
Relative shear stresses
Extreme relative shear stress 1.00
PLAXIS
Finite Element Code for Soil and Rock Analyses
London Canal Station 14+00 NAVD88, Canal Elevation +8, Crack
London_North_14+00_v8-19
133
05/03/06
U.S. Army Corps of Engineers


300.00
350.00
400.00
0.00
-50.00
-100.00
1.000
0.900
0.800
0.700
0.600
0.500
0.400
0.300
0.200
0.100
-0.000
Relative shear stresses
Extreme relative shear stress 1.00
PLAXIS
Finite Element Code for Soil and Rock Analyses
London Canal Station 14+00 NAVD88, Canal Elevation +8.0, Full Crack
London_North_14+00_v8-20
61
05/03/06
U.S. Army Corps of Engineers

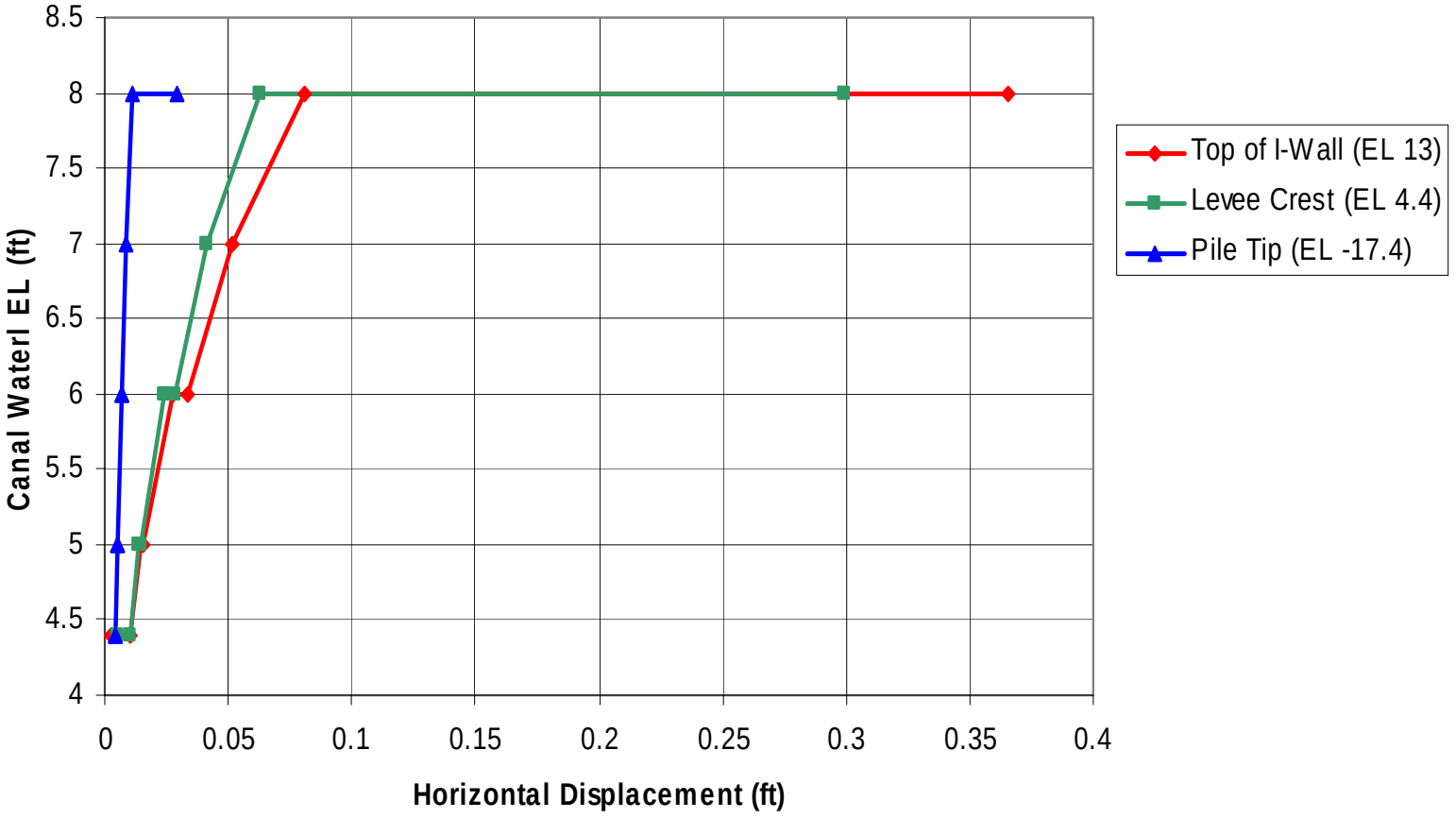

PLAXIS V8
150.00
200.00
250.00
300.00
350.00
400.00
50.00
0.00
-50.00
-100.00
[%]
40.000
36.000
32.000
28.000
24.000
20.000
16.000
12.000
8.000
4.000
0.000
Shear strains
Extreme shear strain 59.88 %
PLAXIS
Finite Element Code for Soil and Rock Analyses
London Canal Station 14+00 NAVD88, Canal Elevation +8.0, Crack
London_North_14+00_v8-19
133
05/03/06
U.S. Army Corps of Engineers


300.00
350.00
400.00
[%]
7.000
6.300
5.600
4.900
4.200
3.500
2.800
2.100
1.400
0.700
0.000
0.00
-50.00
-100.00
Shear strains
Extreme shear strain 12.72 %
PLAXIS
Finite Element Code for Soil and Rock Analyses
London Canal Station 14+00 NAVD88, Canal Elevation +8.0, Full Crack
London_North_14+00_v8-20
61
05/03/06
U.S. Army Corps of Engineers

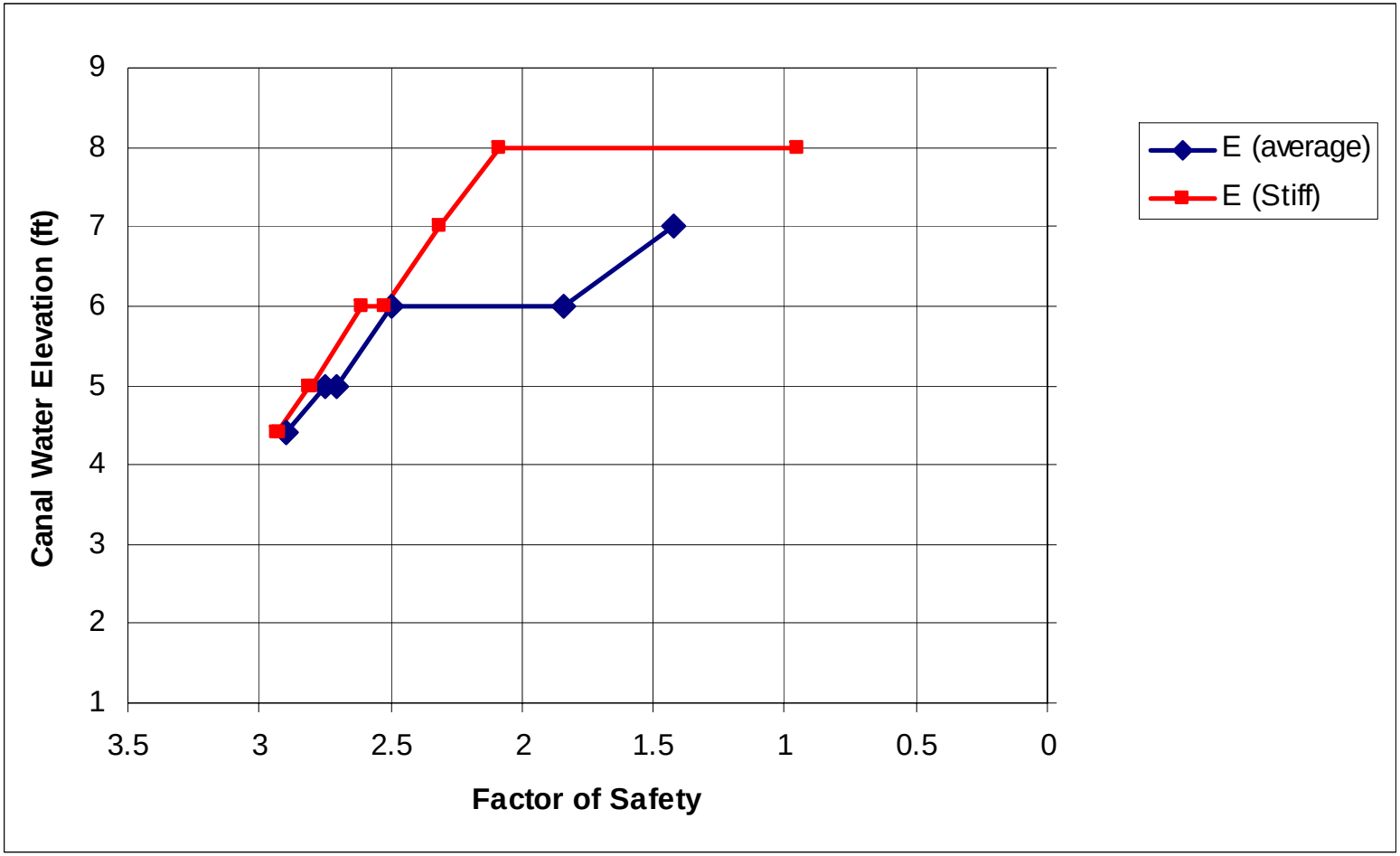
E average


7.5
7
6.5
6
5.5
5
4.5
4
0
0.2
0.4
0.6
0.8
1
Canal Water EL (ft)
Horizontal Displacement (ft)
Top of I-Wall (EL 13)
Levee Crest (EL 4.4)
Pile Tip (EL -17.4)

E stiff


8.5
8
7.5
7
6.5
6
5.5
5
4.5
4
Canal Waterl EL (ft)
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
Horizontal Displacement (ft)
Top of I-Wall (EL 13)
Levee Crest (EL 4.4)
Pile Tip (EL -17.4)

