Structural, Material, and Geotechnical Solutions to Levee and Floodwall Construction and Retrofitting

Southeast Region Research Initiative (SERRI)

Semi-Annual Project Review

September 16, 2008, Jackson, MS

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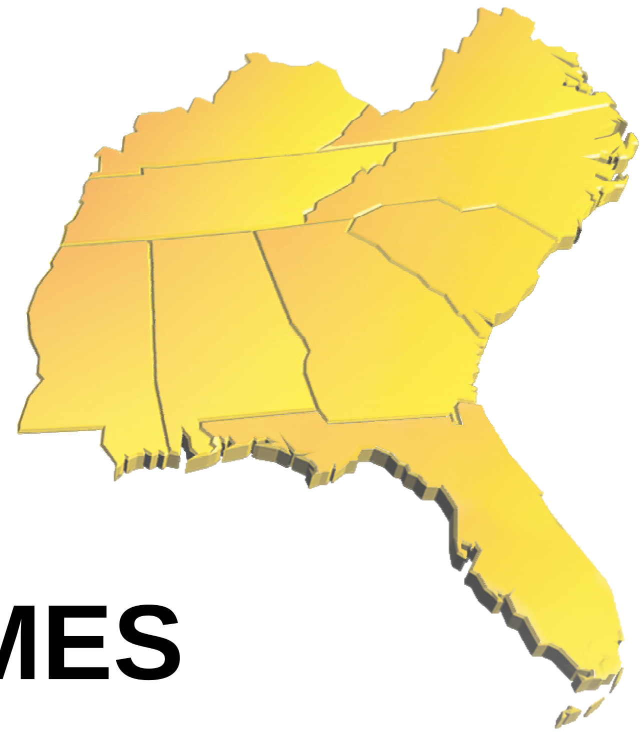
PROJECT DESCRIPTION

Purpose of Project

- To find geotechnical, structural, and material solutions for the retrofitting and new design of floodwall and levee systems.
  - Innovative
  - Practical
  - Affordable
  - Resilient

PROJECT OUTCOMES



Outcomes

- Geotechnical solutions: Improved floodwall section design to prevent overturning, pile foundation support, clay and bentonite apron to reduce the seepage, and levee back side protection to minimize erosion.
- Structural solutions: Lateral bracing to increase the lateral stiffness, cross-sectional design to increase the bending stiffness of the sheet piles to minimize deflection.
- Material solutions: Lighter, stronger, and non-corrosive materials to improve the performance of the system in terms of strength, durability, and resistance to sabotage.

Relevance to DHS S&T Objectives

- The proposed research addresses the *Structural Water Management* and the *Natural Disaster Recovery* relevance areas.

Statement

- Through this research, an advanced understanding of the potential material, structure, and geotechnical solutions to the nation’s levee and floodwall systems, will be gained. The technologies developed can be used for a cost effective levee and floodwall retrofitting and new construction program.

LANDSCAPE ASSESSMENT

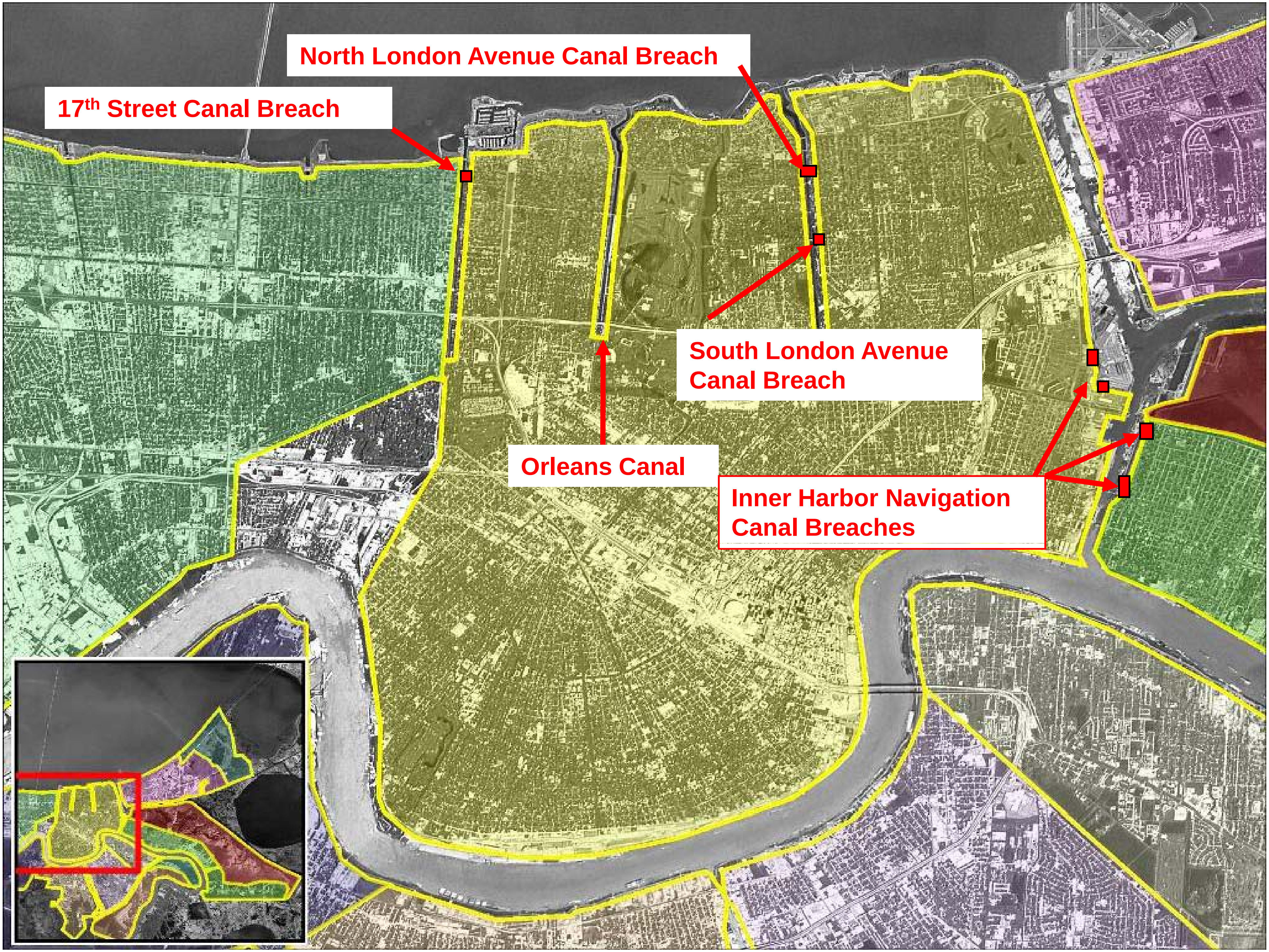
Uniqueness of Project

Previous levee design was focused on the geotechnical failure. Forensic investigation of New Orleans levee failure pointed to a triggering event caused by a slight structural underperformance, leading to a progressive, catastrophic failure of the system. The current research combines the structural, geotechnical, and material technologies to provide resilient solutions for the retrofitting and construction of levee and floodwall systems.

TECHNICAL REVIEW

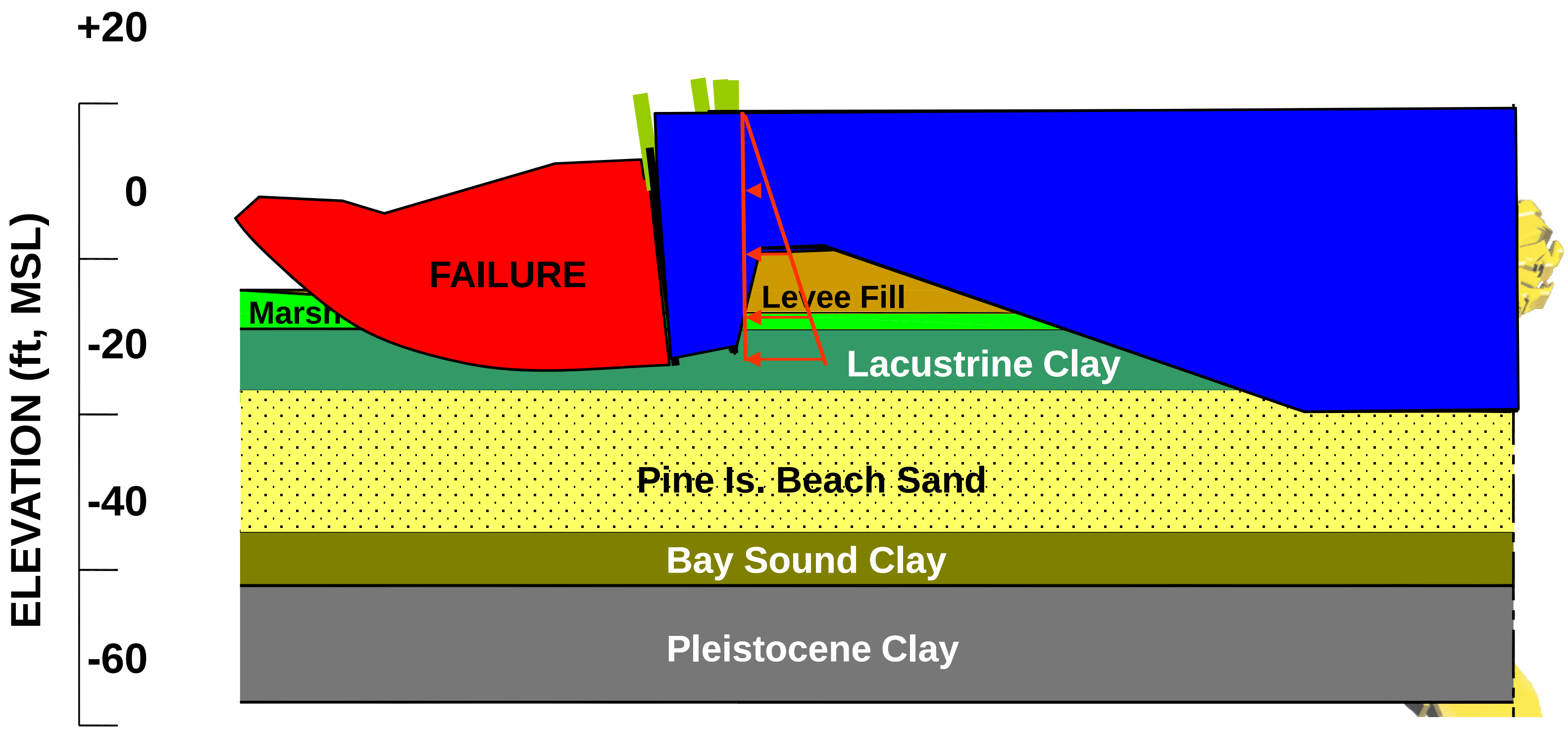

City of New Orleans
Ground Elevations
LAKE PONTCHATRAIN
B
A
NEW ORLEANS
M I S S I S S I P P I R.
From Canal St. at Mississippi River to the Lakefront at U.N.O.
FLOODWALL ALONG MISSISSIPPI RIVER
30
20
10
0
-10
-20
ELEVATIONS IN FEET NGVD
A
23 FT
PROJECT DESIGN FLOWLINE (20 FEET)
20 SEP 05 MISSISSIPPI RIVER ELEVATION (3.5 FEET)
LONDON AVENUE CANAL FLOODWALL
HURRICANE LEVEE / FLOODWALL (14.0 FEET)
INTERIM LEVEL PROTECTION (10.0 FEET)
20 SEP 05 LEVEL PROTECTION (5.0 FEET)
B
20 SEP 05 LAKE ELEVATION (1.5 FEET)
MISSISSIPPI RIVER BANK
CANAL ST AT RIVER
ST. LOUIS CATHEDRAL
ESPLANADE AT ST. CLAUDE
DERBIGNY AT I-10
GENTILLY BLVD AT ALLEN
DILLARD UNIV CAMPUS
ST. ANTHONY AT WILDAIR DR
WAINRIGHT DR AT L.C. SIMON
UNO SIDE OF WAINRIGHT DR
LAKE PONTCHARTRAIN SHORE

The Threat Is Not Over


North London Avenue Canal Breach
17th Street Canal Breach
South London Avenue
Canal Breach
Orleans Canal
Inner Harbor Navigation
Canal Breaches