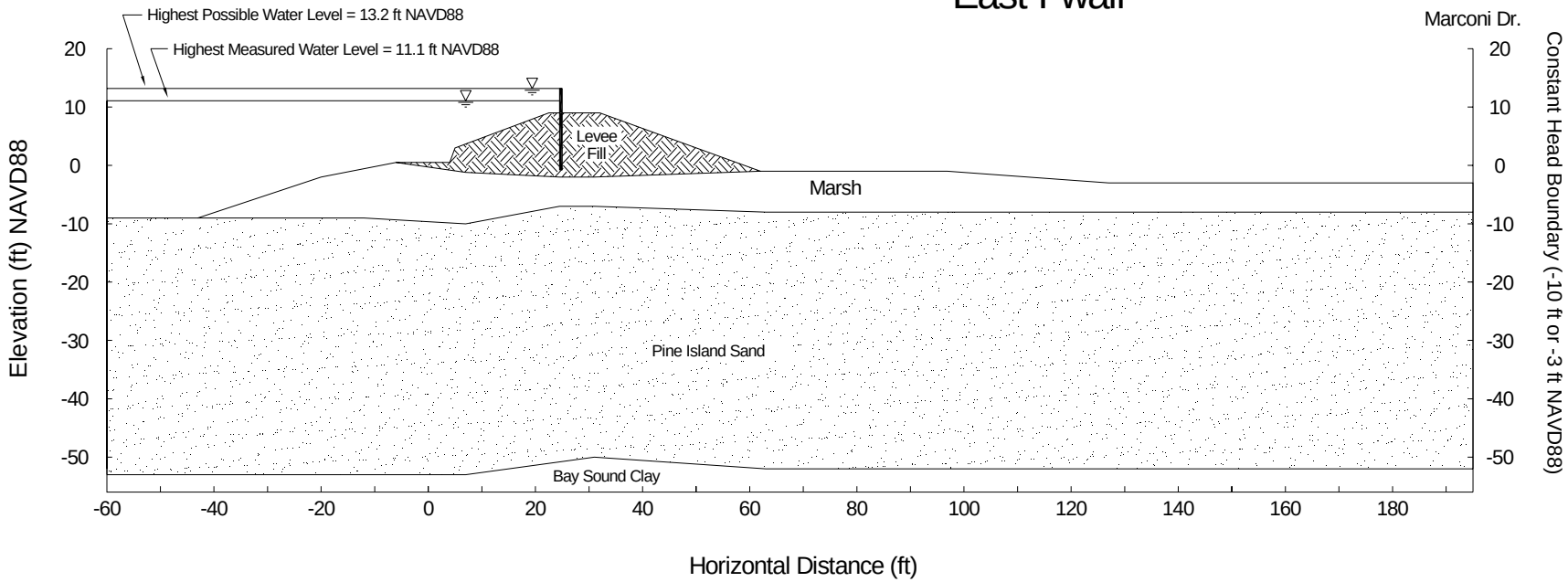
Factor of Safety



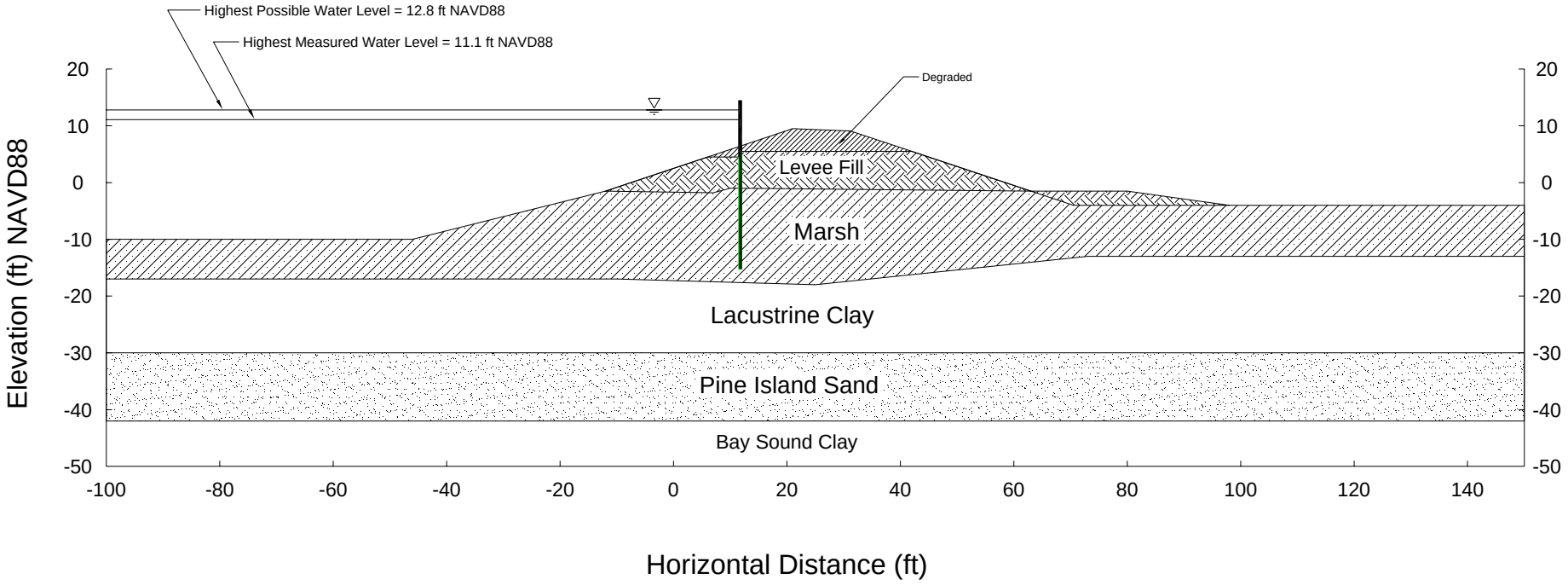
Analysis of Performance
Orleans Canal I-wall

Principal Findings

Orleans Avenue Canal - South
Station 8+61
East I-wall



Orleans Avenue Canal - North
Station 64.27
East I-wall



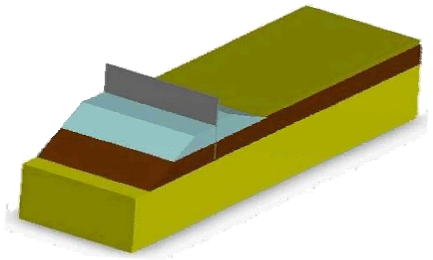
Factors of safety – maximum Observed water level

Breach	$F_{erosion}$	$F_{instability}$
South	0.89 to 4.6	1.86 to 2.71
North	NA	1.62

Probabilities – maximum observed water level

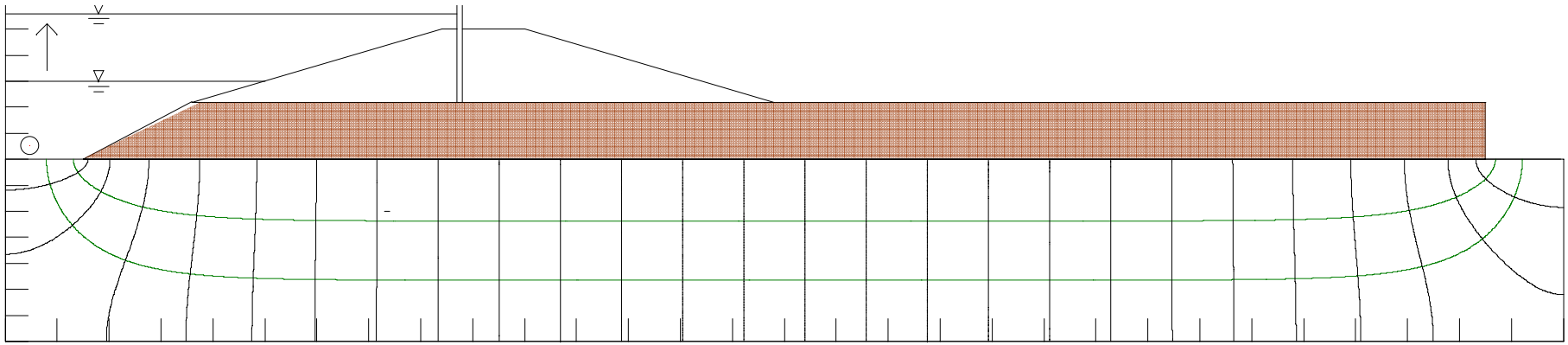
Breach	$P_{erosion}$	$P_{instability}$
South	3% to 28%	Less than 10^{-6}
North	NA	Less than 1%

Orleans Canal



Model test plan

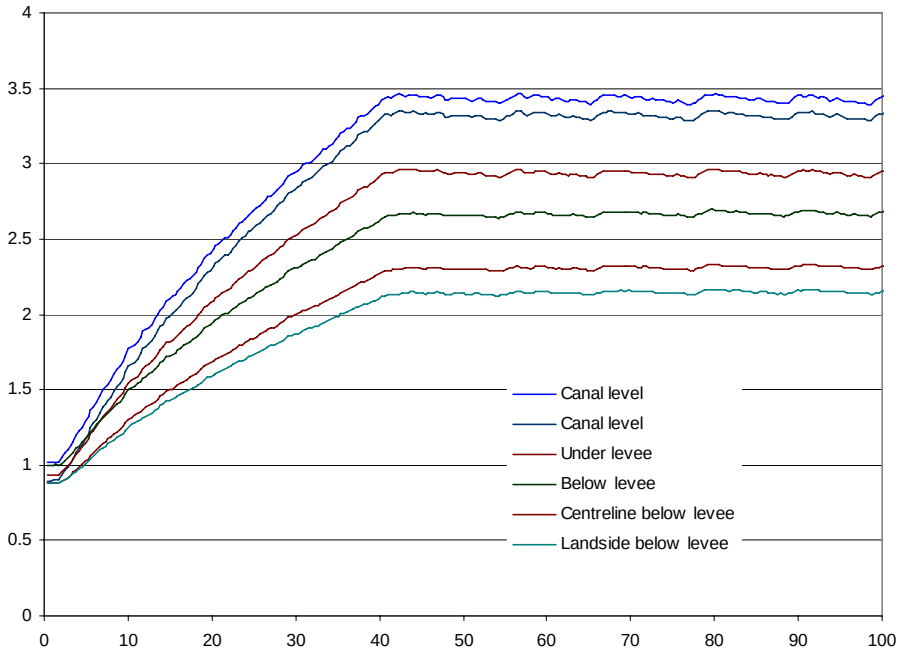
- Stage 1: Raise water to Katrina level and wait
- Stage 2: Raise water to top of wall and wait