FAILURE MODE 1: HYDROSTATIC PRESSURE

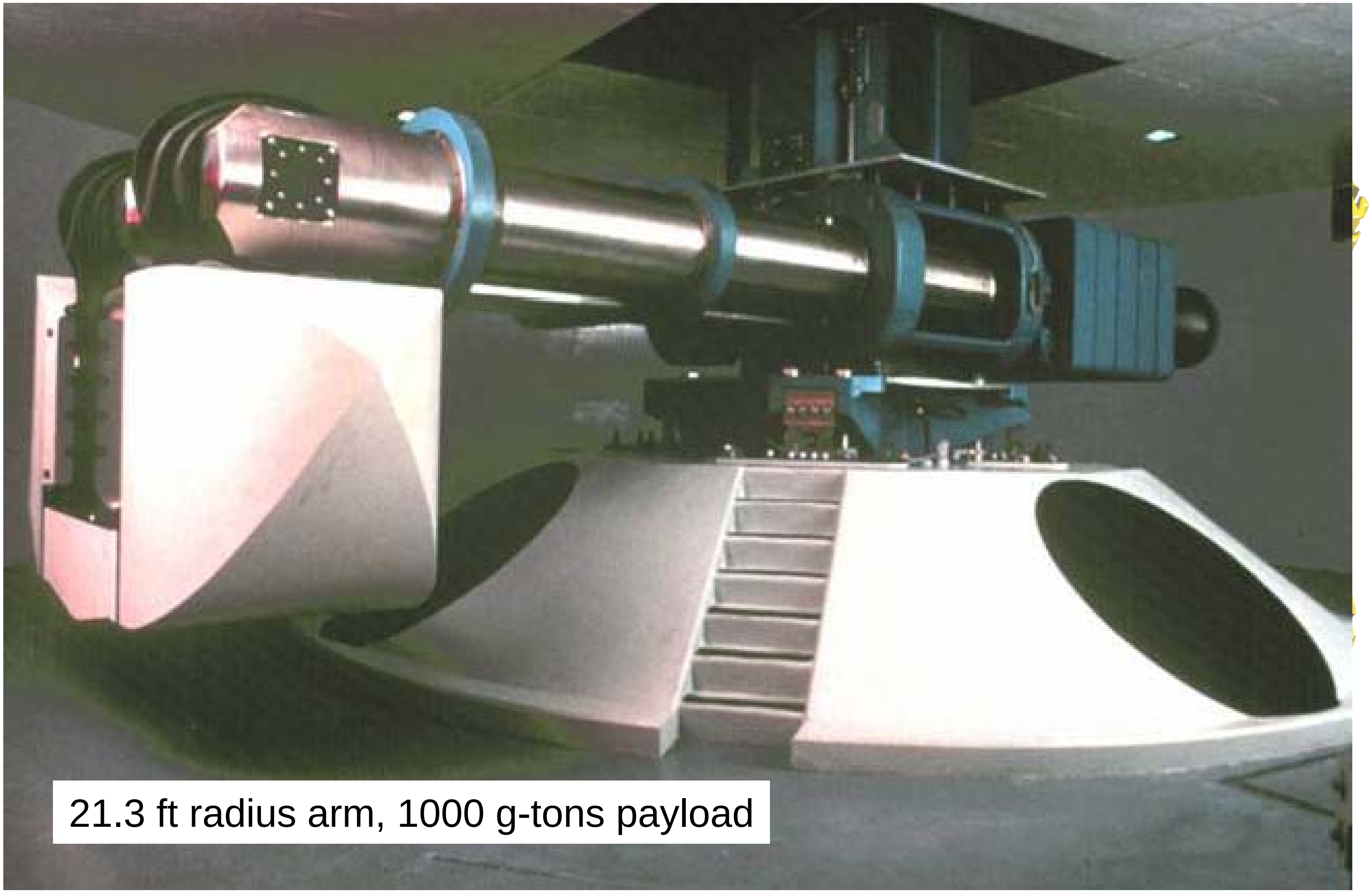
17^{th} Street Canal Breach



17th Street Canal Breach


Gap located
next to the
floodwall on
the flood side

Centrifuge tests to study failure mechnism

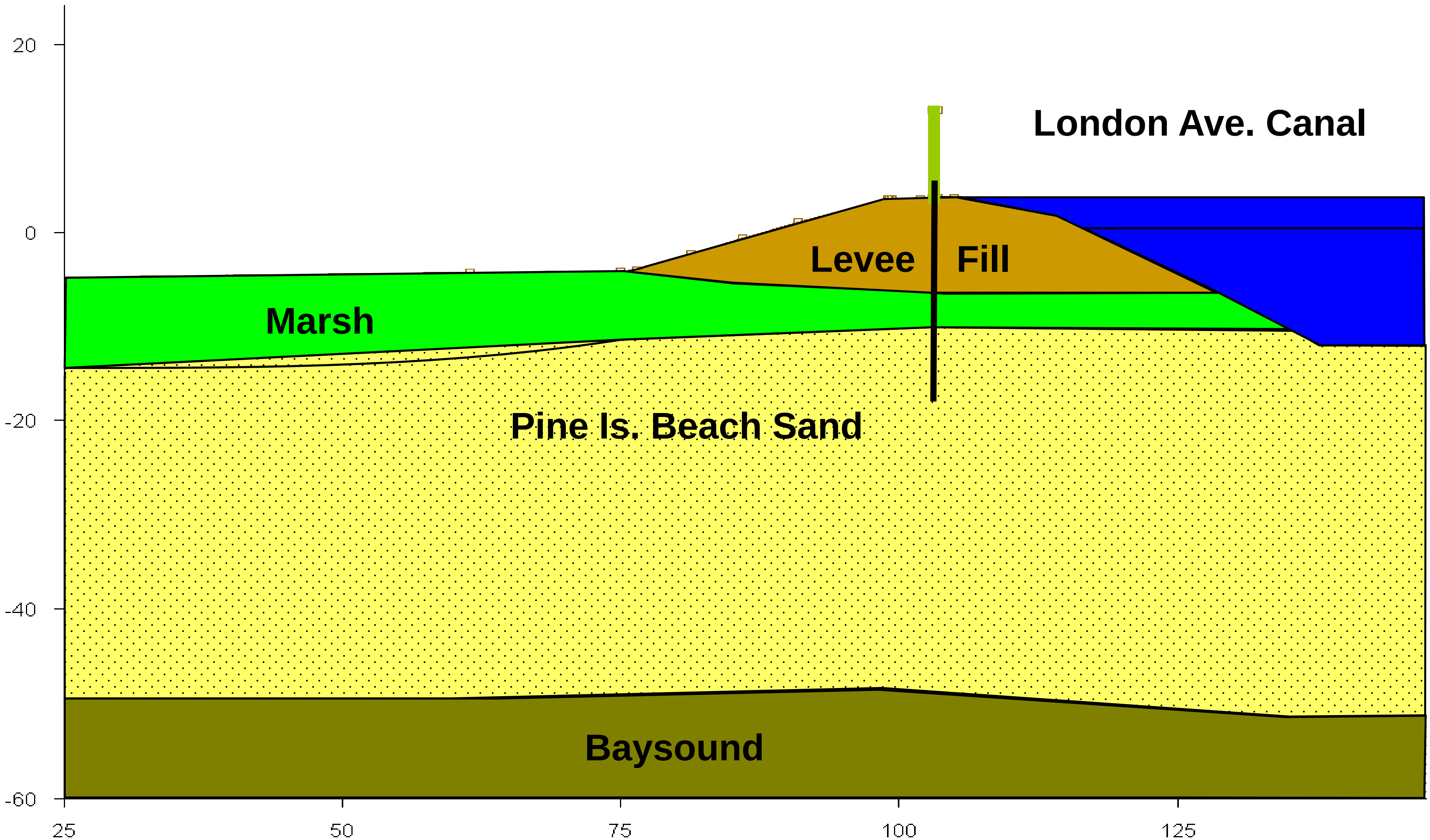


21.3 ft radius arm, 1000 g-tons payload

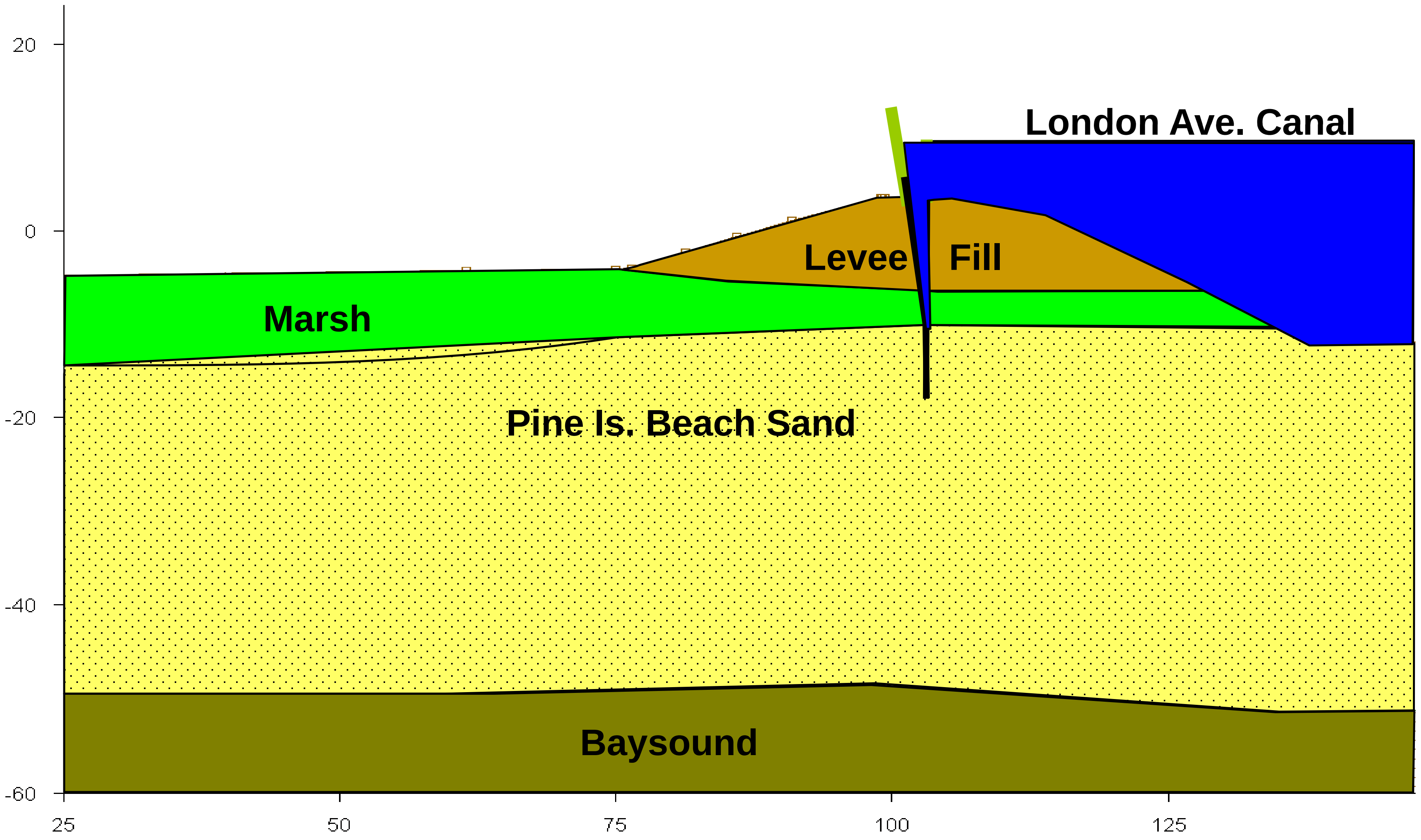
FAILURE MODE 2: SEEPAGE

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

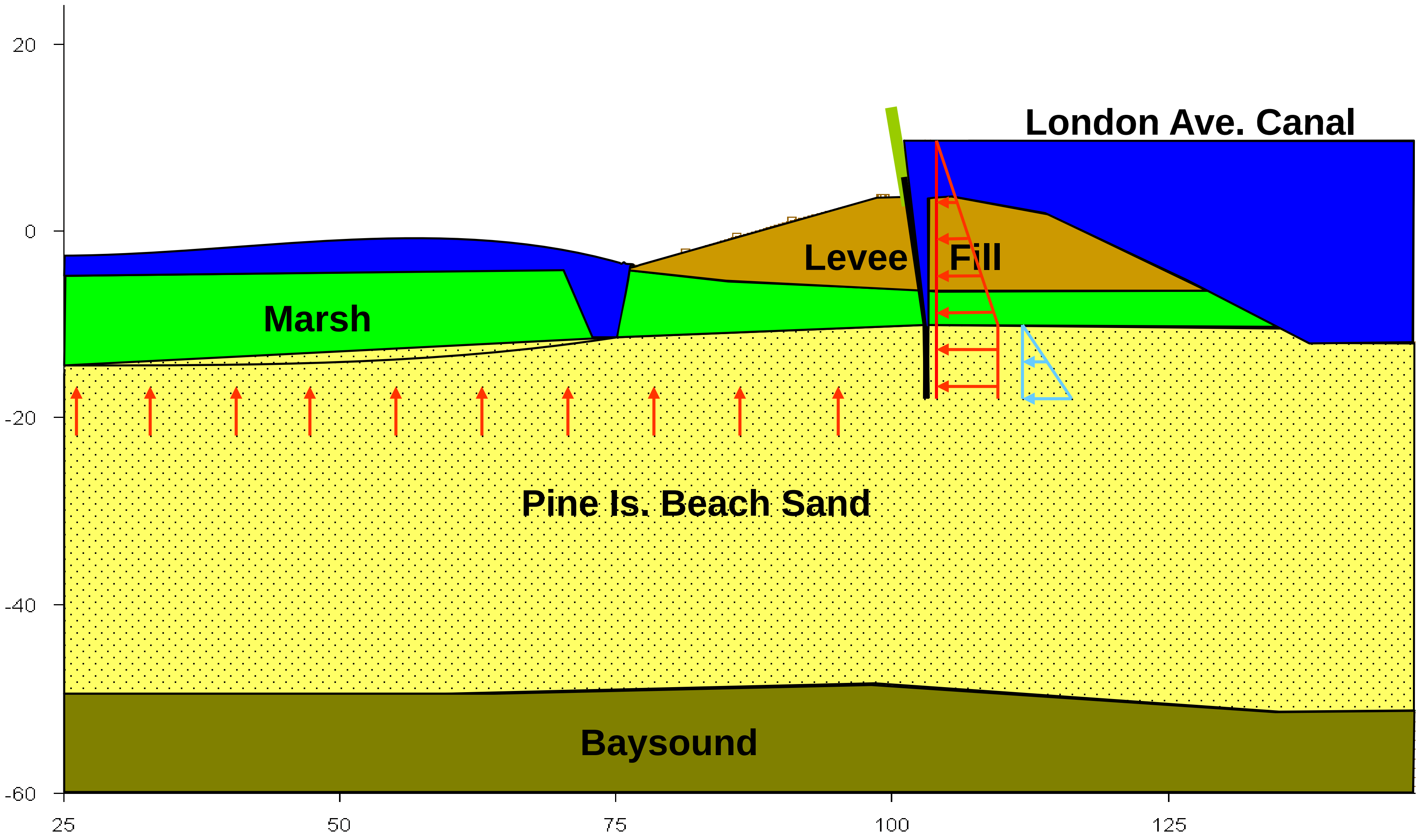
London Ave. Canal – South Breach