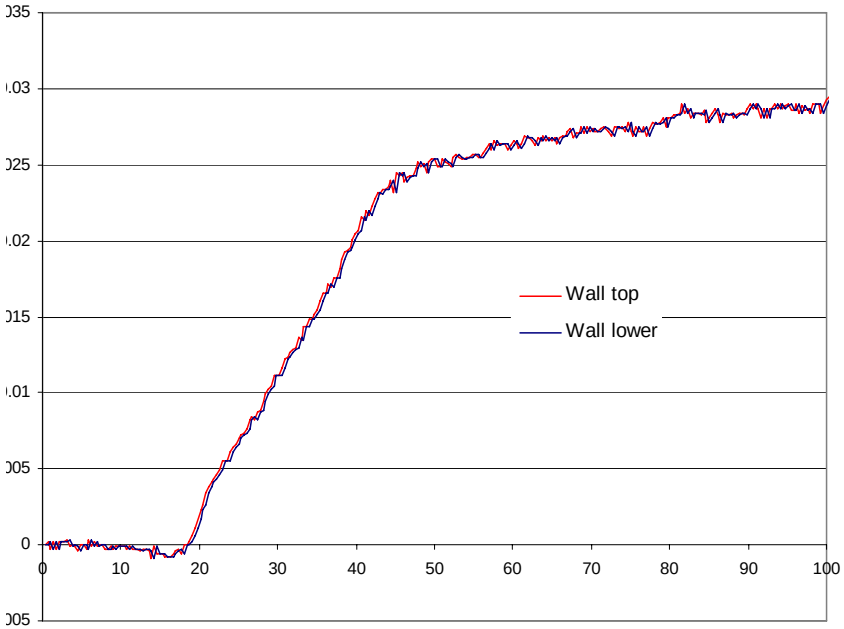


Orleans Canal – Stage 1

Orleans Canal – end Stage 1

Orleans Canal – end Stage 1

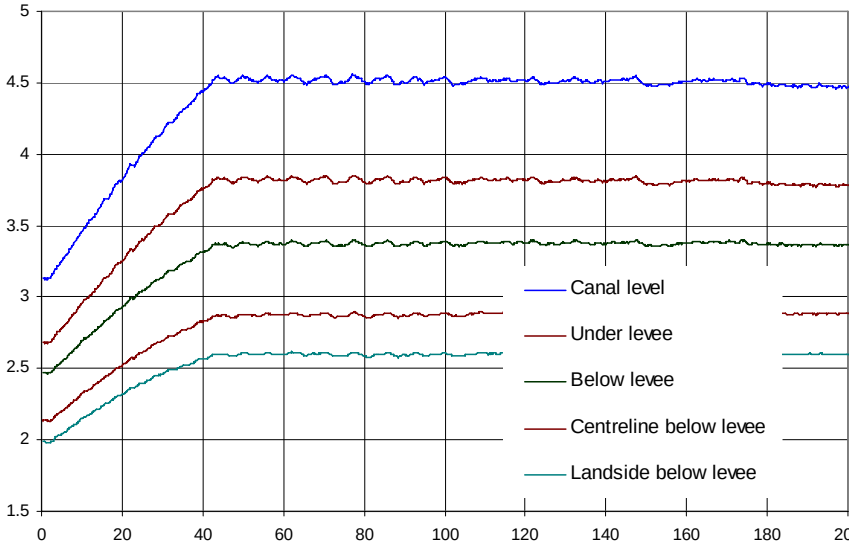


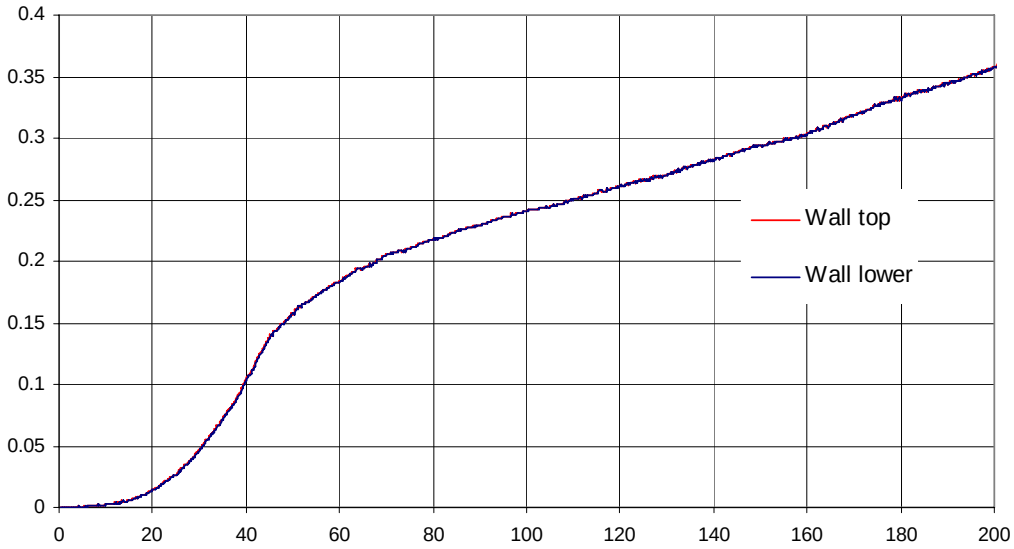


Piezometric levels under the canal side levee berm rise as water rises in the canal, (RPI Orleans Canal). Movement of the wall very small.

Orleans Canal – Stage 2

Orleans Canal – end of Stage 2



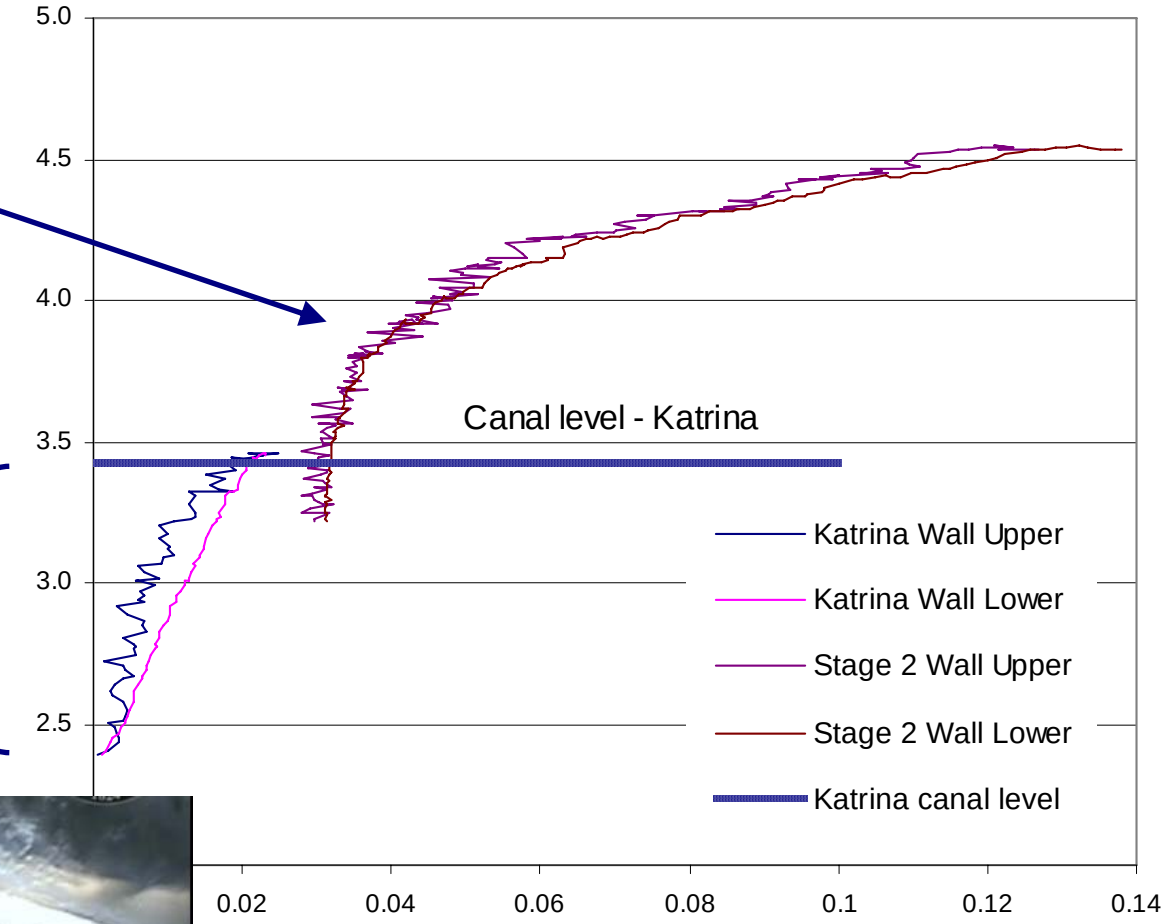


Piezometric levels under the canal side levee berm rise again as water rises to the top of the wall in the canal, (RPI Orleans Canal). Movement of the wall ten times greater small.

Orleans Canal – crack formation

Reduction of stiffness indicative of crack formation with canal 0.5m above Katrina level

Katrina loading

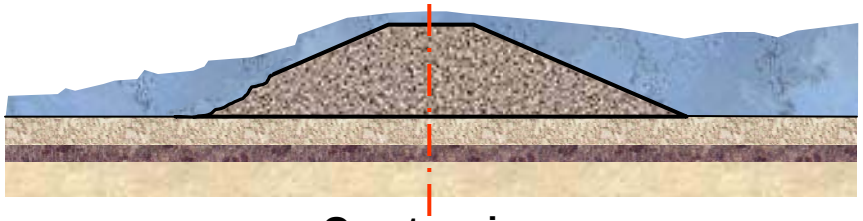


Loading of wall leads to crack formation in translation at canal levels above Katrina levels, wall remains stable at maximum water level

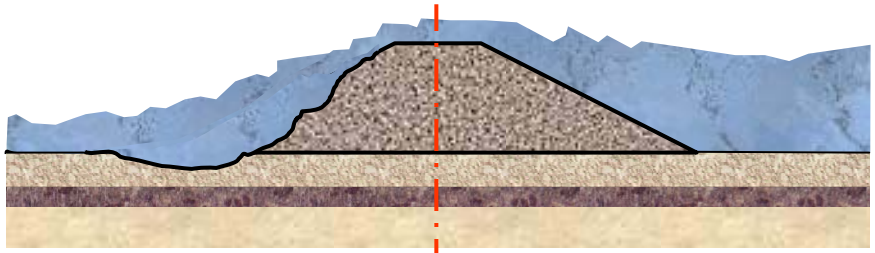
Performance

Performance

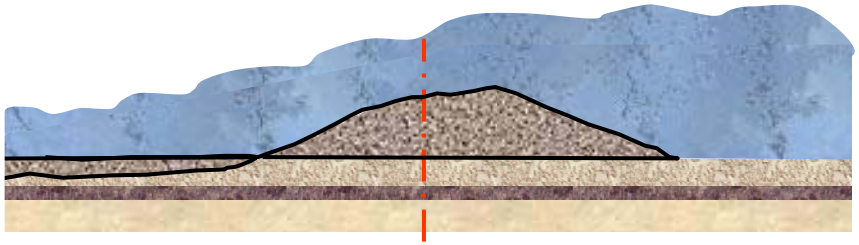
Levee Scour and Erosion Breach Analysis



Overtopping



Scour



Erosion

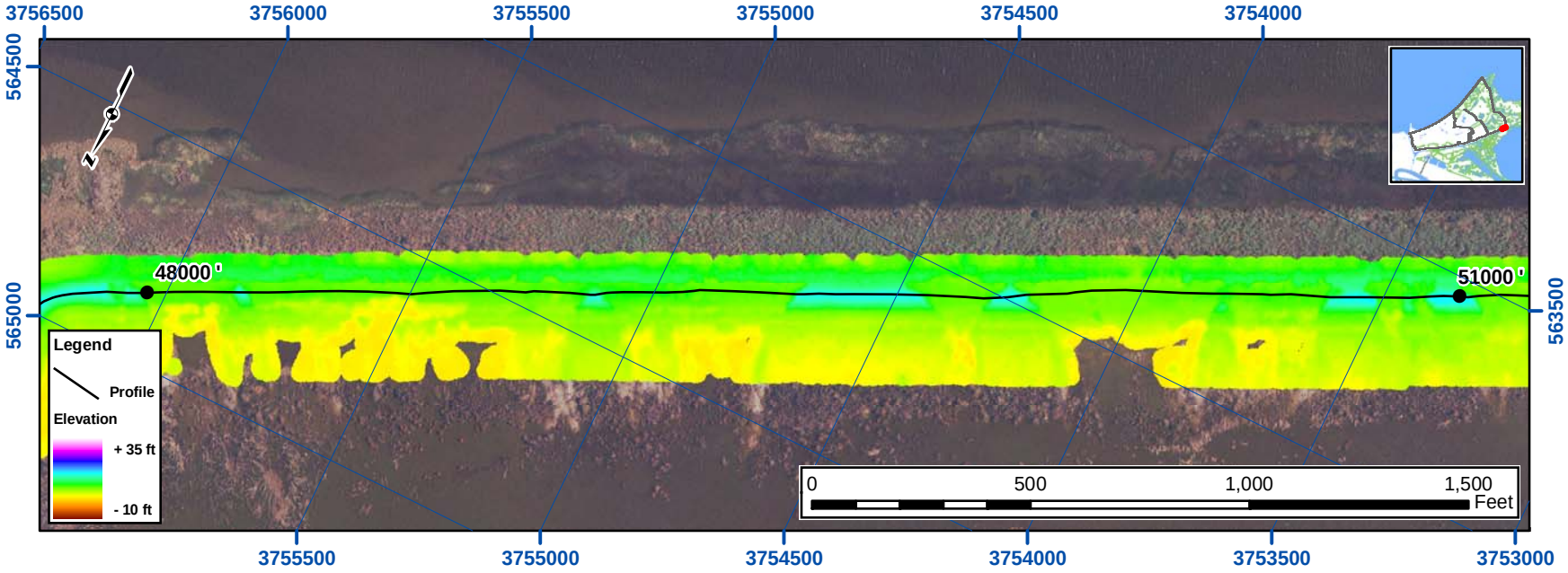
Levee Scour and Erosion Breach Mechanism

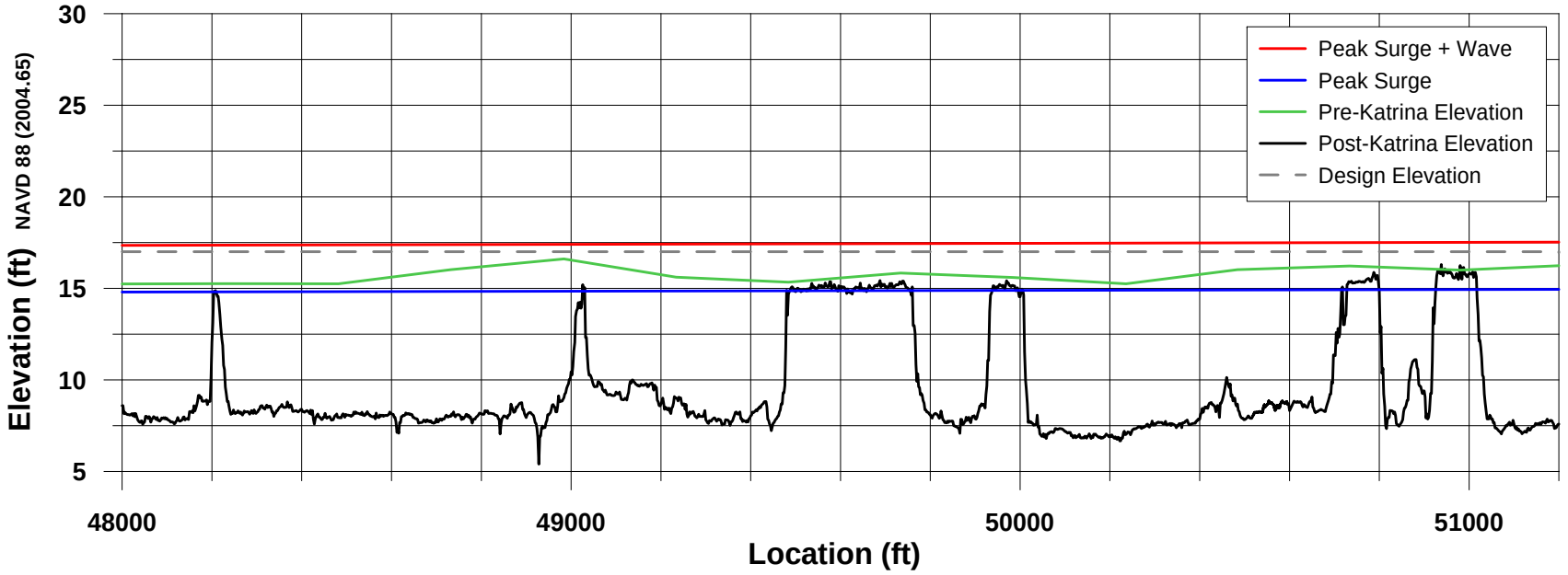
- **Overtopping by surge and waves**
- **Hydraulically filled levees**
  - **High silt and sand content in the levee**
- **Water flowing over the levee causes scour and erosion of levee**