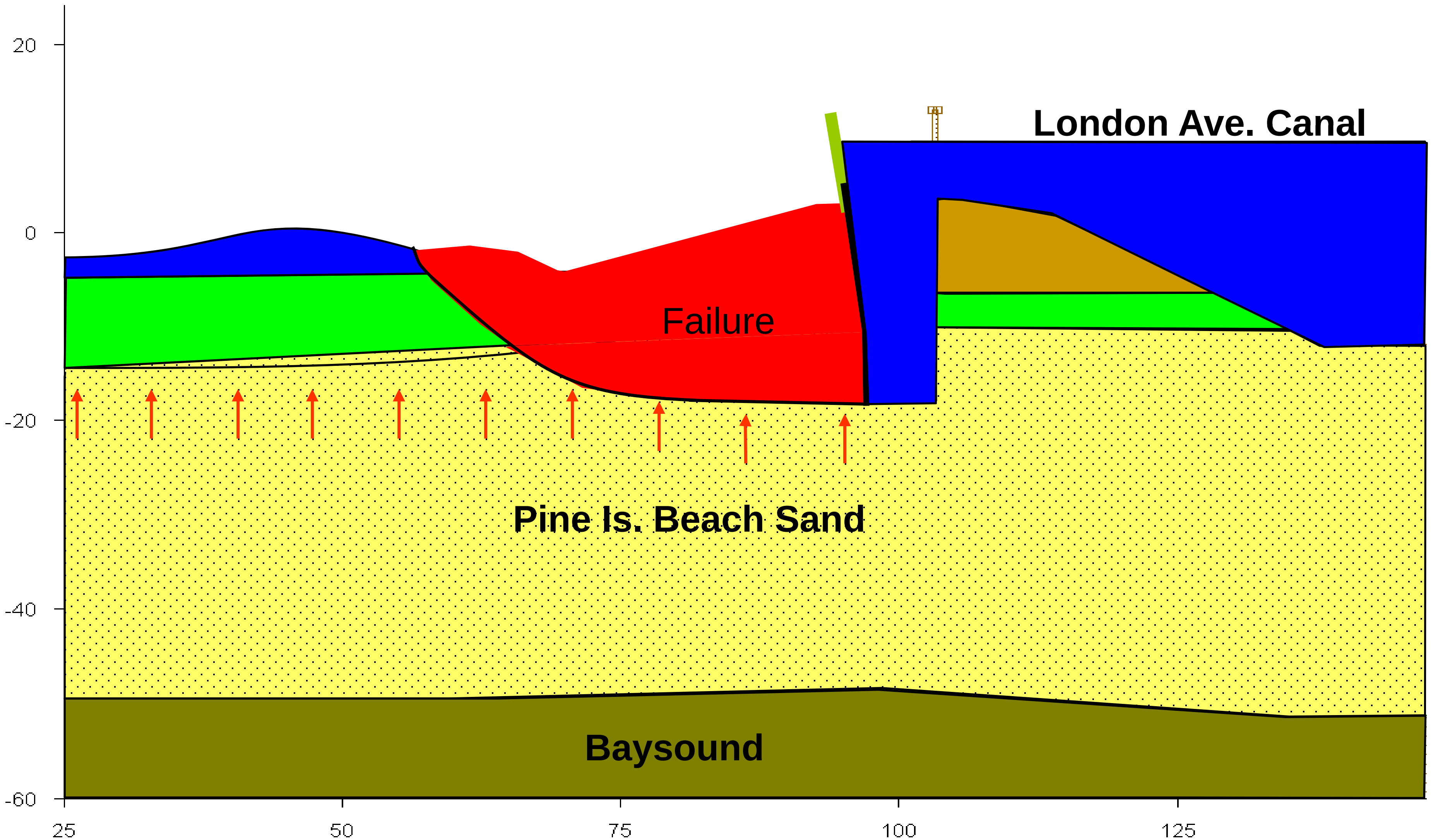
London Ave. Canal – South Breach



London Ave. Canal – South Breach



London Ave. Canal – South Breach

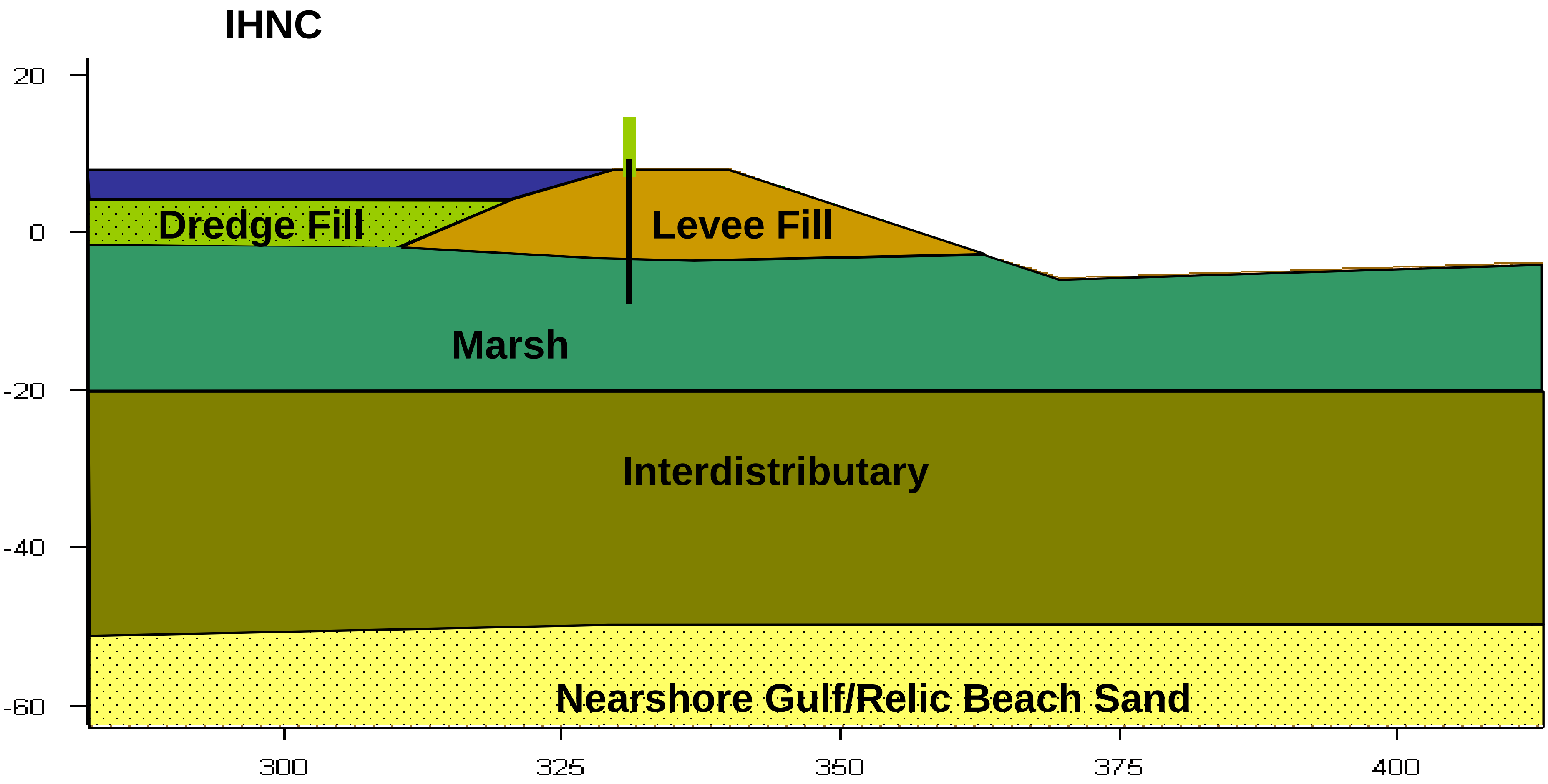


FAILURE MODE 3: OVERTOPPING

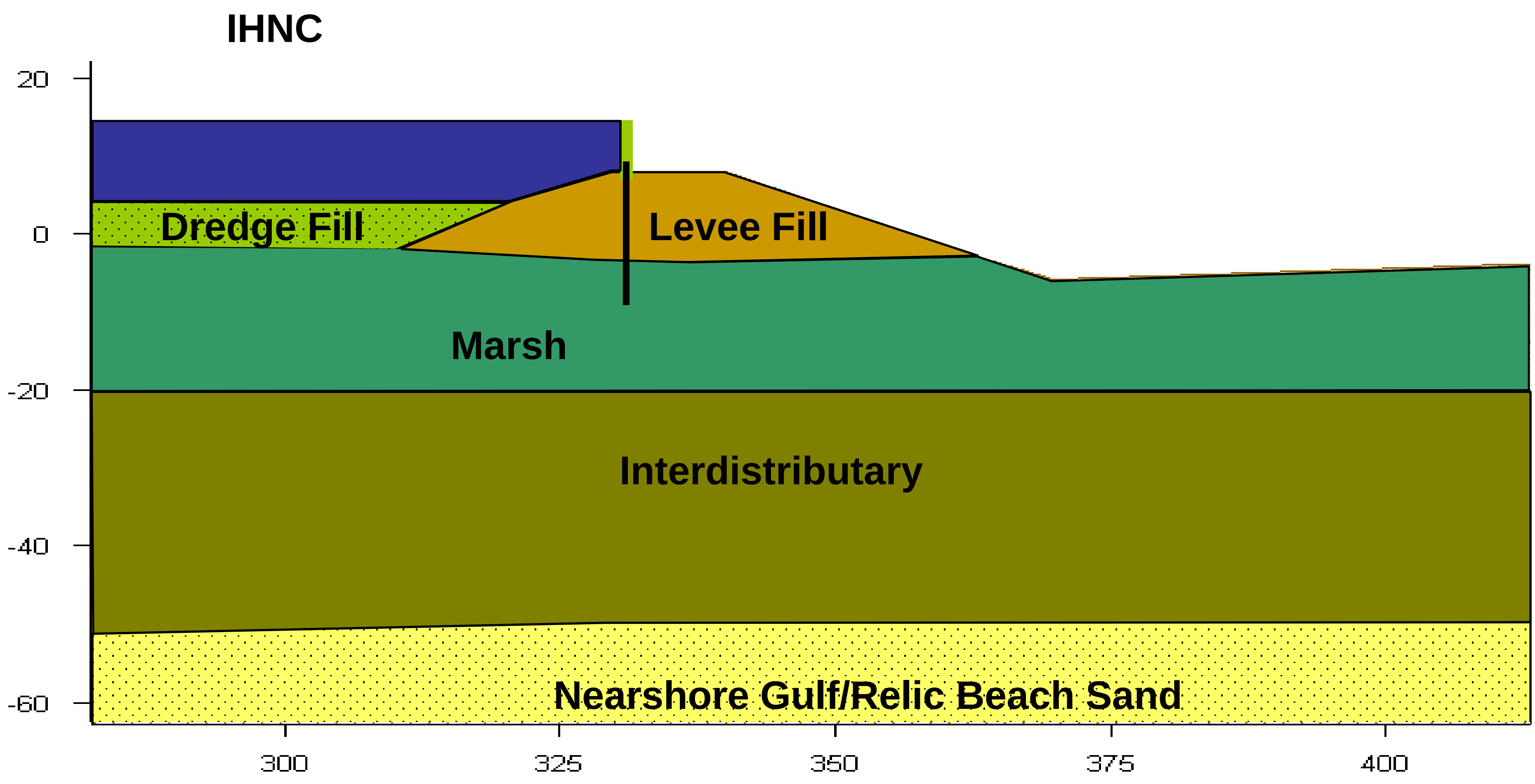
Overtopping Scour/Erosion – I-walls

9th Ward Breach

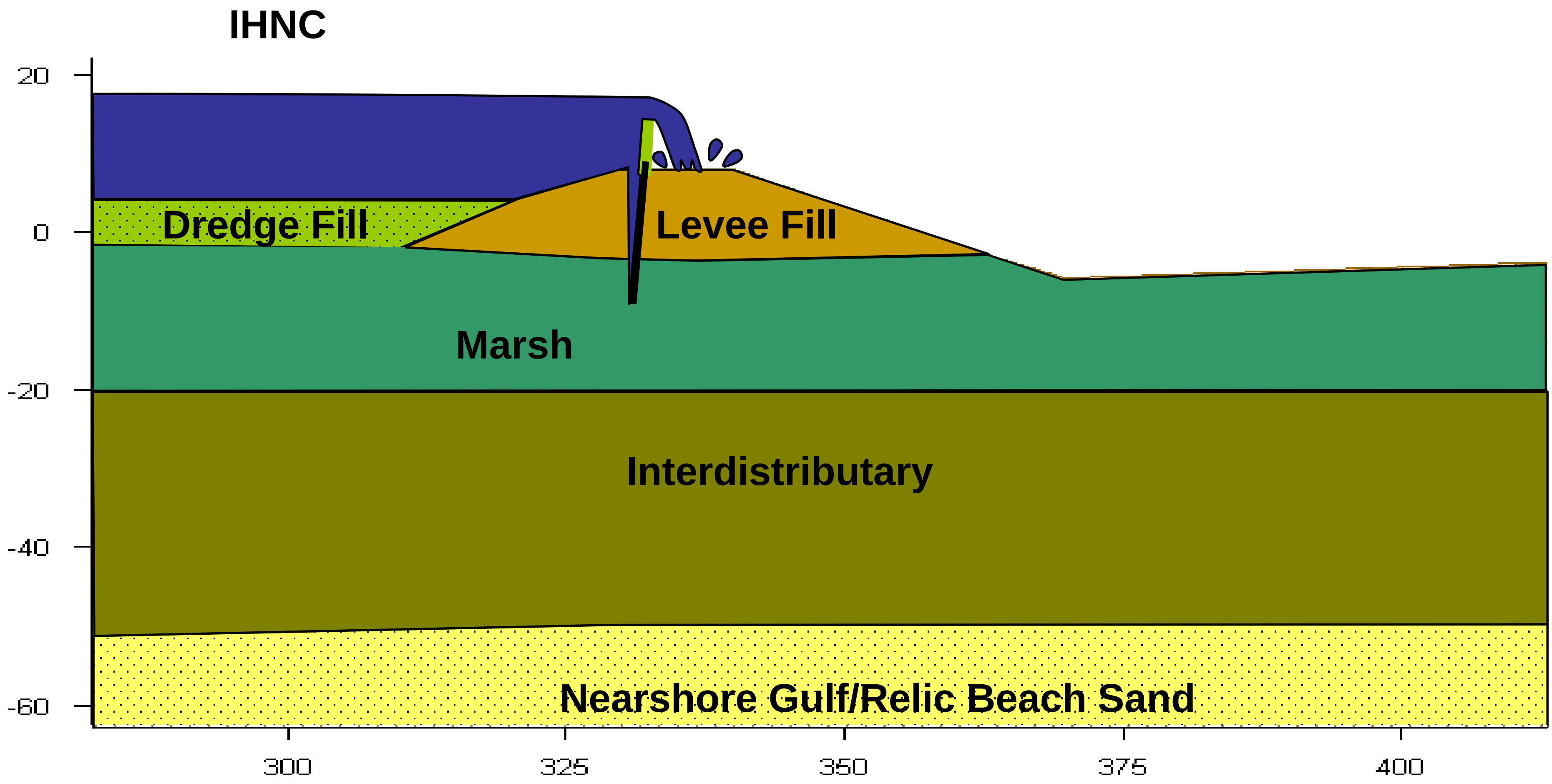
9th Ward Breach



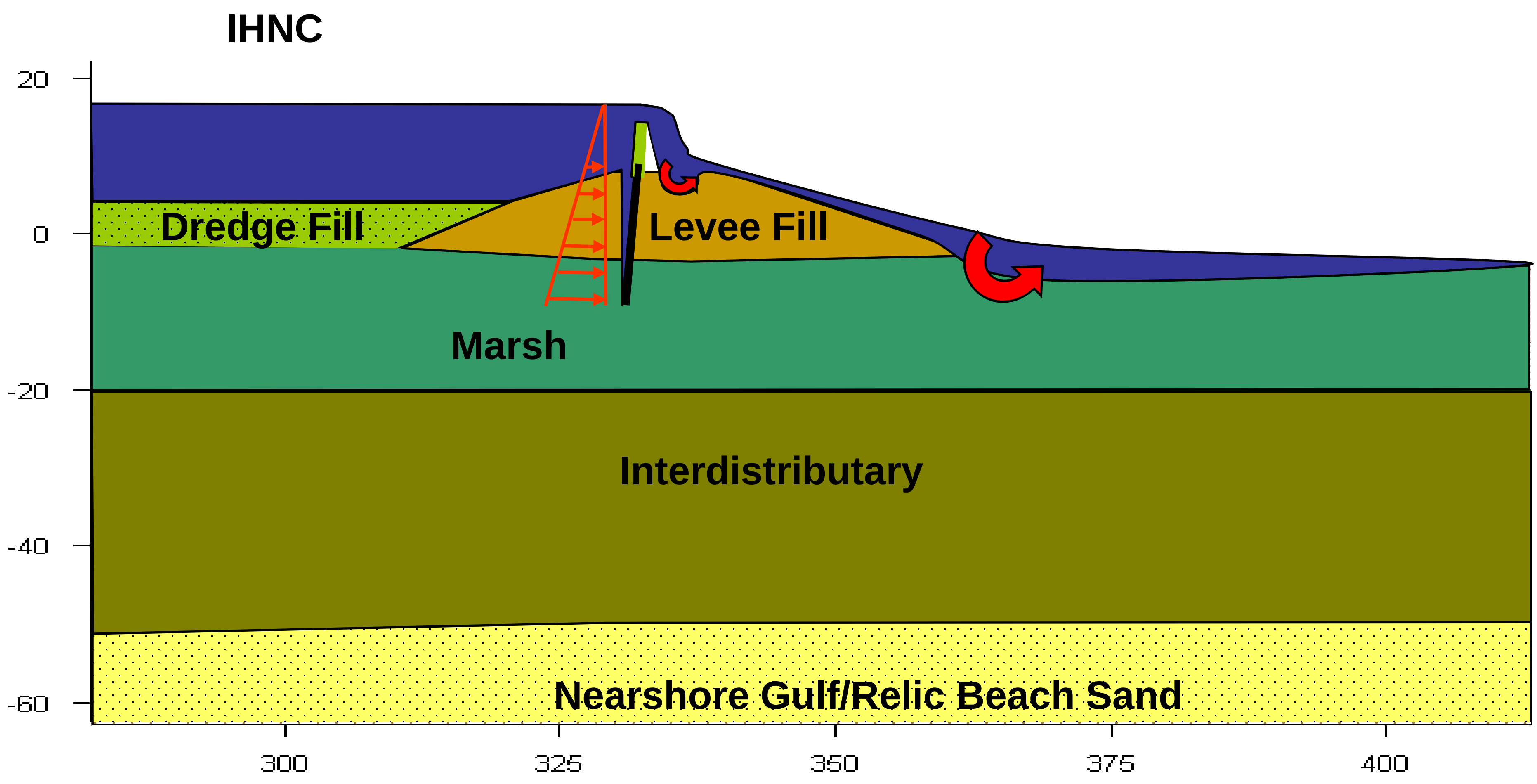
9th Ward Breach



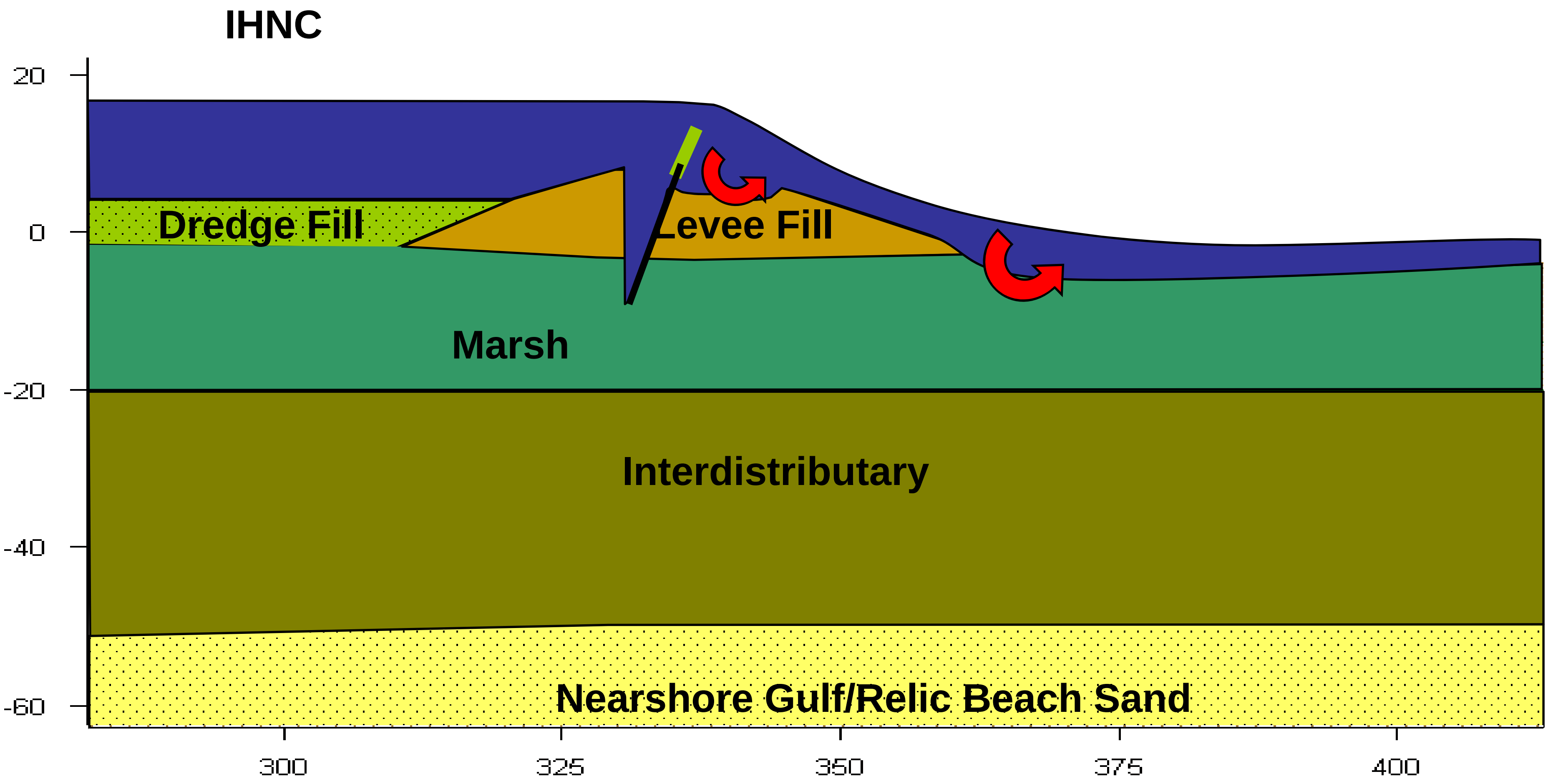
9th Ward Breach