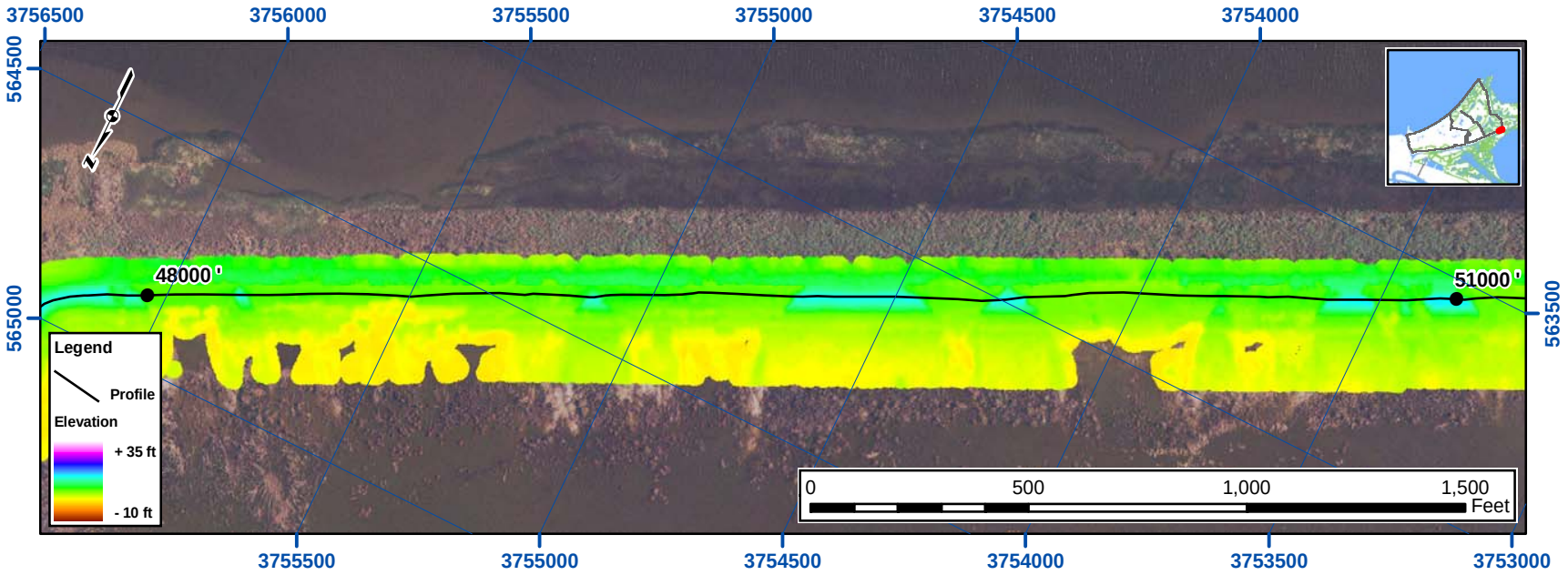

New Orleans East
N
W
E
S
Legend
Levee Footprint
Levee Breaches
1 0.5 0 1 2
Miles

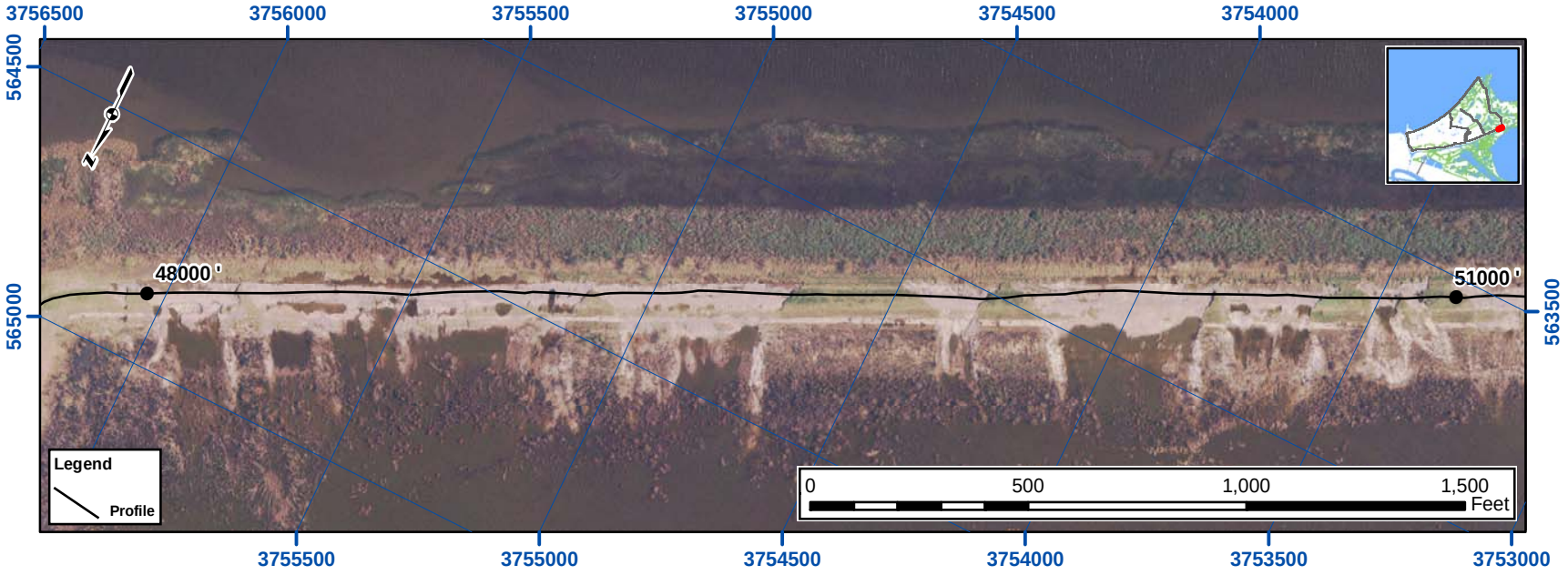

Legend
Levee Footprint
Hydraulic Fill
Hauled Fill
1 0.5 0 1 2
Miles

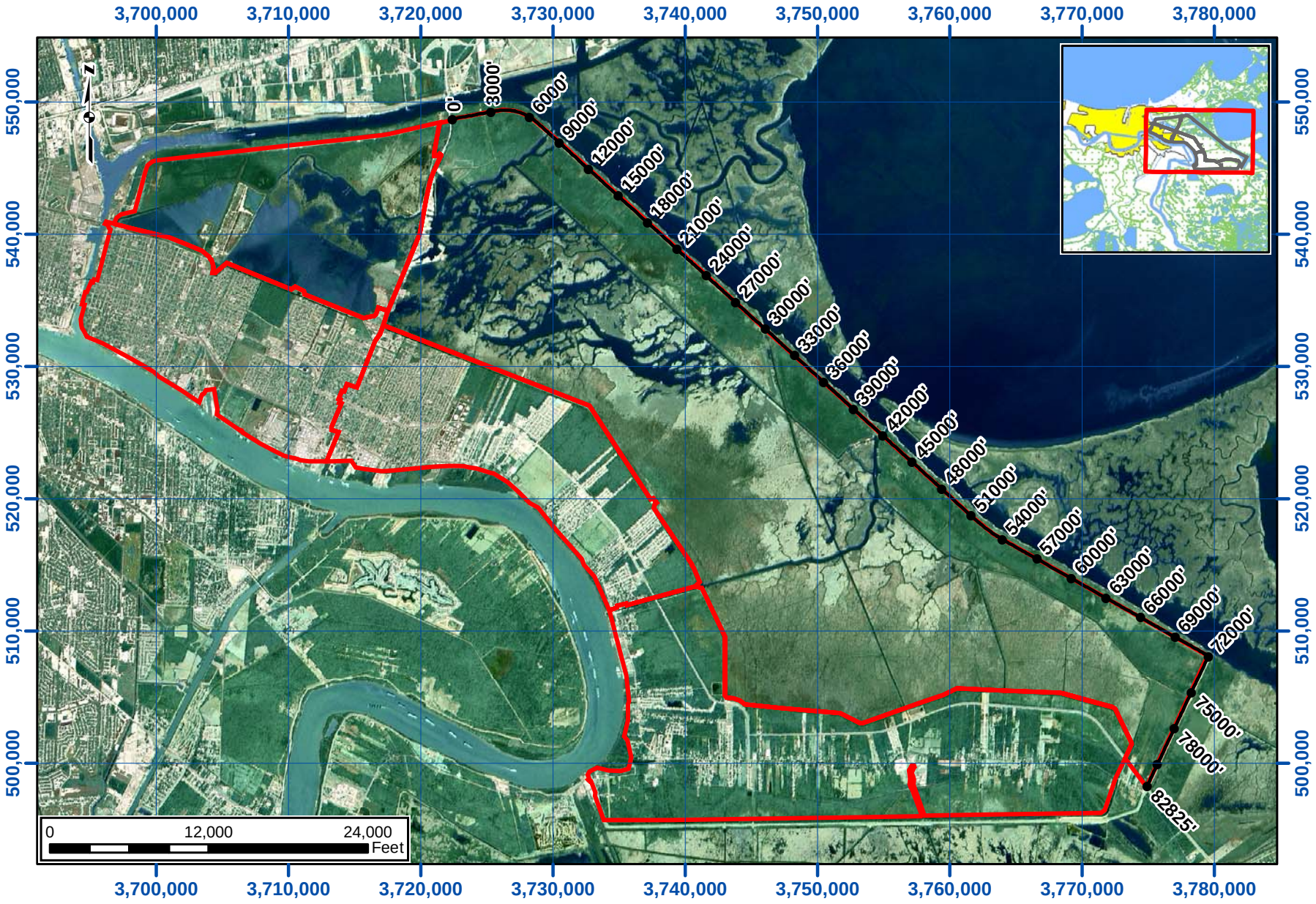

3,690,000
3,700,000
3,710,000
3,720,000
3,730,000
3,740,000
3,750,000
3,760,000
3,770,000
600,000
590,000
580,000
570,000
560,000
550,000
N
0
3000
6000
9000
12000
15000
18000
21000
24000
27000
30000
33000
36000
39000
42000
45000
48000
51000
54000
57000
60000
63000
66000
69000
72000
75000
81000
90000
93000
96000
99000
0
12,000
24,000
Feet

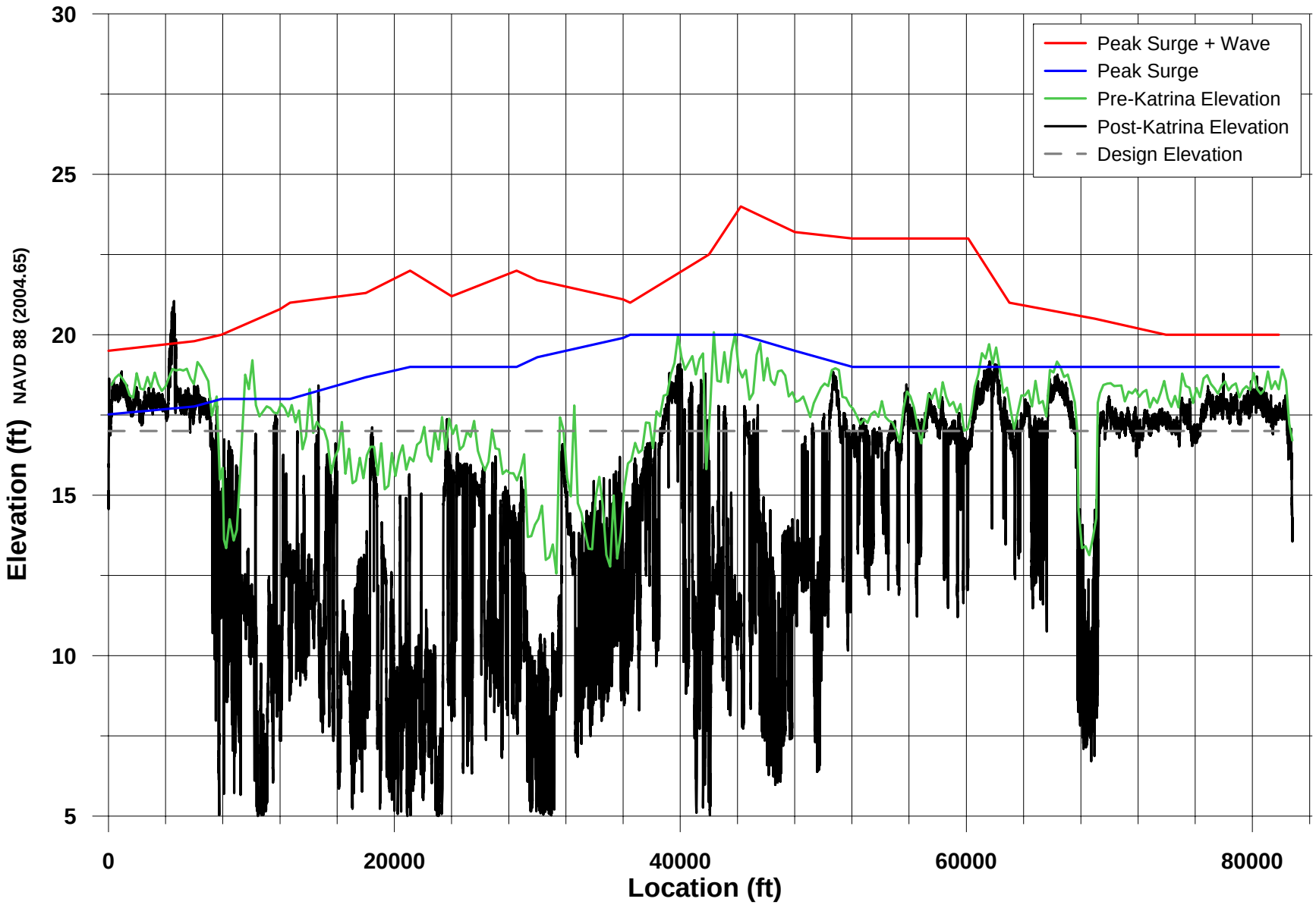

3756500
3756000
3755500
3755000
3754500
3754000
564500
565000
563500
48000 '
51000 '
Legend
Profile
Elevation
+ 35 ft
- 10 ft
0
500
1,000
1,500
Feet
3755500
3755000
3754500
3754000
3753500
3753000