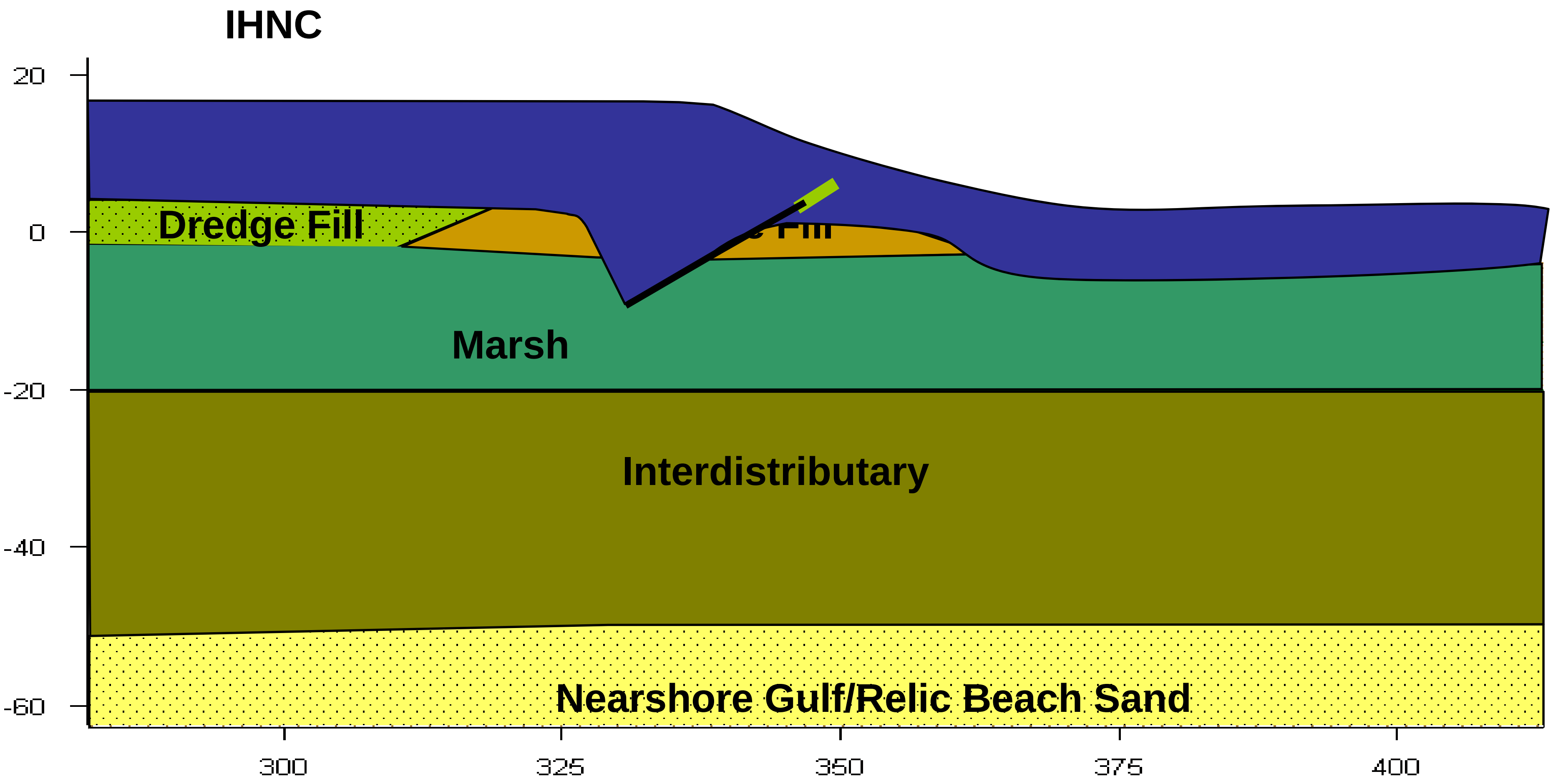
9th Ward Breach



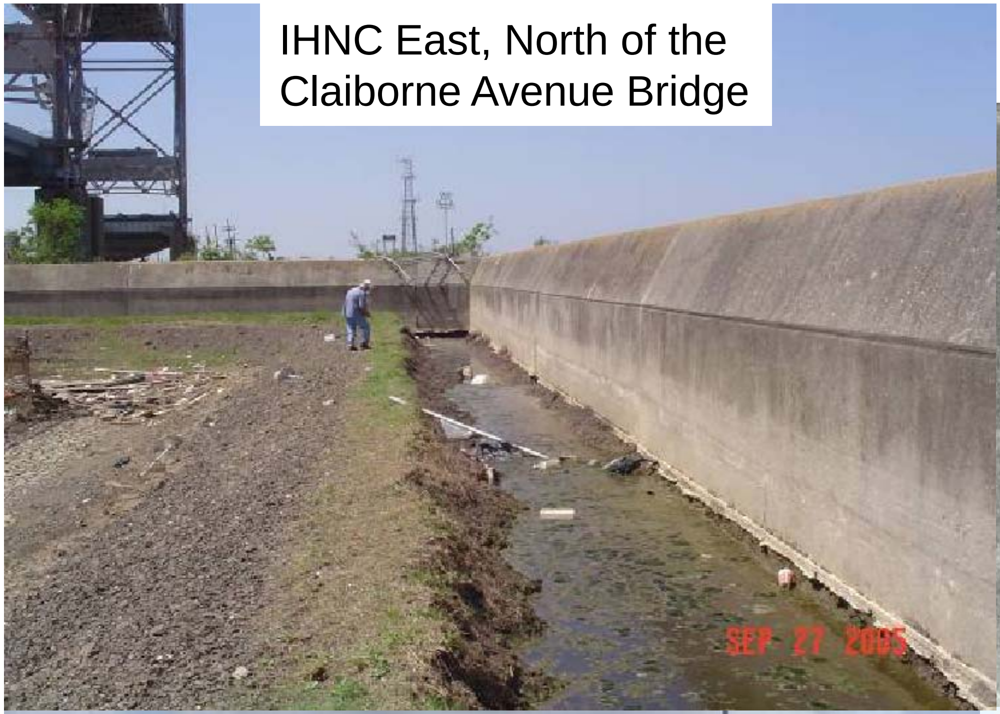
9th Ward Breach



9th Ward Breach



IHNC East, North of the Claiborne Avenue Bridge



East Side IHNC near N. Claiborne Ave. Bridge

HNC West Side at Container Facility

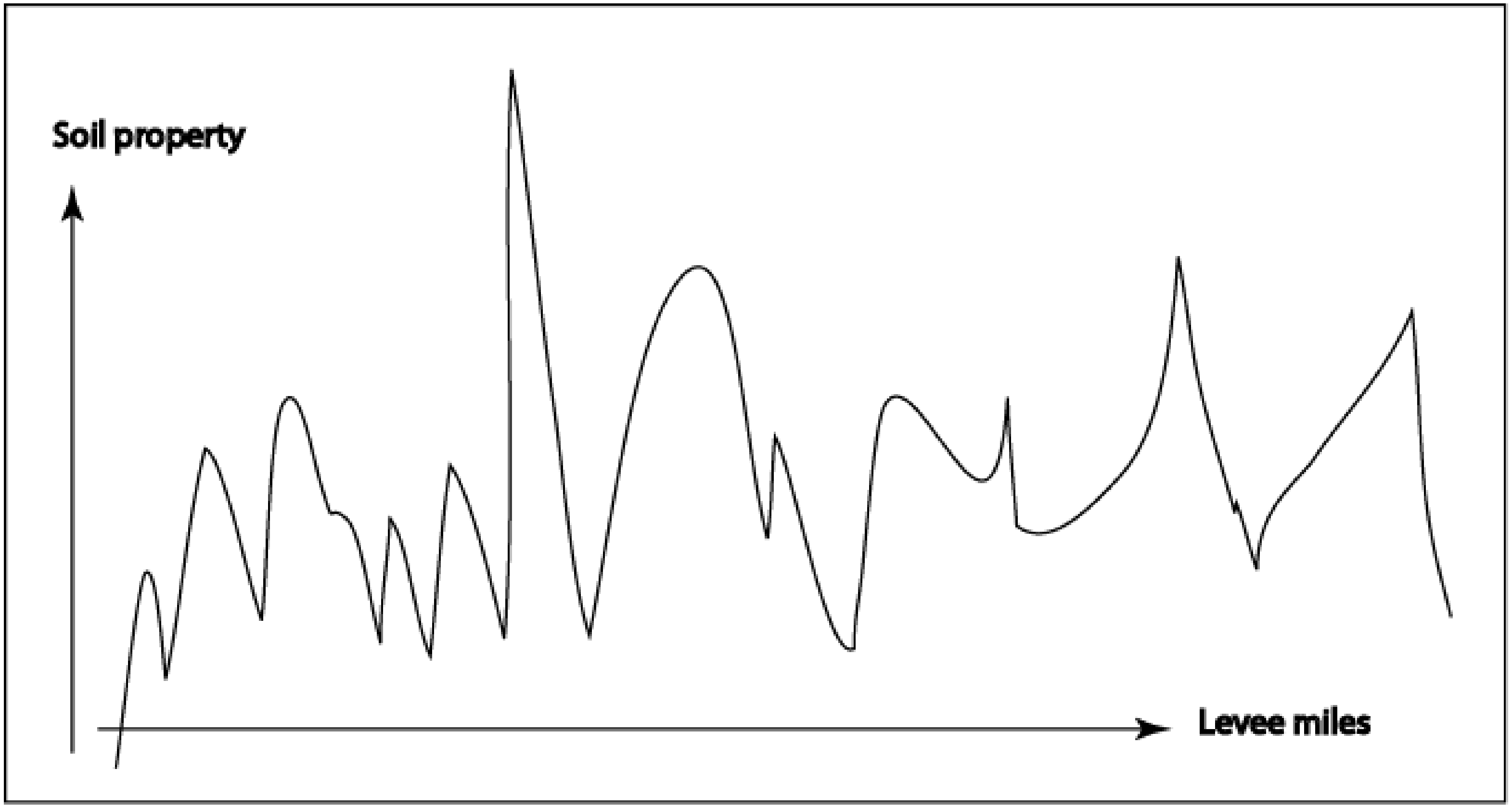
HNC West Side at Container Facility

PROPOSED SOLUTIONS

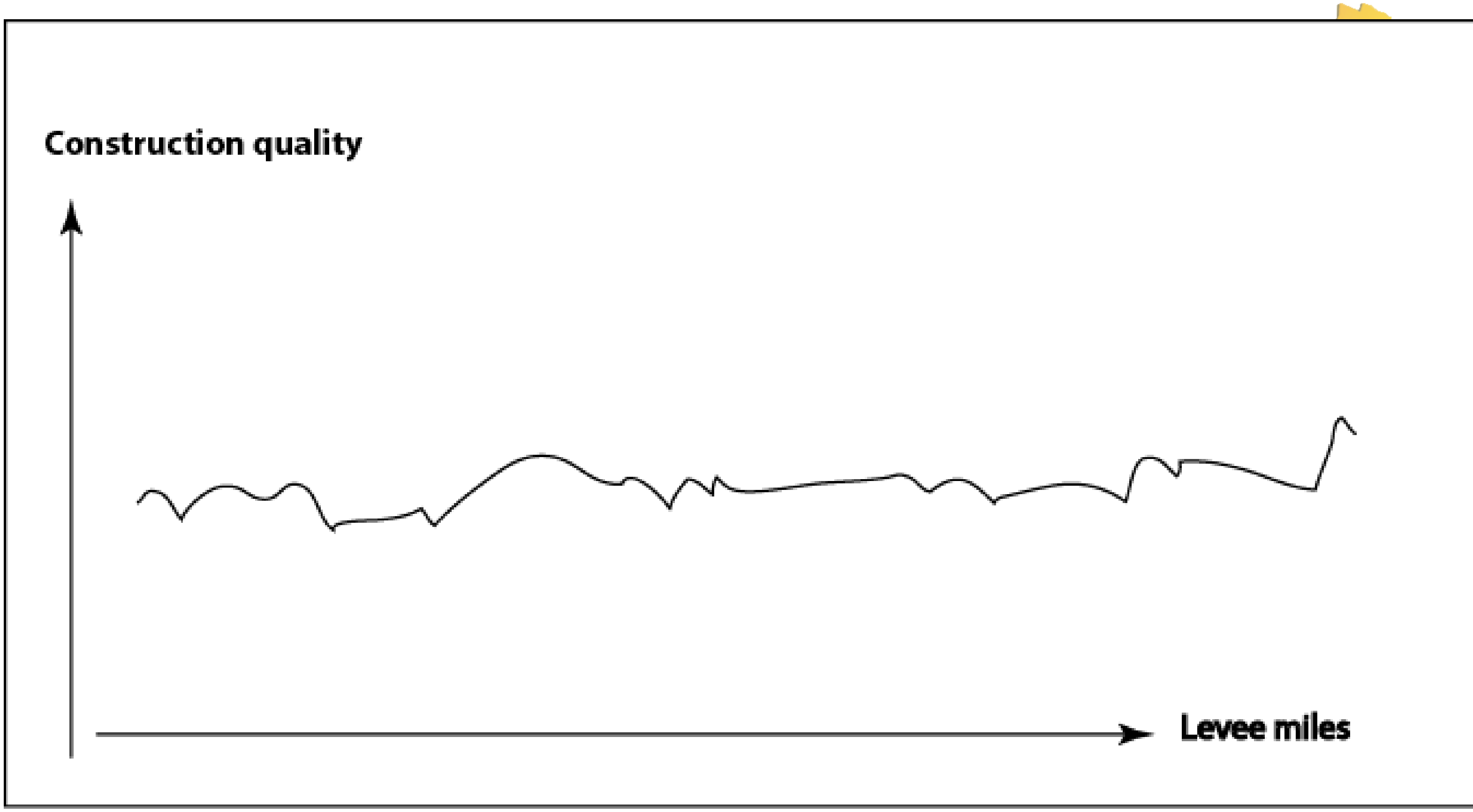
Uncertainties

- Soil variability
- Construction quality
- Loading force variability
- Information uncertainty