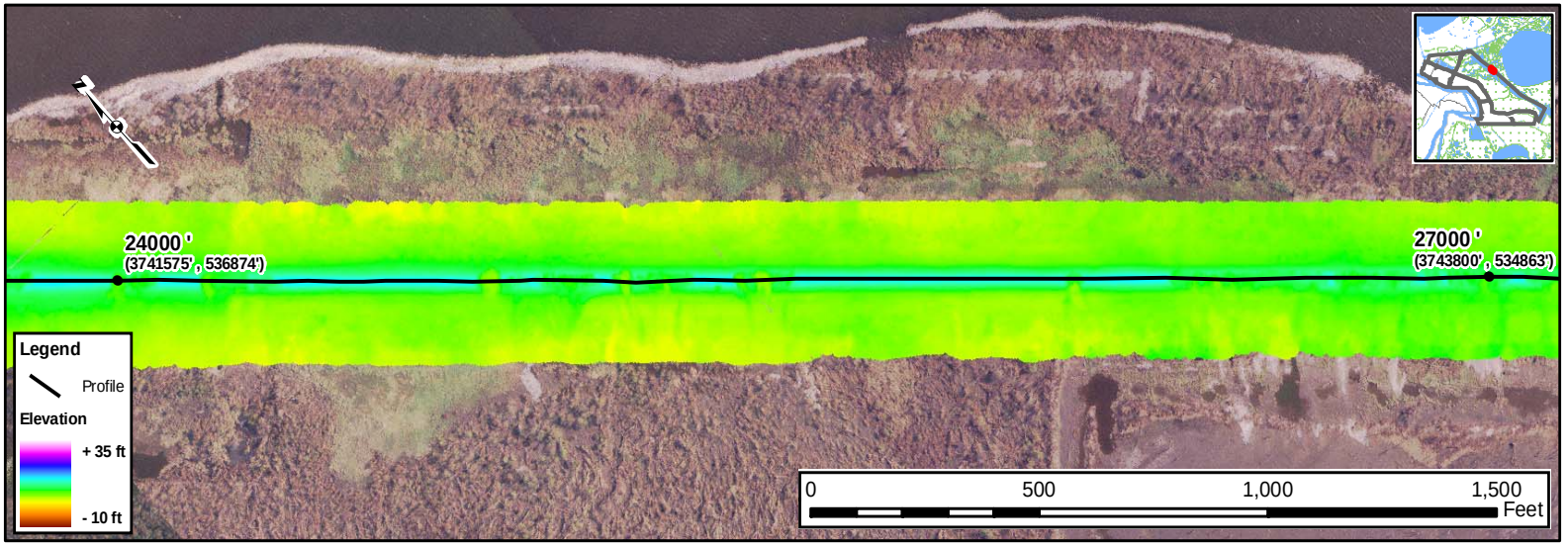

30
25
20
15
10
5
NAVD 88 (2004.65)
Elevation (ft)
Peak Surge + Wave
Peak Surge
Pre-Katrina Elevation
Post-Katrina Elevation
Design Elevation
48000
49000
50000
51000
Location (ft)

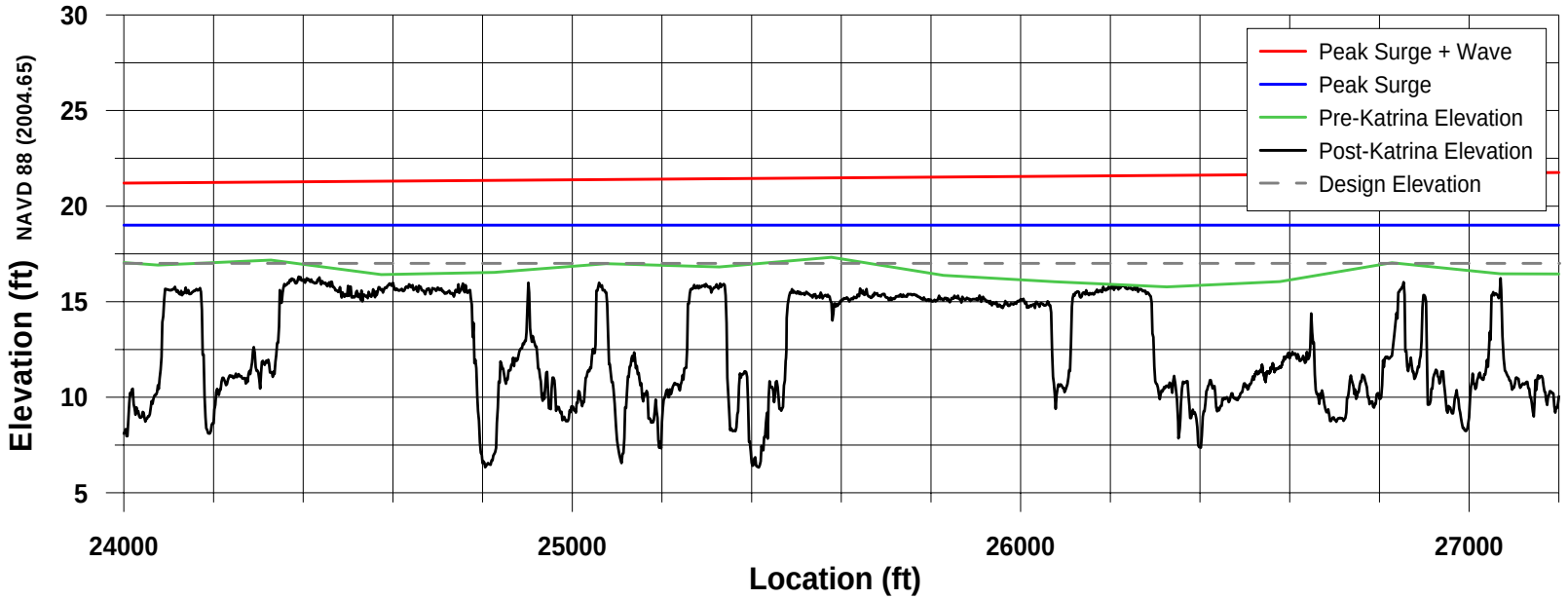

3756500
3756000
3755500
3755000
3754500
3754000
564500
565000
563500
48000 '
51000 '
Legend
Profile
Elevation
+ 35 ft
- 10 ft
0
500
1,000
1,500
Feet
3755500
3755000
3754500
3754000
3753500
3753000

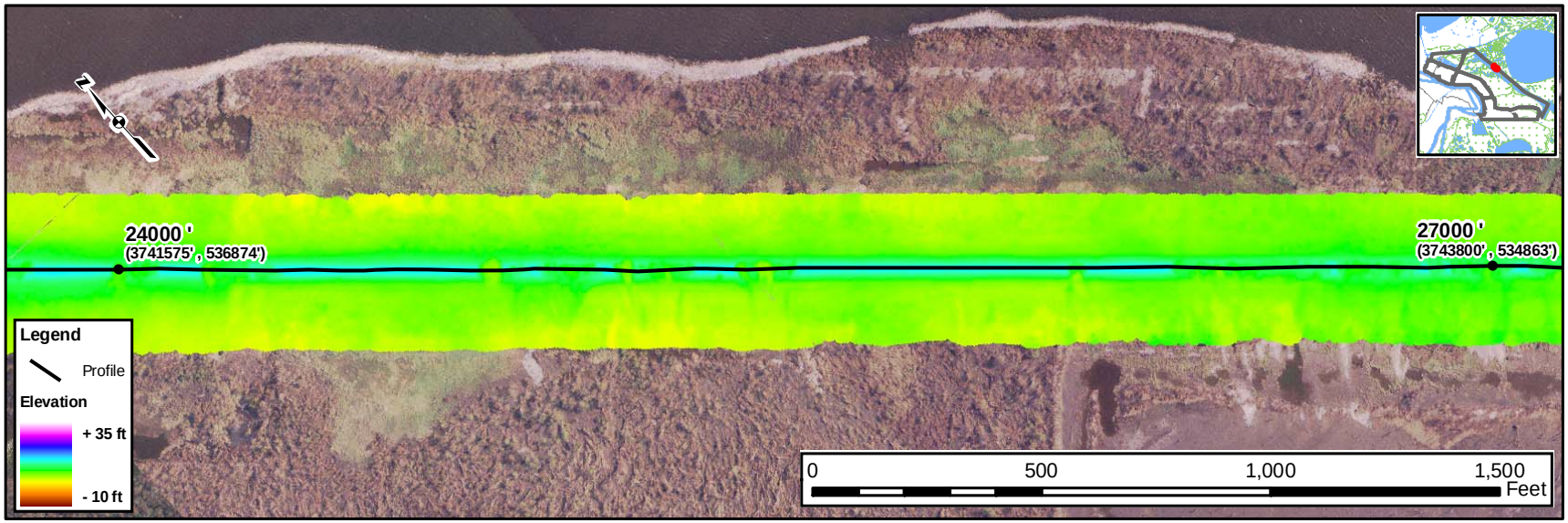

3756500
3756000
3755500
3755000
3754500
3754000
564500
565000
563500
48000 '
51000 '
Legend
Profile
0
500
1,000
1,500
Feet
3755500
3755000
3754500
3754000
3753500
3753000

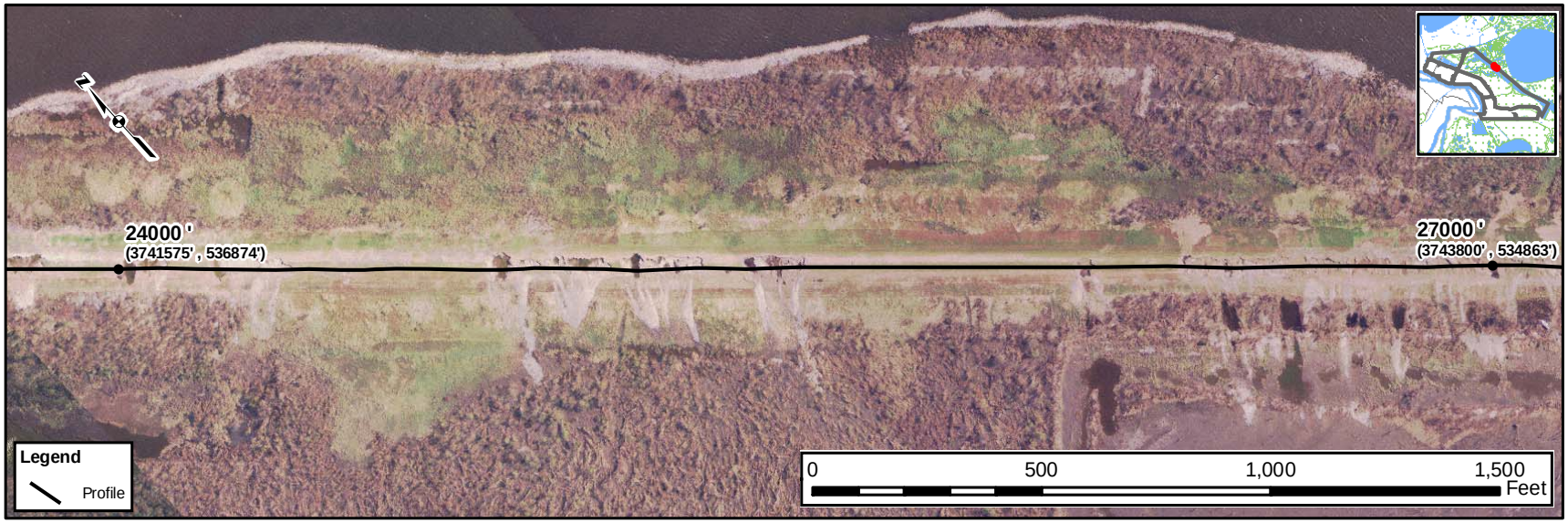

3,700,000
3,710,000
3,720,000
3,730,000
3,740,000
3,750,000
3,760,000
3,770,000
3,780,000
550,000
540,000
530,000
520,000
510,000
500,000
N
0'
3000'
6000'
9000'
12000'
15000'
18000'
21000'
24000'
27000'
30000'
33000'
36000'
39000'
42000'
45000'
48000'
51000'
54000'
57000'
60000'
63000'
66000'
69000'
72000'
75000'
78000'
82825'
0
12,000
24,000
Feet