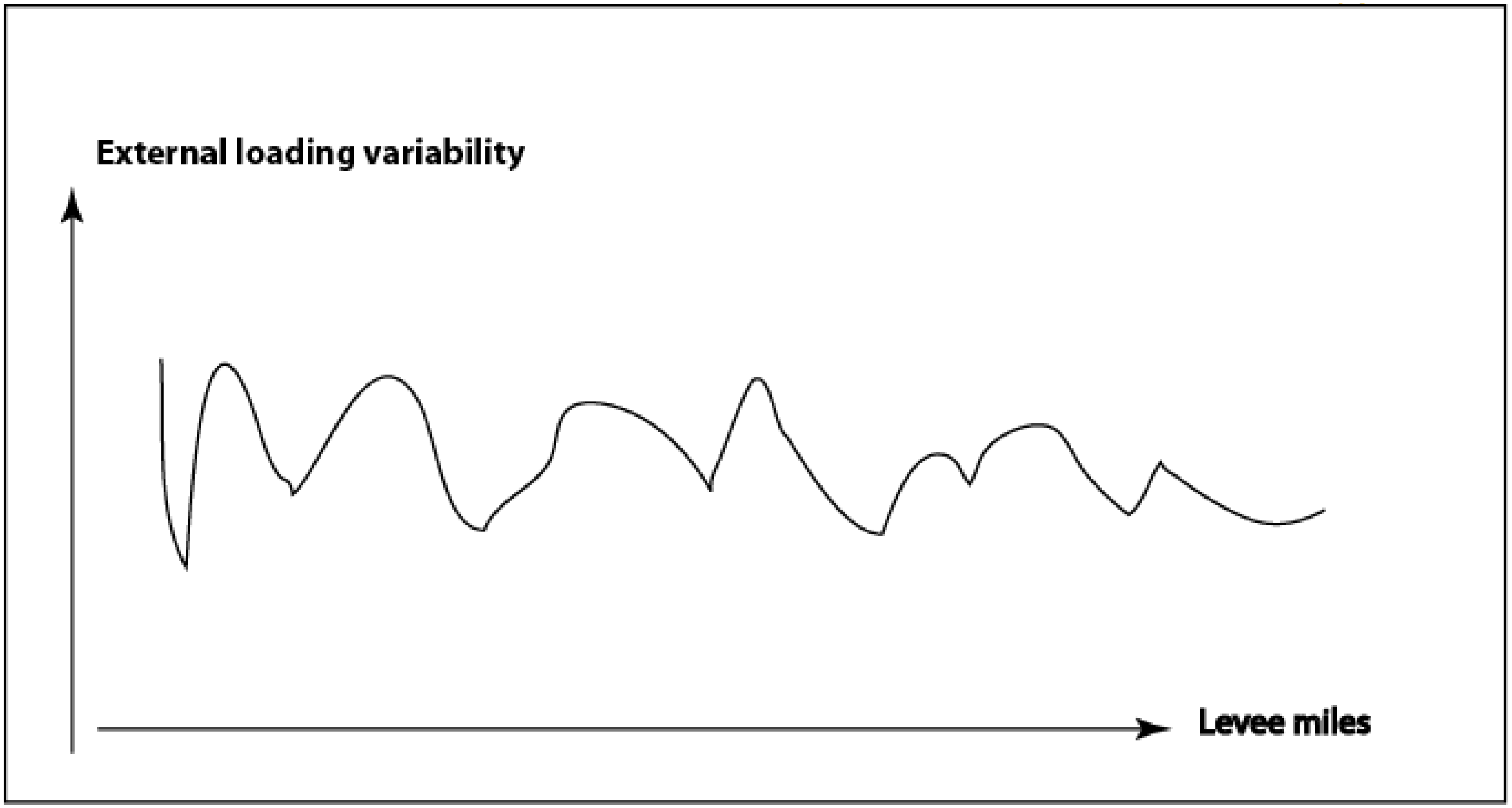
Soil Variability



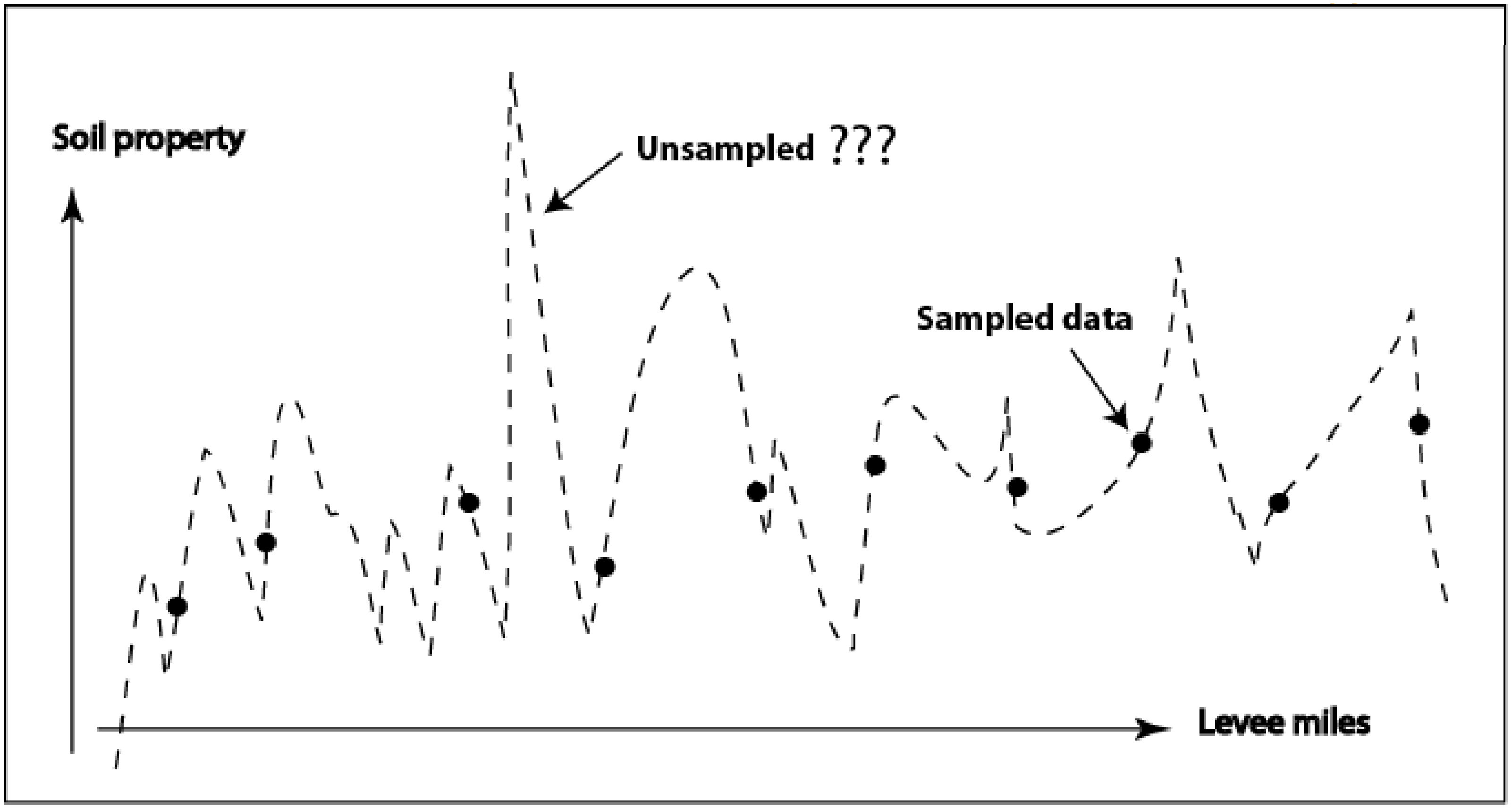
Construction Quality



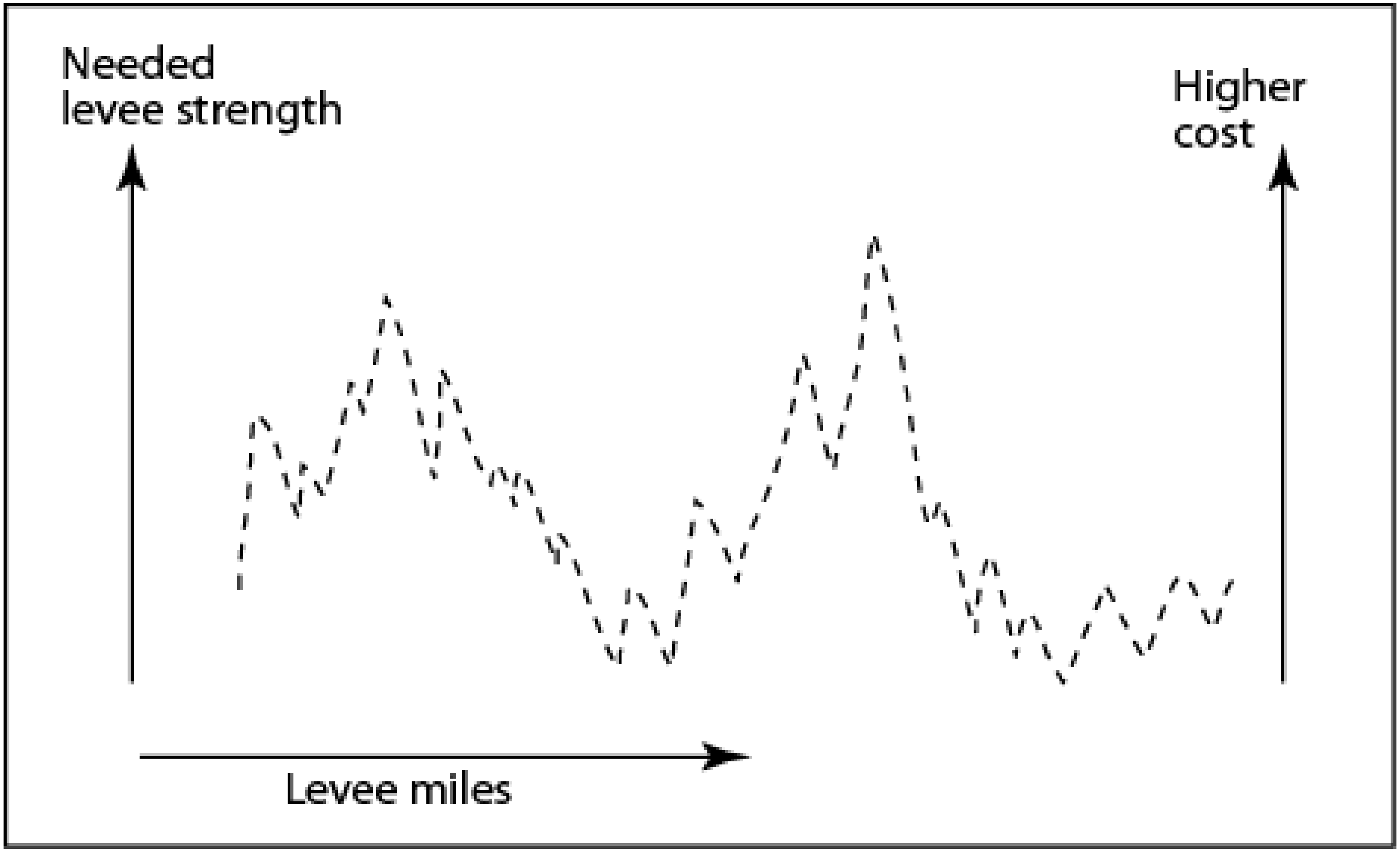
External Loading Variability



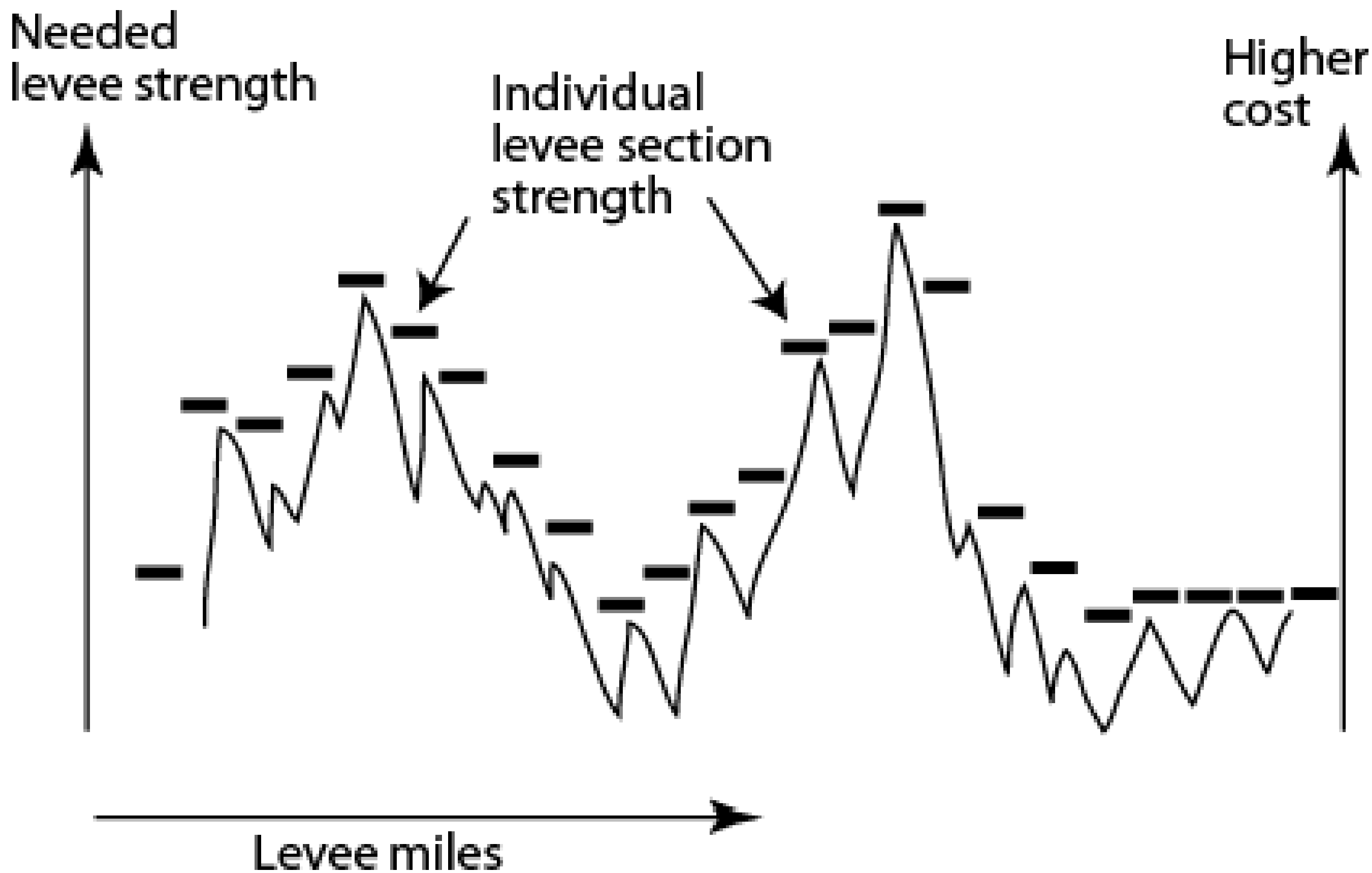
Information Uncertainty



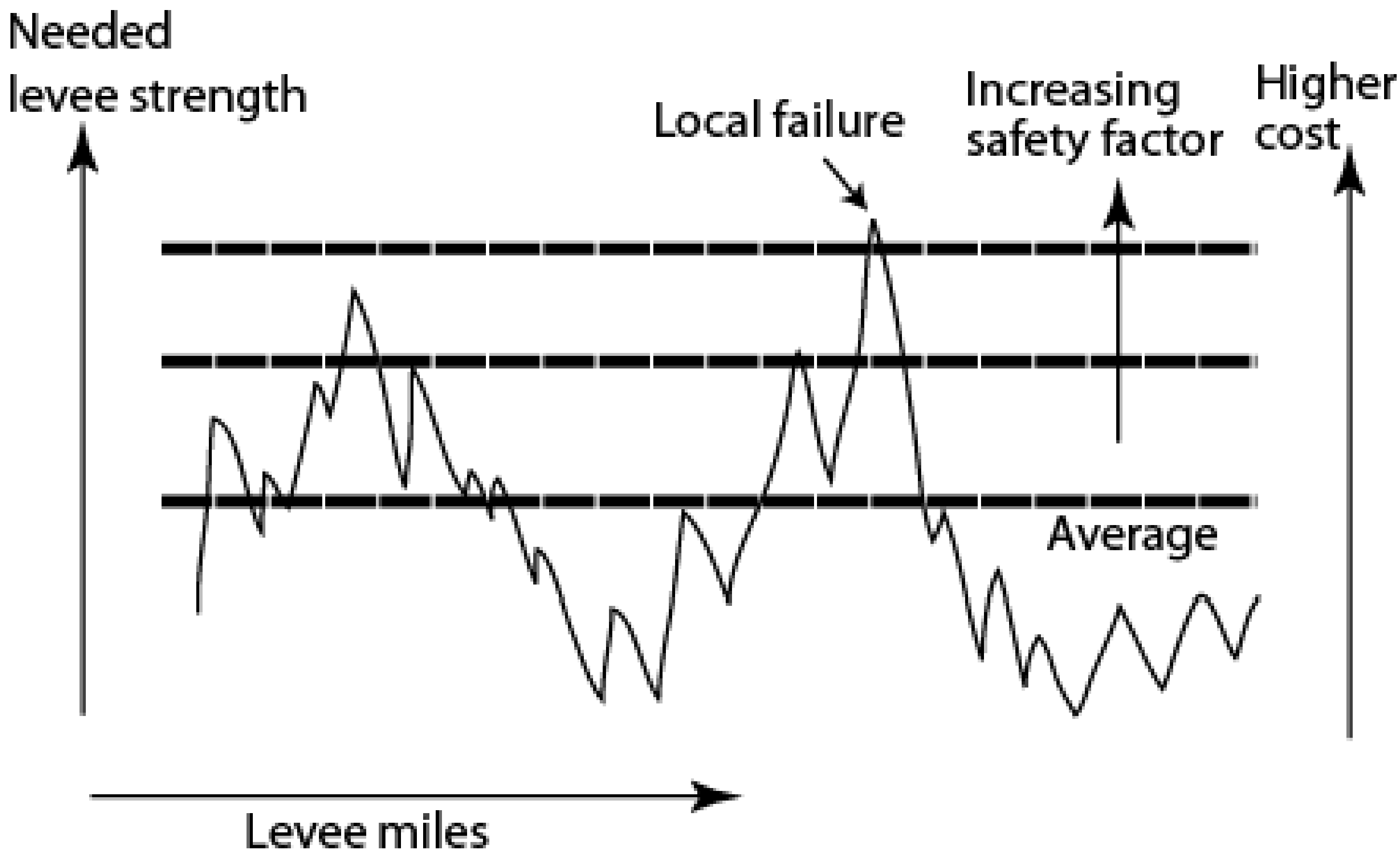
Variability and Uncertainty in Floodwall Design



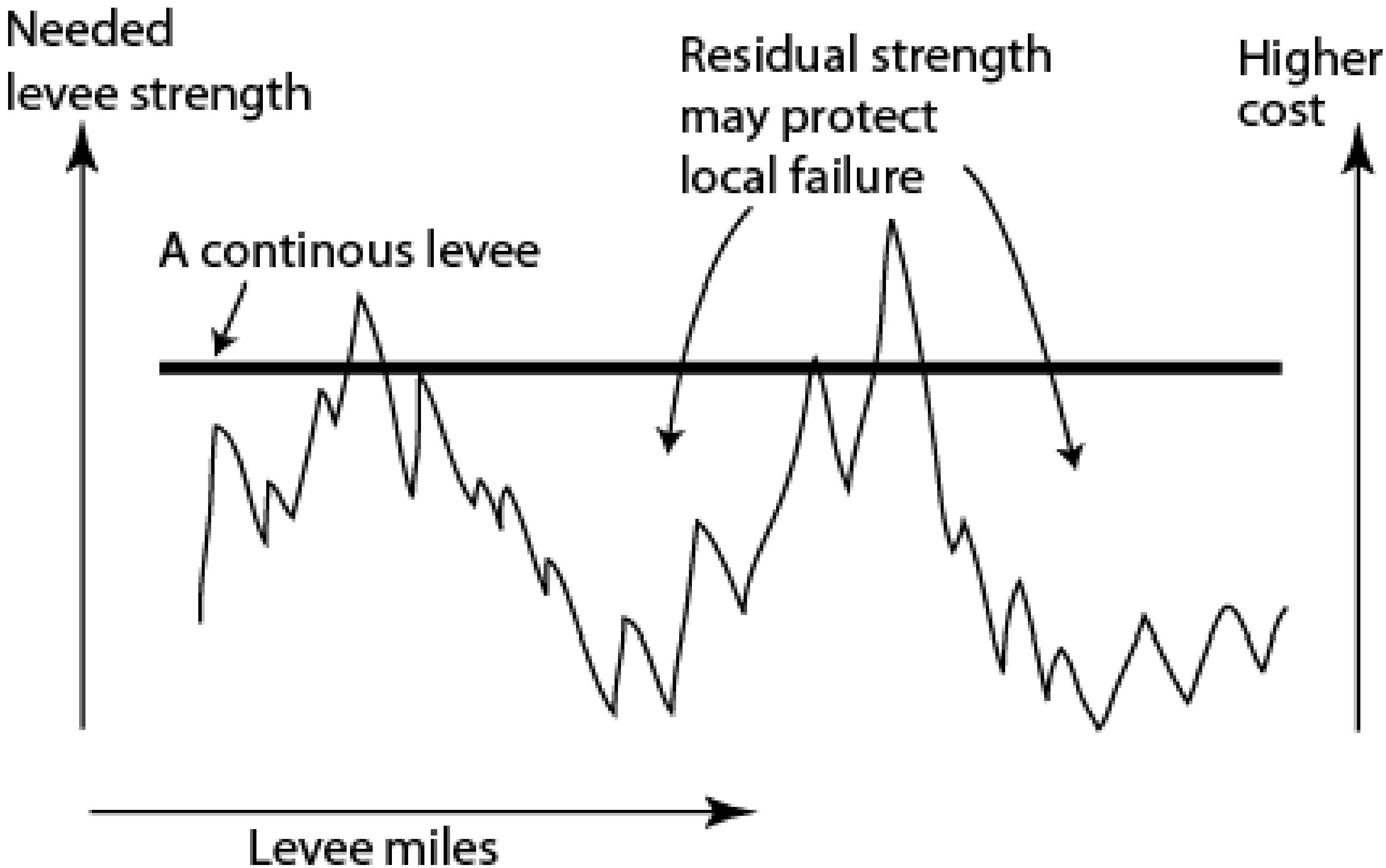
Most Cost Effective Design



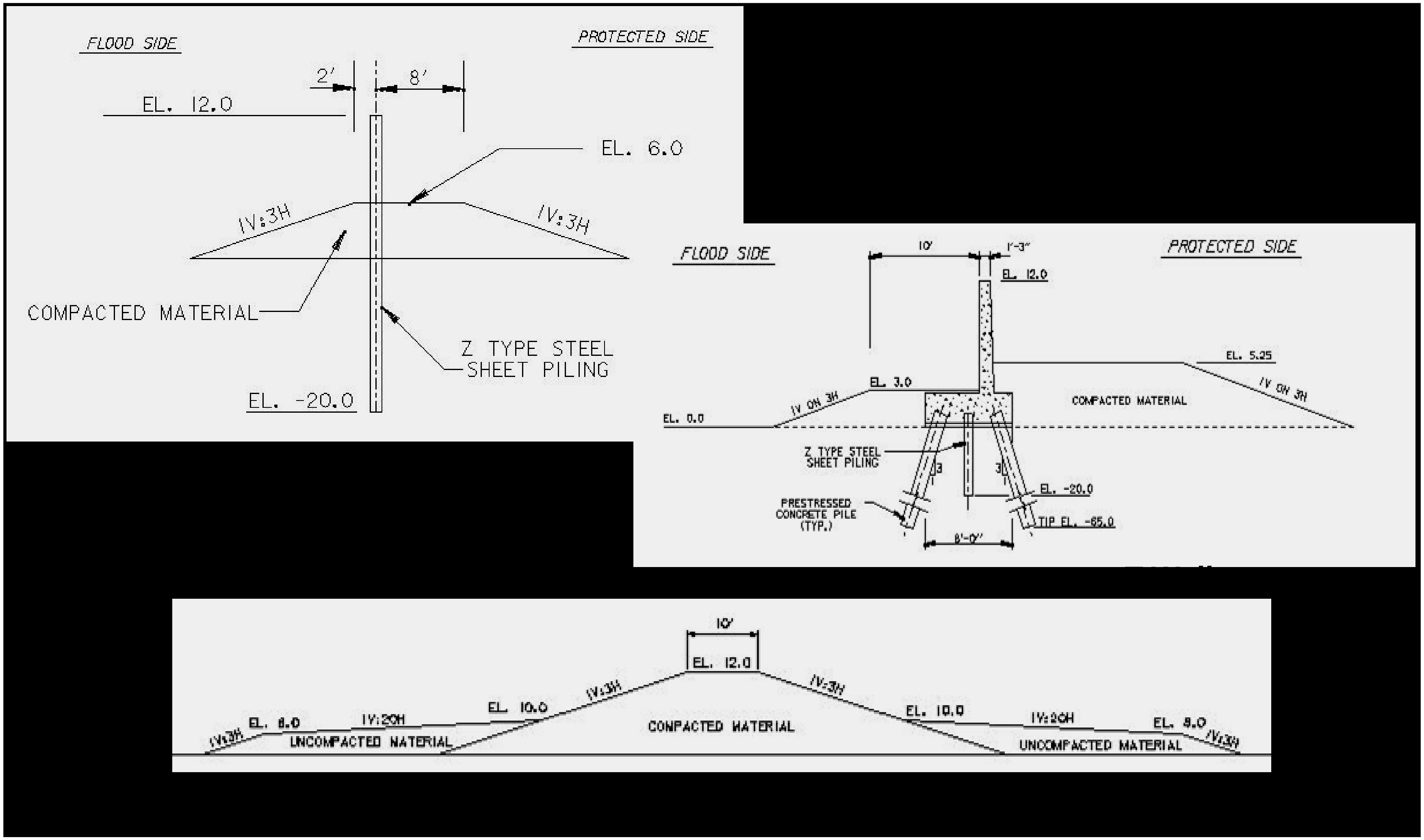
Design Reality



Structural Solution



General schematic of major hurricane protection structures used in New Orleans and Vicinity.



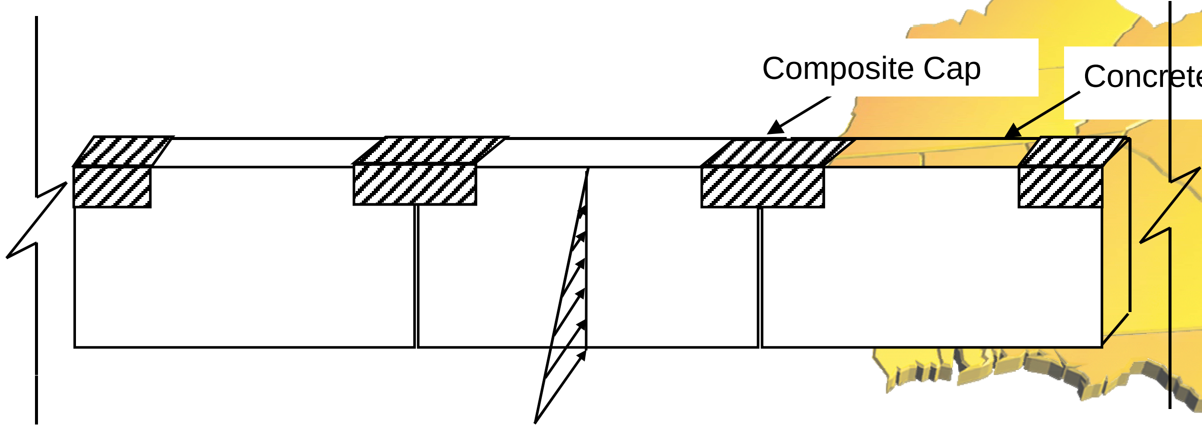
I-WALL

T-WALL


BOUCHARD

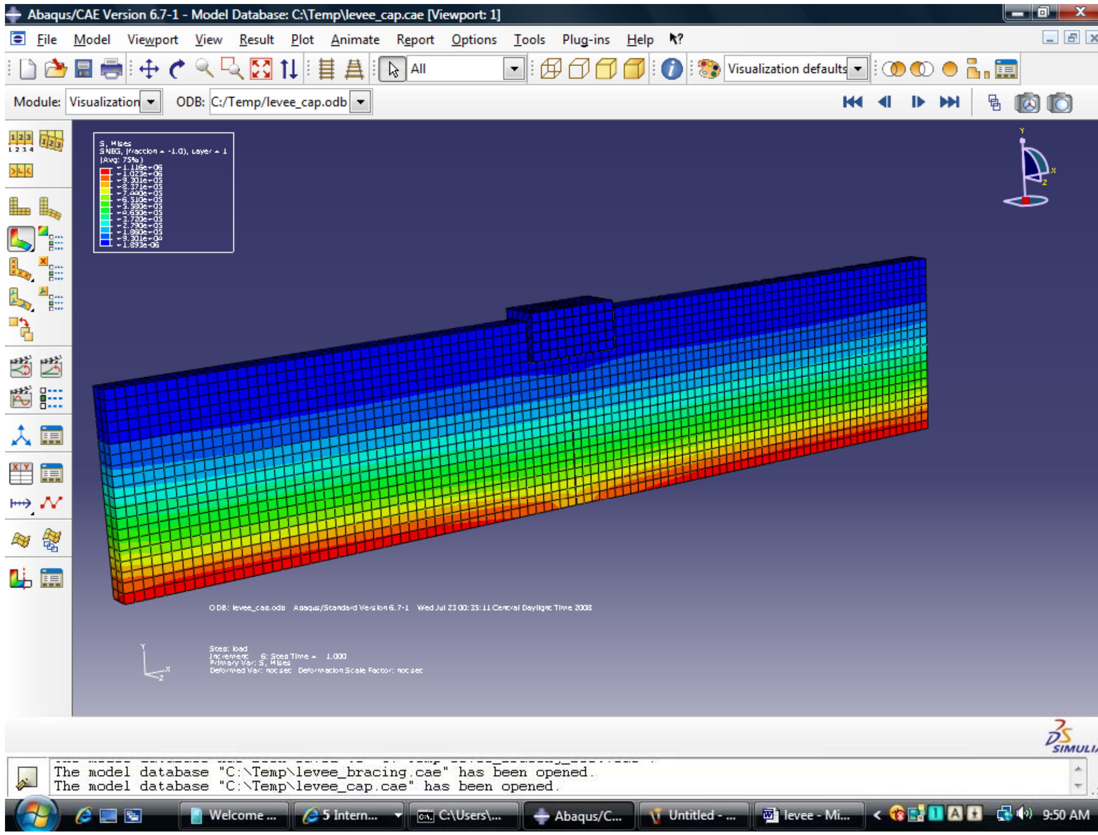

Southern Louisiana
USGS

Structure Solution Scheme

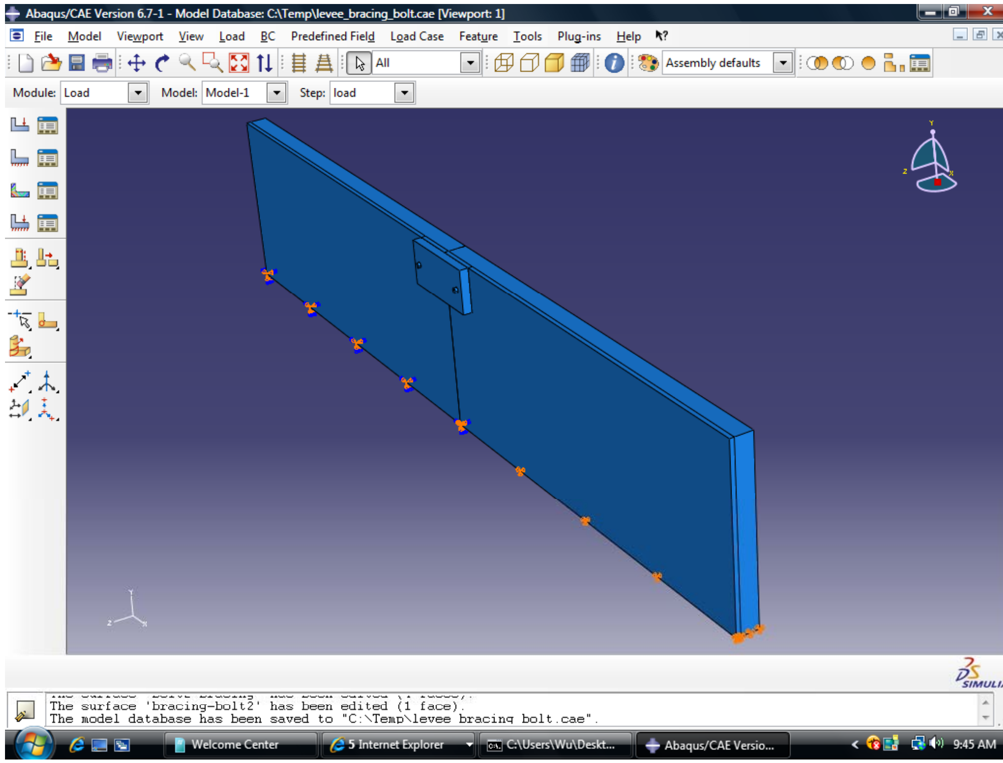


Composite caps connect all the individual floodwalls together

Case 2 Stress Contour



Cap V.S. Plate



Is cap a better choice?

Deliverables-Structural

- An analysis of the floodwall failure mechanism under the storm surge conditions,
- Design parameters of the anchor stations with test results, and
- Design parameters of the joint stiffeners using FRP braces with laboratory test results

GEOTECHNICAL SOLUTION

Geotechnical Aspects of Levee Failure

- Failure Modes
  - Lateral displacement of the flood wall (17th St. Canal)
  - Piping through underlain layers (London Ave. Canal)
  - Erosion associated with overtopping (9th Ward)
  - Slope scour/erosion (St. Bernard Parish)
  - Slope failure associated with insufficient shear strength of soils (17th St. Canal)

Map is shown in the next page.

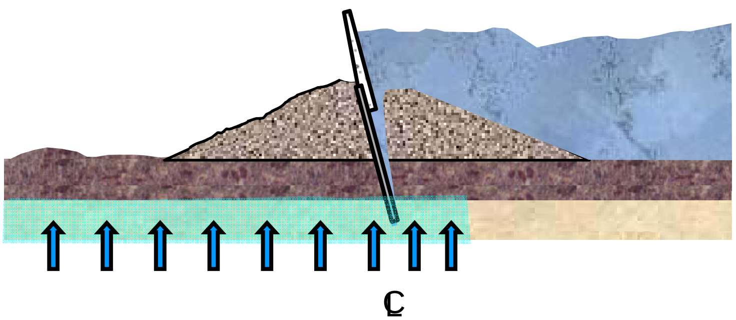
Geotechnical Solutions

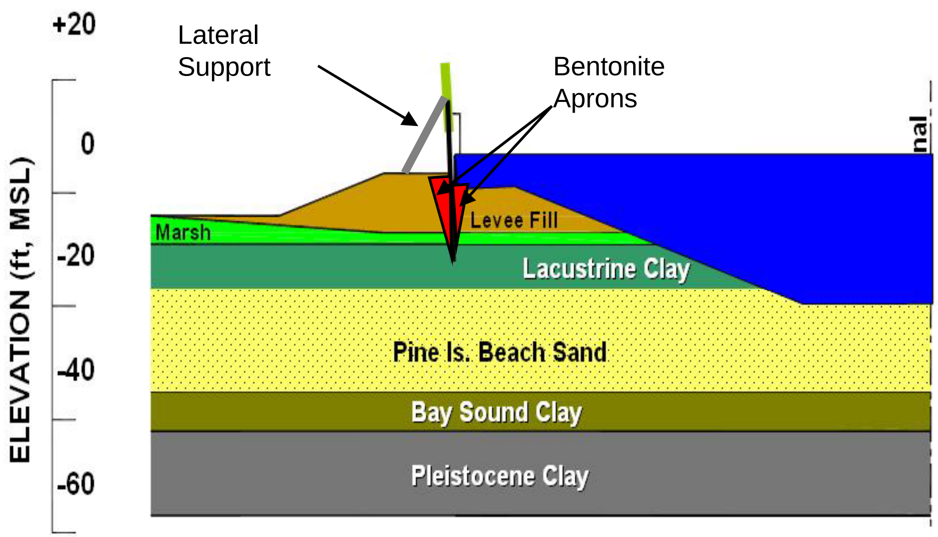
- Intended to provide a resilient levee and floodwall system to prevent or reduce damages from overturning, sliding or erosion.
  - Task 1: Improved wall design using a self healing flood wall
  - Task 2: Levee backside erosion protection
  - Task 3: Soil-structure-fluid coupled analysis

Details of individual method shown in the next slide.