Peak Surge + Wave
Peak Surge
Pre-Katrina Elevation
Post-Katrina Elevation
Design Elevation
Elevation (ft) NAVD 88 (2004.65)
30
25
20
15
10
5
0
20000
40000
60000
80000
Location (ft)


24000 '
(3741575', 536874')
27000 '
(3743800', 534863')
Legend
Profile
Elevation
+ 35 ft
- 10 ft
0
500
1,000
1,500
Feet

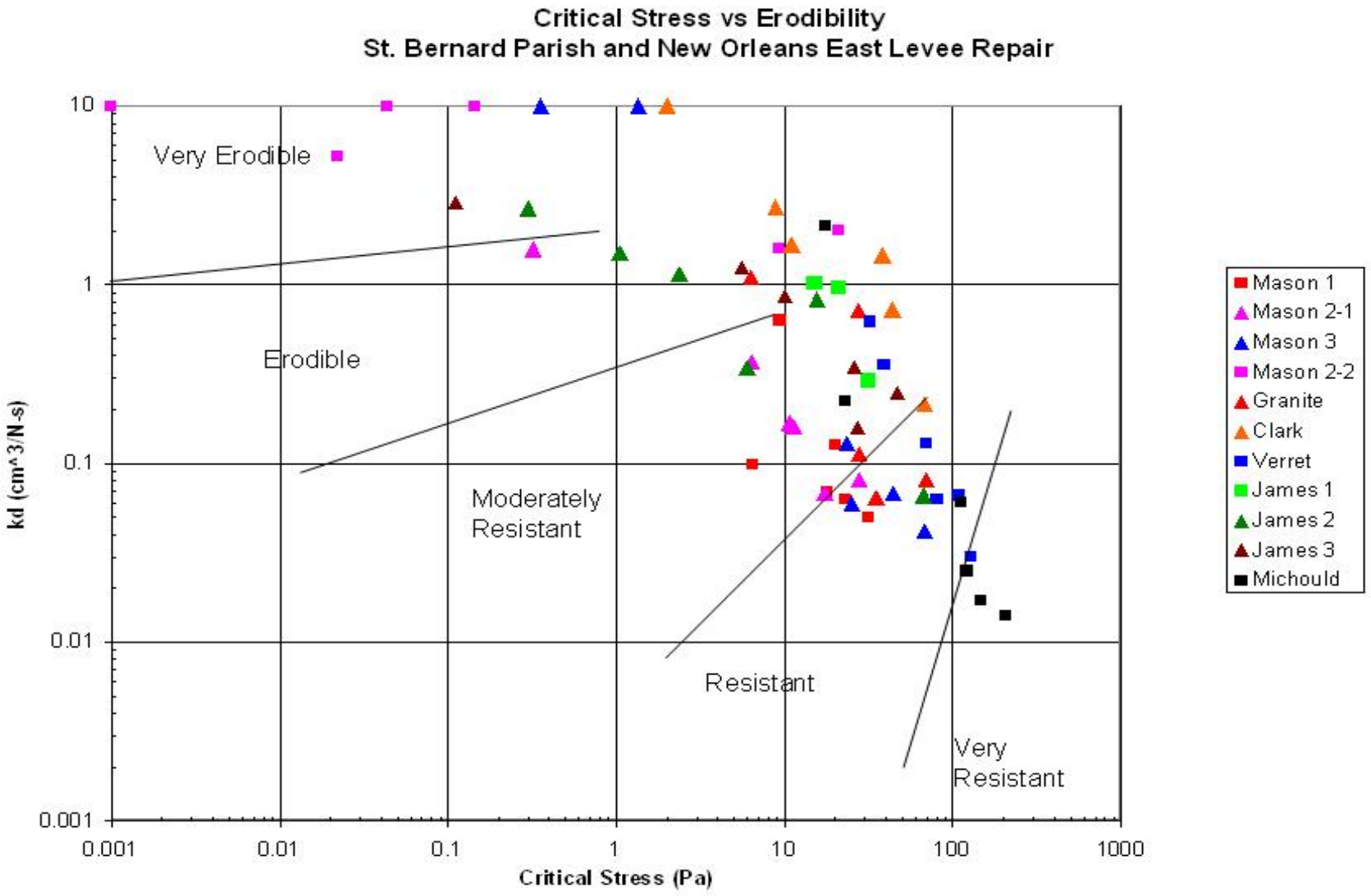

Elevation (ft) NAVD 88 (2004.65)
30
25
20
15
10
5
24000
25000
26000
27000
Location (ft)
Peak Surge + Wave
Peak Surge
Pre-Katrina Elevation
Post-Katrina Elevation
Design Elevation


N
24000 '
(3741575', 536874')
27000 '
(3743800', 534863')
Legend
Profile
Elevation
+ 35 ft
- 10 ft
0
500
1,000
1,500
Feet


N
24000 '
(3741575', 536874')
27000 '
(3743800', 534863')
Legend
Profile
0
500
1,000
1,500
Feet

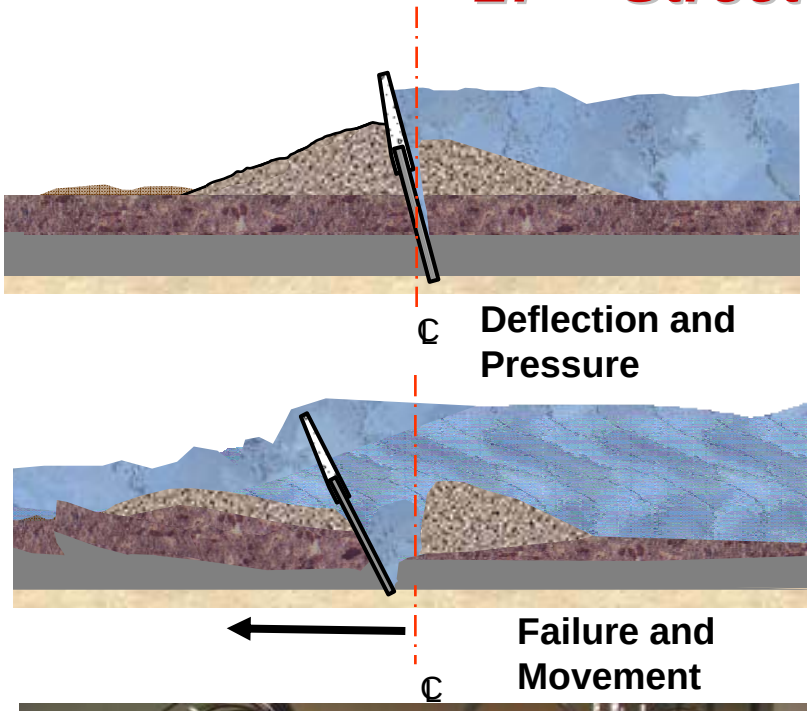
Field Erosion Jet Tests

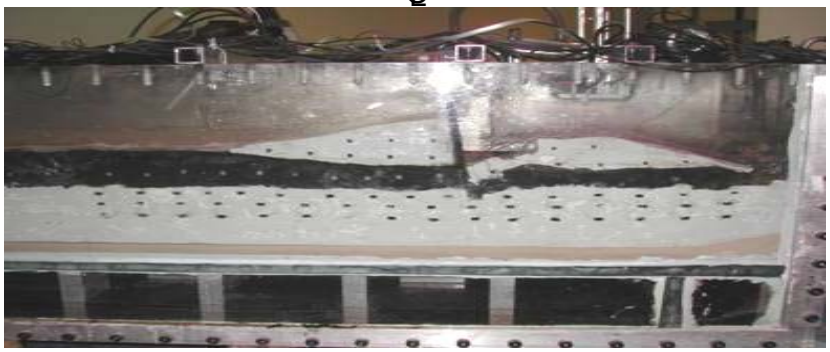
Jet Test Apparatus Set in Place


Critical Stress vs Erodibility
St. Bernard Parish and New Orleans East Levee Repair
Very Erodible
Erodible
Moderately Resistant
Resistant
Very Resistant
kd (cm^3/N-s)
Critical Stress (Pa)
10
1
0.1
0.01
0.001
0.001
0.01
0.1
1
10
100
1000
Mason 1
Mason 2-1
Mason 3
Mason 2-2
Granite
Clark
Verret
James 1
James 2
James 3
Michould

Performance

17th Street Canal Breach Analysis





Confirmation in Centrifuge

17th Street Canal Breach Mechanism

- Deflection of I–wall by surge/waves
- Full hydrostatic pressure along wall splits levee into two blocks
- Weaker clay at levee toe causes failure in subsurface clay layer
- Soil block from wall back displaced

Displacement of wall and part of levee

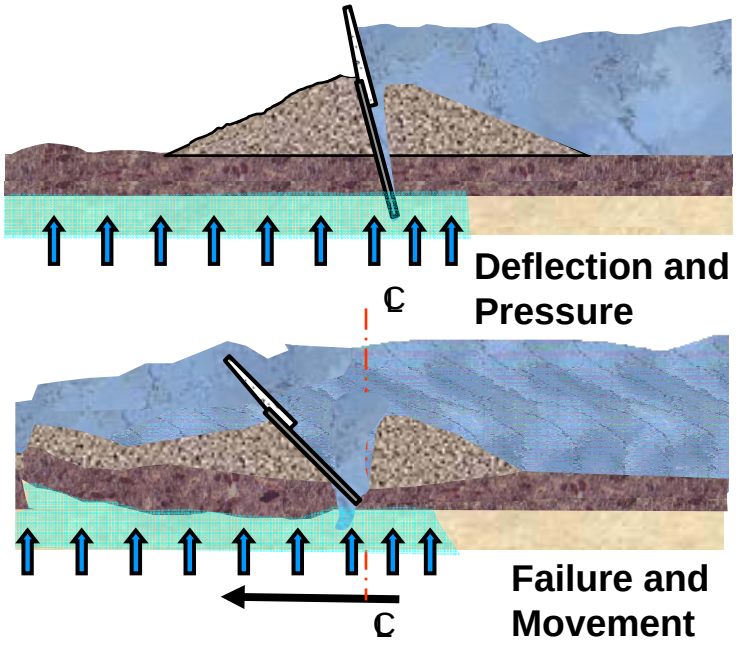
Findings and Lessons Learned

17th Street Canal Breach

- **Failure Mechanisms:**
  - Gap formation between the wall and levee soil adjacent to canal side of the wall
  - Variation in shear strength from the levee crest to the toe and beyond
- **Lessons Learned:**
  - Consider the vertical and horizontal variation in shear strength throughout the critical cross sections
  - Assume that the gap will occur and design the walls and levees to ensure that they are stable
    - Increase the levee toe footprint
    - Add stability berms