Geotechnical Solutions

Task 1: Improved wall design using a self healing flood wall





Lateral displacement in the flood side of the wall triggered the penetration of flood water and increased the lateral pressure to the gap.

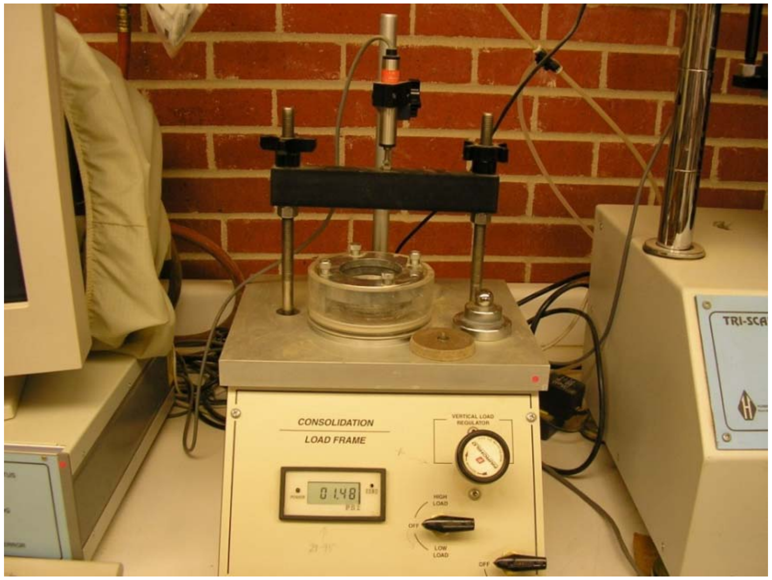
Providing self expanding/healing bentonite aprons will seal the gap on contact with water. (e.g. bentonite/butyl rubber. Hydrophilic material, Yazoo clay)

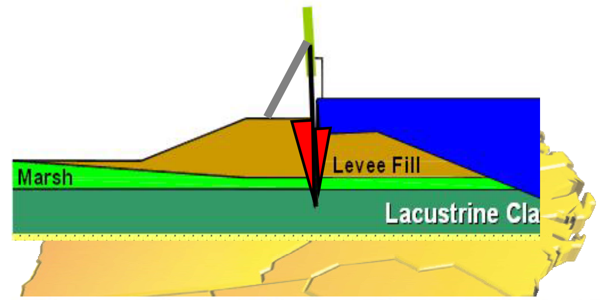
Prevent a triggering mechanism of the levee failure.

Major work: Evaluation of optimal apron shapes and required material properties

Geotechnical Solutions

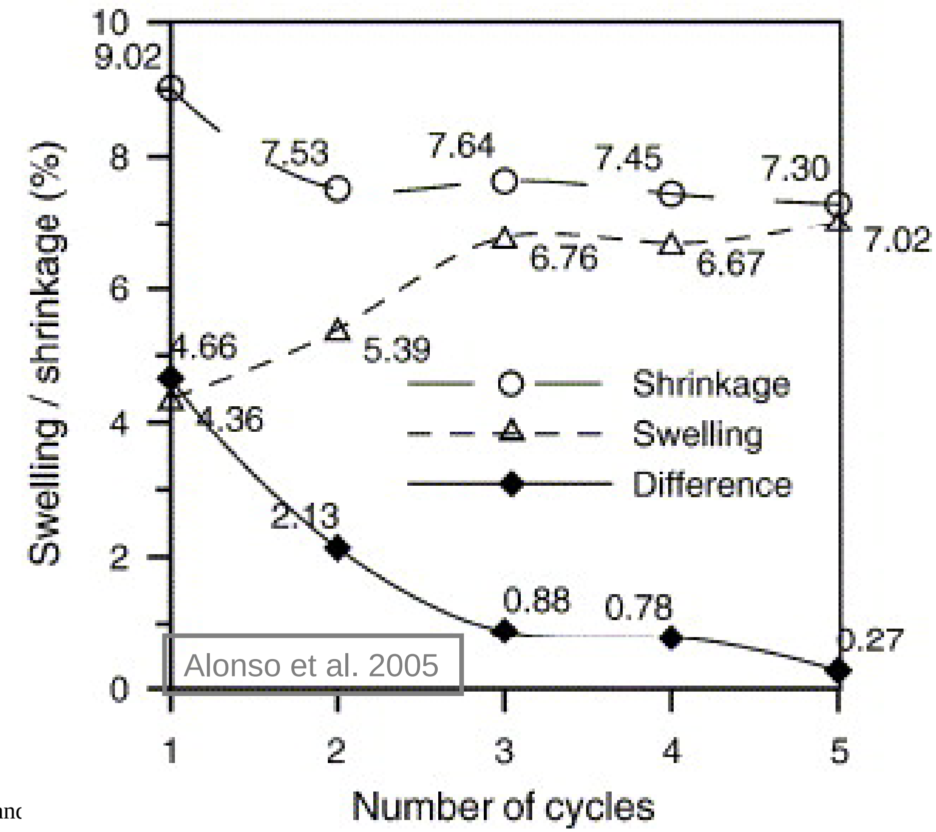
Task 1: Improved wall design using a self healing flood wall





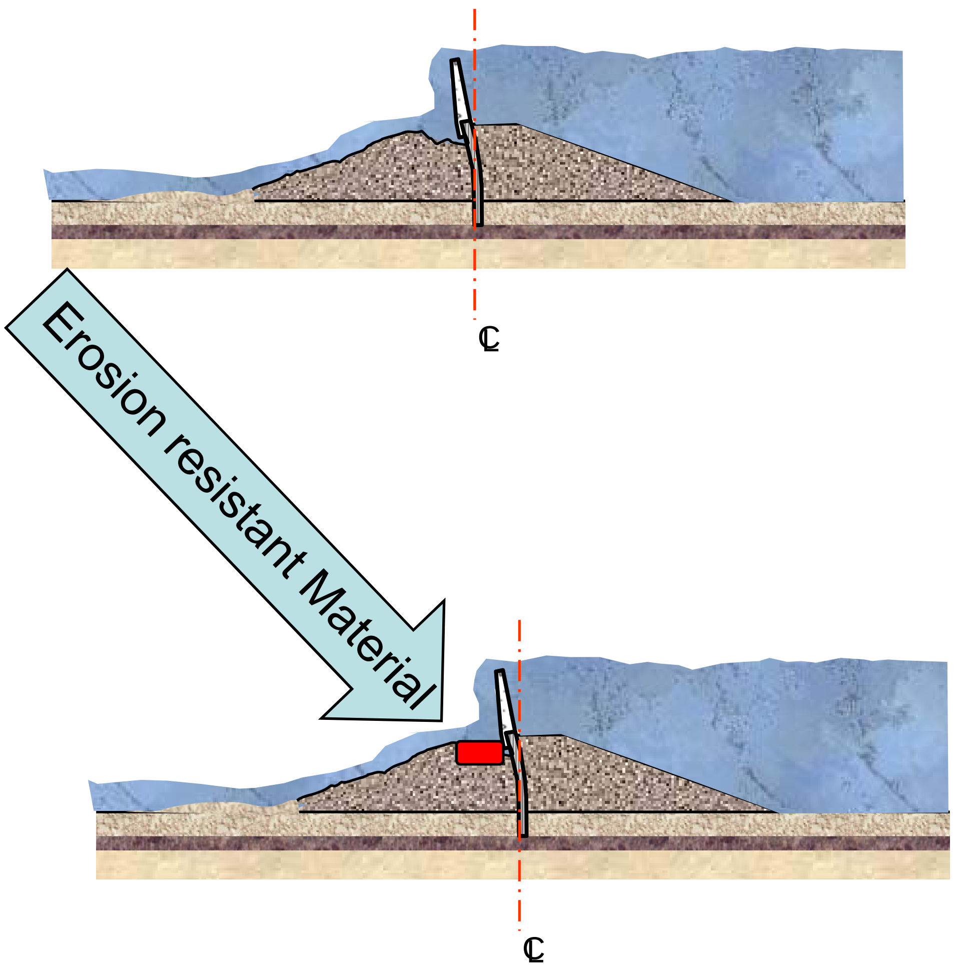
Major work: Evaluation of optimal apron shapes and required material properties

Bentonite powder is in.
Butyl rubber compound and hydrophilic materials are not in yet.



Geotechnical Solutions

Task 2: Levee backside erosion protection



Backside erosion due to overtopping was another major failure mechanism.

Retrofitting the levee with an erosion/scour resistant/retardant surface shall prevent/retard the levee erosion/scour.

Major work: Experimental evaluation of scour resistant materials, such as fiber reinforced soil, soil concrete, geotextile, soil vegetation etc.

It also includes the fabrication of erosion testing equipment as shown in the next slide.

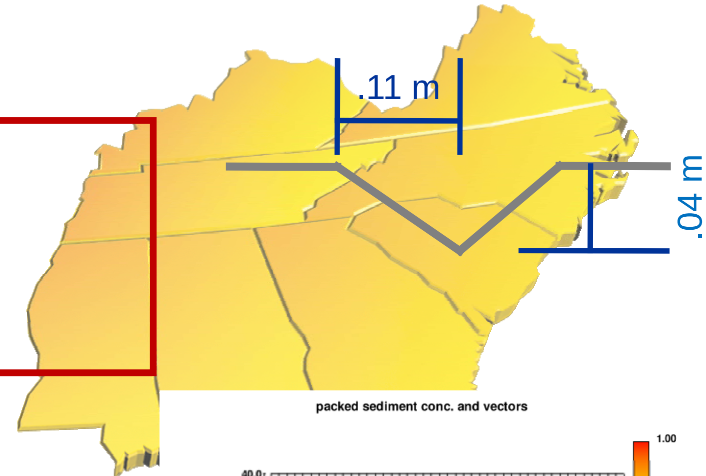
Task 2: Levee backside erosion protection

ASTM 6459-07 Erosion Test (Jet Device)

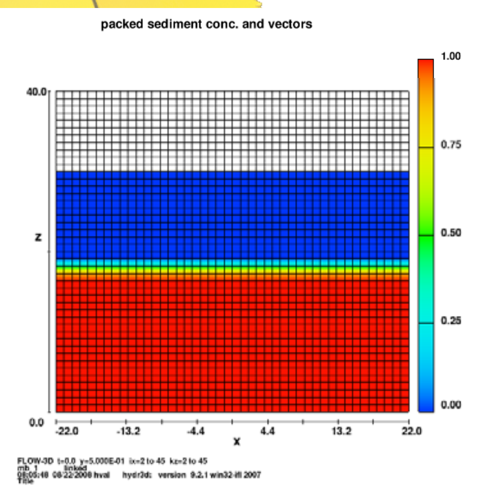
Task 2: Levee backside erosion protection

Verification of Numerical Model Using Jet Test Results for ASTM C-190 Standard Ottawa Sand

D_{50} : 0.71 mm
G_s : 2.67
Shape: Round
Cohesion: 0



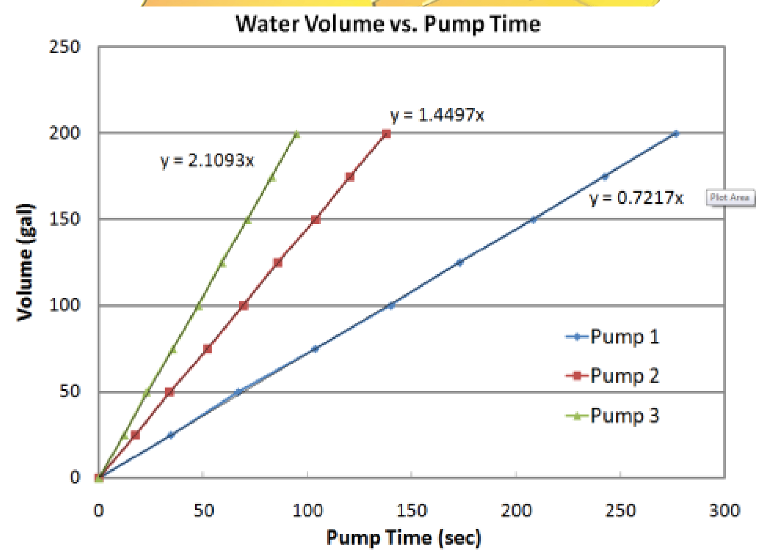
Erodibility Coefficient:
3.1x10^{-5} m^3/N.s
Critical Shear Stress:
0.005 Pa.
Angle of Repose: 18 - 21^{o}



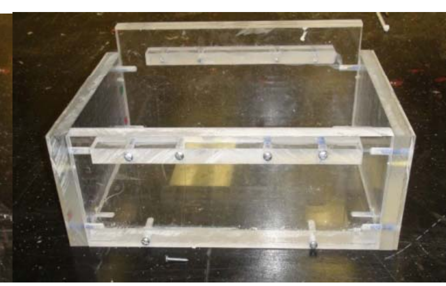
Task 2: Levee backside erosion protection

Verification of Numerical Model Using UM Large Erosion Test Bed for ASTM C-190 Ottawa Sand

Adjustable Flow Rate:
7600 gal/hr, 5219 gal/hr, 2598 gal/hr,







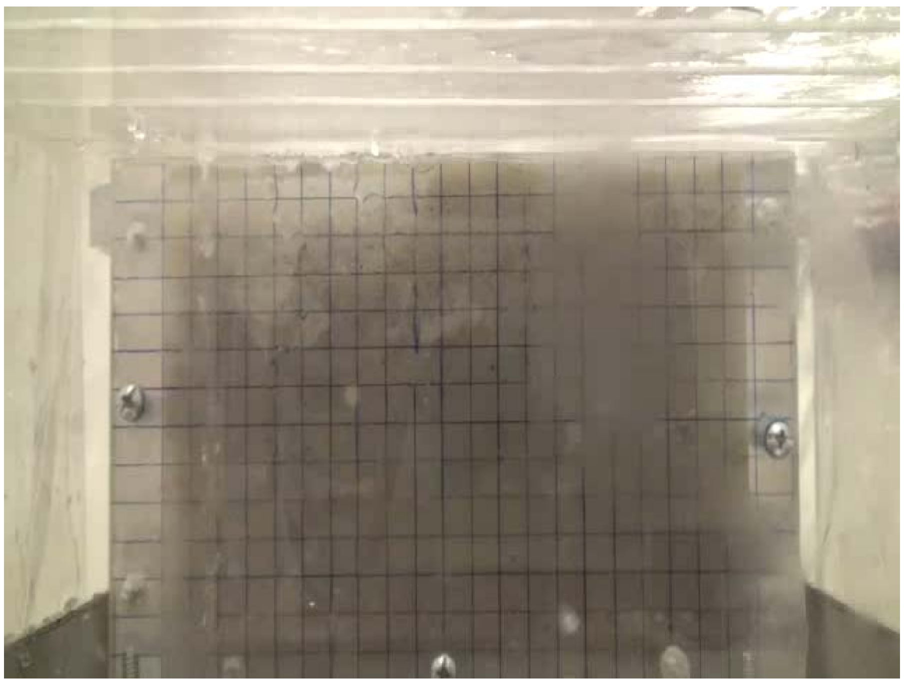

Manag

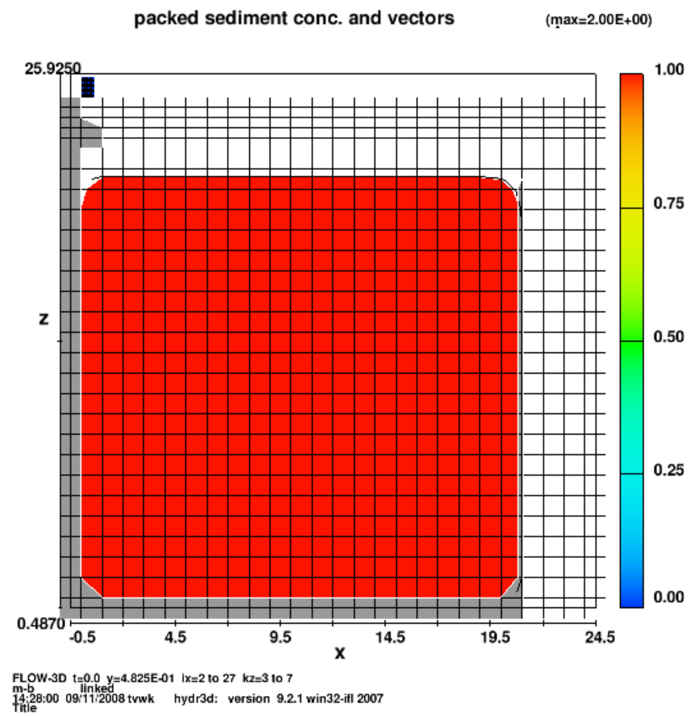
Task 2: Levee backside erosion protection