Performance

London Ave. Canal North Breach Analysis



Confirmation in Centrifuge

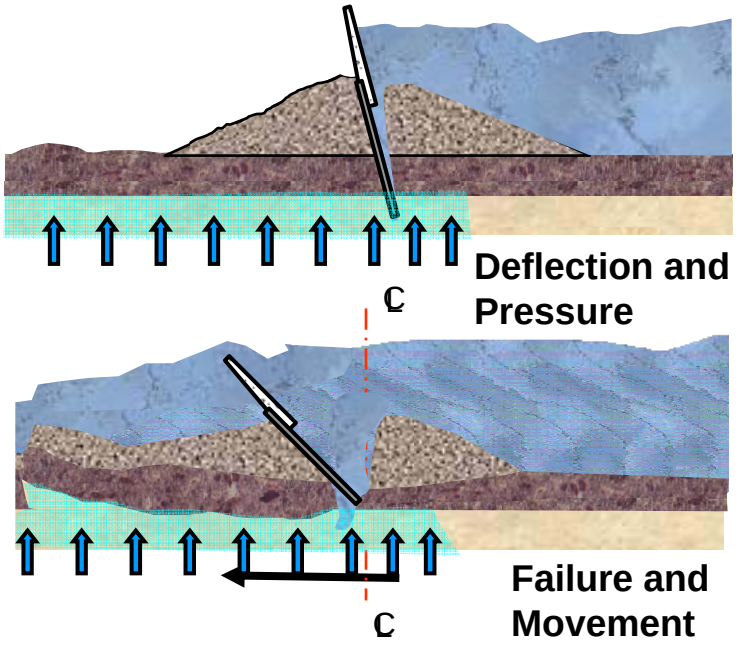
London Ave. Canal North Breach Mechanism

- Deflection of I–wall by surge/waves
- Full hydrostatic pressure along wall splits levee into two blocks and increases pore pressures in underlying sand layer
- High pore pressures cause loss of shear strength in underlying sand layer, leading to sliding instability
- Levee and I-wall displaces laterally

Displacement of wall levee

Performance

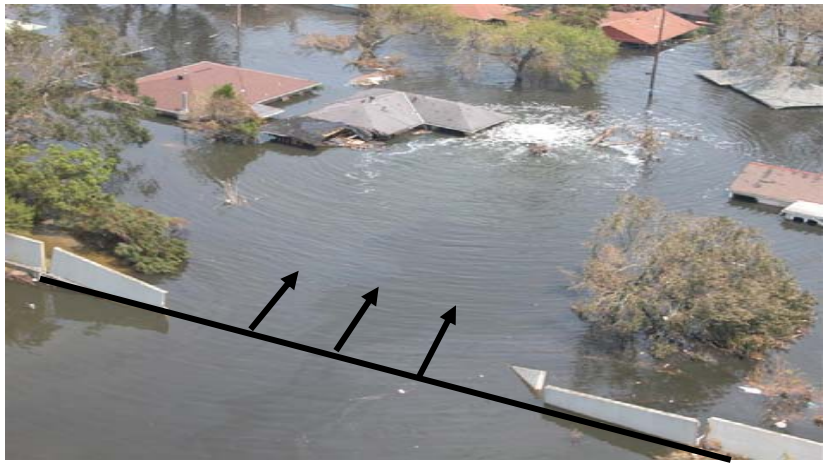
London Ave. Canal South Breach Analysis



Confirmation in Centrifuge

London Ave. Canal South Breach Mechanism

- Deflection of I–wall by surge/waves
- Full hydrostatic pressure along wall splits levee into two blocks and increases pore pressures in underlying sand layer
- High pore pressures cause piping and erosion at the toe, leading to loss of shear resistance
- Levee and I-wall displaces laterally



Displacement of wall levee

Findings and Lessons Learned

London Avenue Canal Breaches:

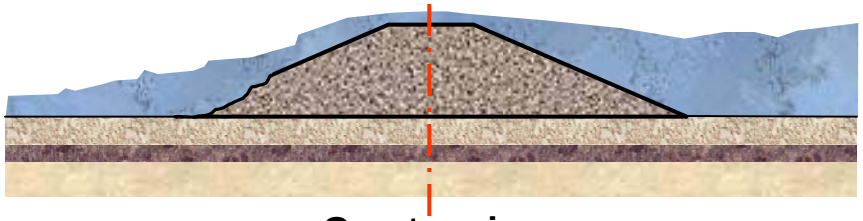
- **Failure Mechanisms:**
  - Gap formation between the wall and levee soil adjacent to canal side
  - Uplift pressures on the base of the levee and the marsh layer led to instability of the I-walls and levees
- **Lessons Learned:**
  - Assume that the gap will occur and design the walls and levees to ensure that they are stable
    - Increase the levee toe footprint
    - Add stability berms
  - Control the underseepage
    - Relief wells
    - Seepage cutoff walls
    - Seepage berms

Performance

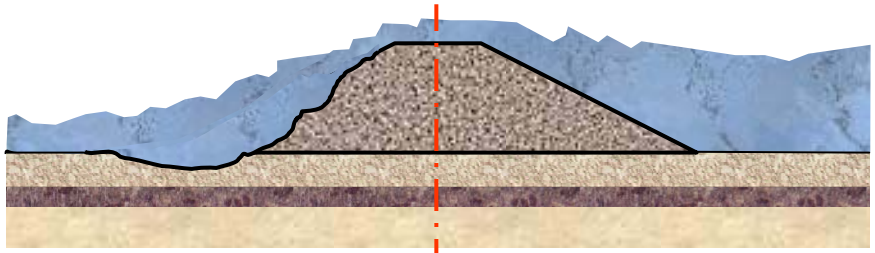
Performance

Levee Scour and Erosion Breach Analysis

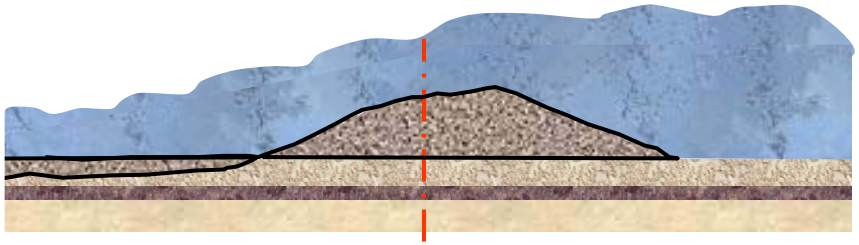
Levee Scour and Erosion Breach Mechanism



Overtopping



Scour



Erosion

- Overtopping by surge and waves
- High silt and sand content in the levee
- Water flowing over the levee causes scour and erosion of levee

Findings and Lessons Learned

Levee Scour and Erosion:

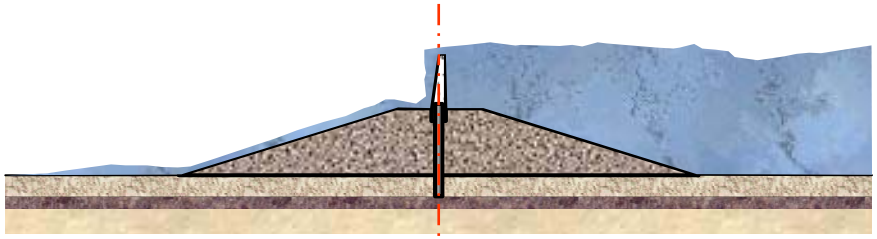
- **Failure Mechanisms:**
  - Overtopping from surge and waves
  - Hydraulically filled levees
    - High content of silts and sands
- **Lessons Learned:**
  - Need to assess the erodibility of the emplace levee materials
  - Avoid silts and sands and hydraulic fills for levee construction
  - Increase the compaction effort for levee materials

Performance

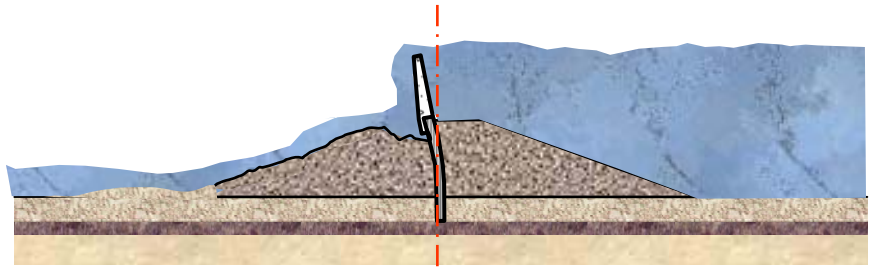
I-wall Scour and Erosion Breach Analysis

I-wall Scour and Erosion Breach Mechanism

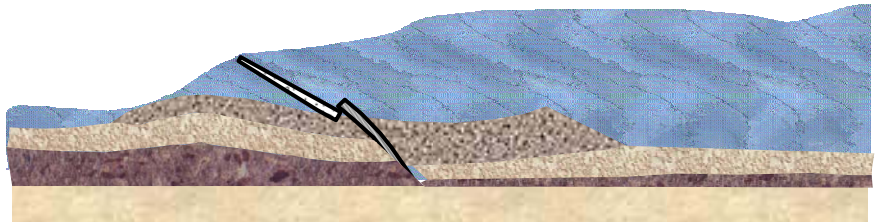
- Overtopping by surge and waves
- Water flowing over the wall causes scour and erosion of levee



Overtopping ℄



Scour ℄



Erosion

Inner Harbor Navigation Canal Breaches

Findings and Lessons Learned

I-Wall Scour and Erosion:

- **Failure Mechanisms:**
  - Overtopping from surge and waves
  - Erosion of the protective side levee embankment adjacent to the wall
- **Lessons Learned:**
  - Provide an erosion-resistant surface on the levee adjacent to the wall on the protected side

ESSAYONS!

Any Questions?