Verification of Numerical Model Using UM Large Erosion Test Bed for ASTM C-190 Ottawa Sand

Experiment Result with 7600 gal/hr Flow Rate

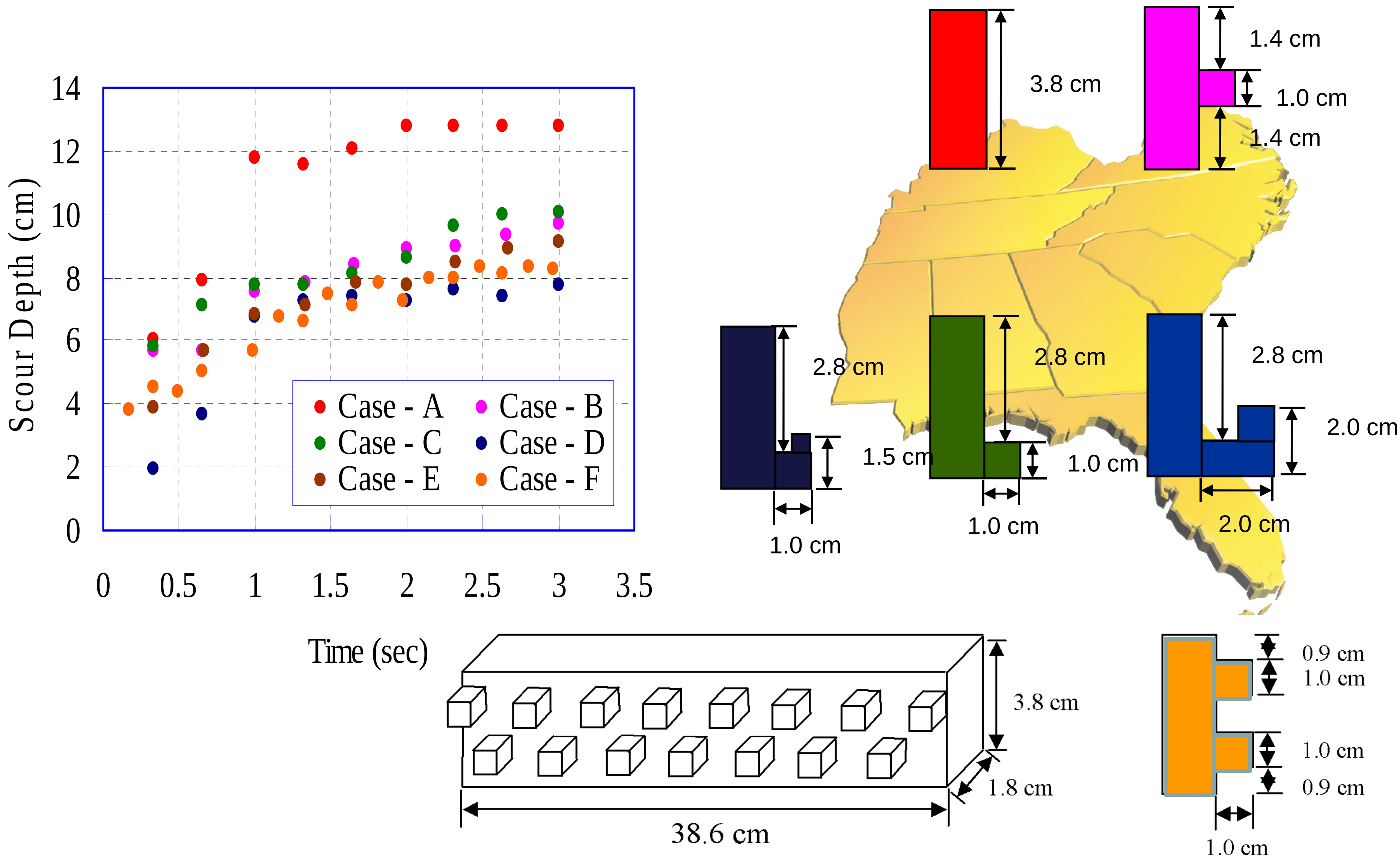
Numerical Result with 7600 gal/hr Flow Rate





Task 2: Levee backside erosion protection

Verification of Numerical Model Using UM Large Erosion Test Bed for ASTM C-109 Ottawa Sand



SERRI
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Major Works for Erosion

- Fabrication and calibration of UM Large Erosion Testing Bed (hereafter called UMETB)
- Validation of UMETB using Jet Tests and Hydrodynamics analysis
- Same as 2 but with HD simulations and tests for various soils (five different soils)
- Erosion analysis for the full scale flood walls (with field soil condition)
- Evaluation of the erodibility parameters of larger aggregates by comparing Jet test results and UMETB results for larger circular nozzles for submerged condition
- Erosion analysis for full size flood walls using FLOW3D with parameters calibrated for aggregate size effects and flood wall size effects. Comparison with field erosion data is also included. Quantification of the erosion time for several (5) different materials is also evaluated (e.g. 10 hrs. 24 hrs….). Erosion resistant materials/design are found.
- Finalize deliverables

Task 3: Soil-structure-fluid coupled analysis : Troubles of I- and T-walls

Advanced analysis and retrofitting of I-wall itself is needed.

Tying I-wall to survived section may prevent/alleviate the failure of I-wall.

- Geotech. + Structure + Mat'l

T-walls survived Hurricane Katrina.

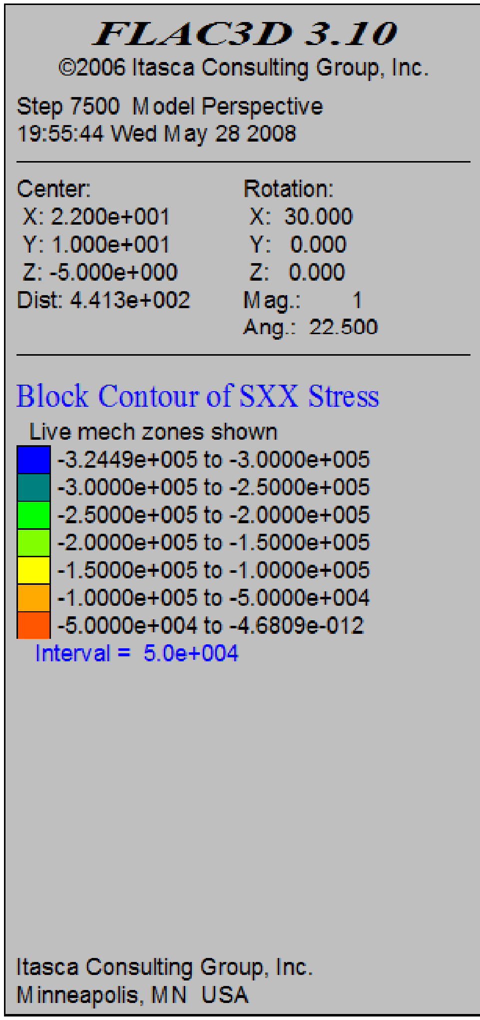
But interface between T-walls and other structures…

Interfaces must be thoroughly studied and reinforced.

- Geotech. + Structure + Mat'l

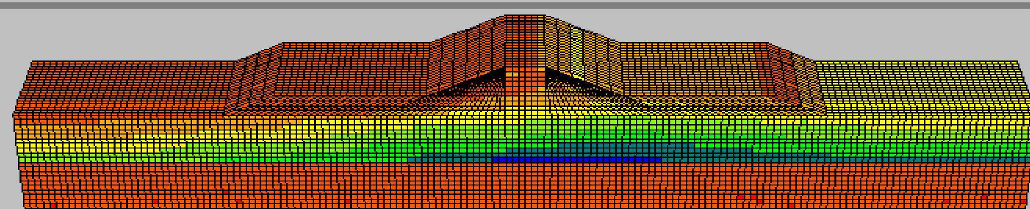
Task 3: Soil-structure-fluid coupled analysis

Modeling and Numerical Simulation of Levee and Floodwall



Coupled Analysis of Soil-Structure-Flood Interaction.

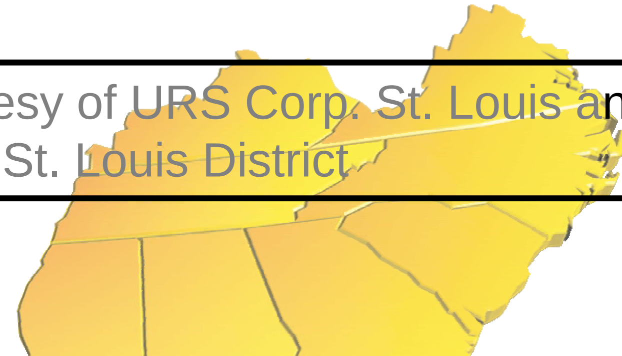
Large strain analysis + Rate of flood water rise + Seepage analysis + Soil Structure interaction+Coupled analysis + 3D condtition.



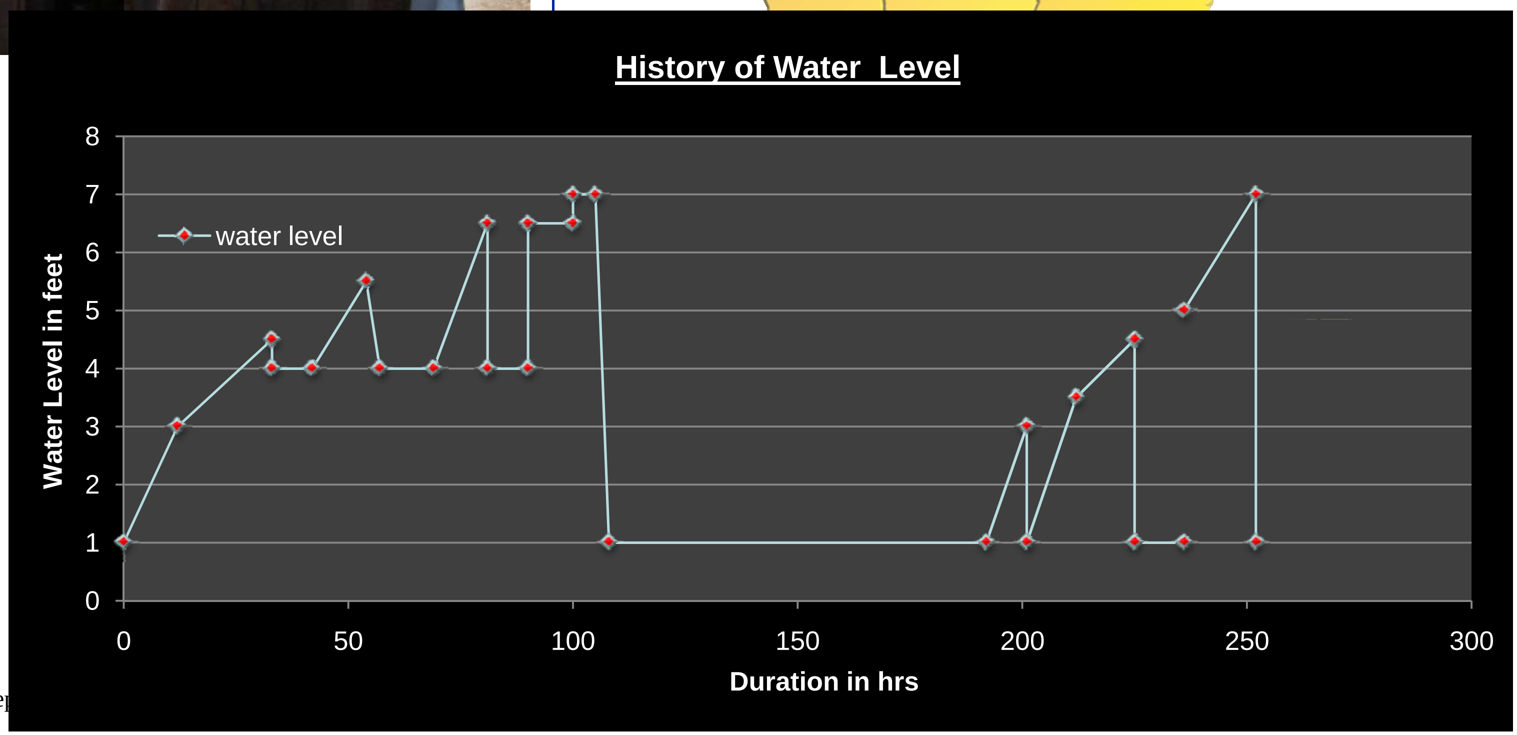
As the water level rises, the seepage condition in the levee changes. So does the stability of the levee.

Following animation shows the transient seepage lines due to the water level rise.

Task 3: Soil-structure-fluid coupled analysis : Analysis of Full Scale I-wall Test Using FLAC London Ave. Canal



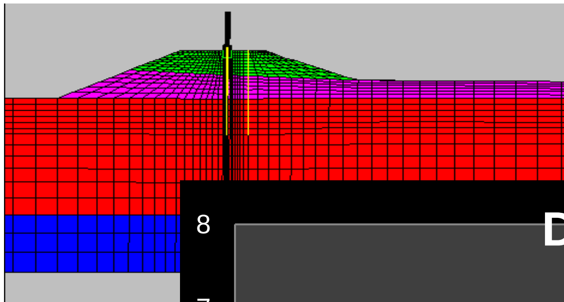
Courtesy of URS Corp. St. Louis and COE, St. Louis District

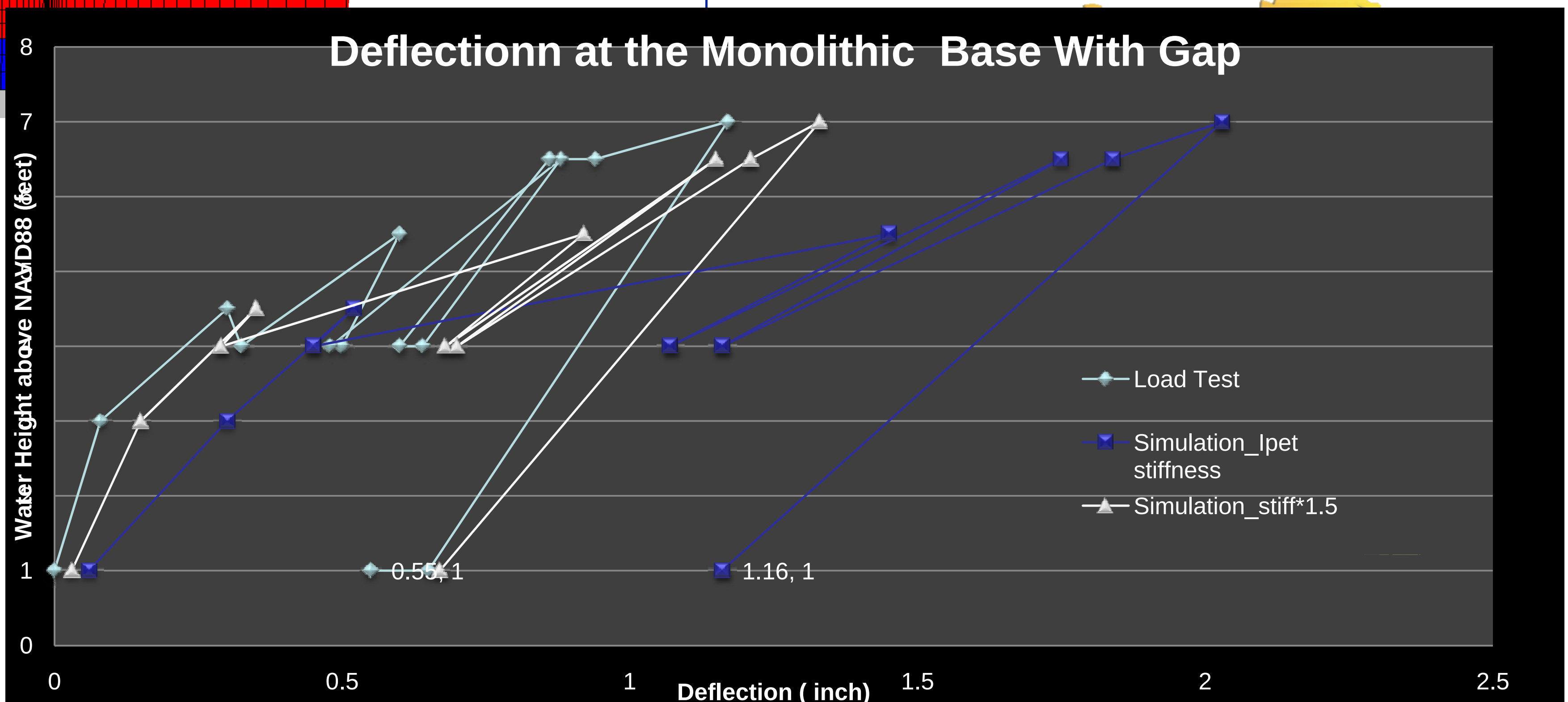


Task 3: Soil-structure-fluid coupled analysis

Analysis of Full Scale I-wall Test Using FLAC

London Ave. Canal- Data Calibration



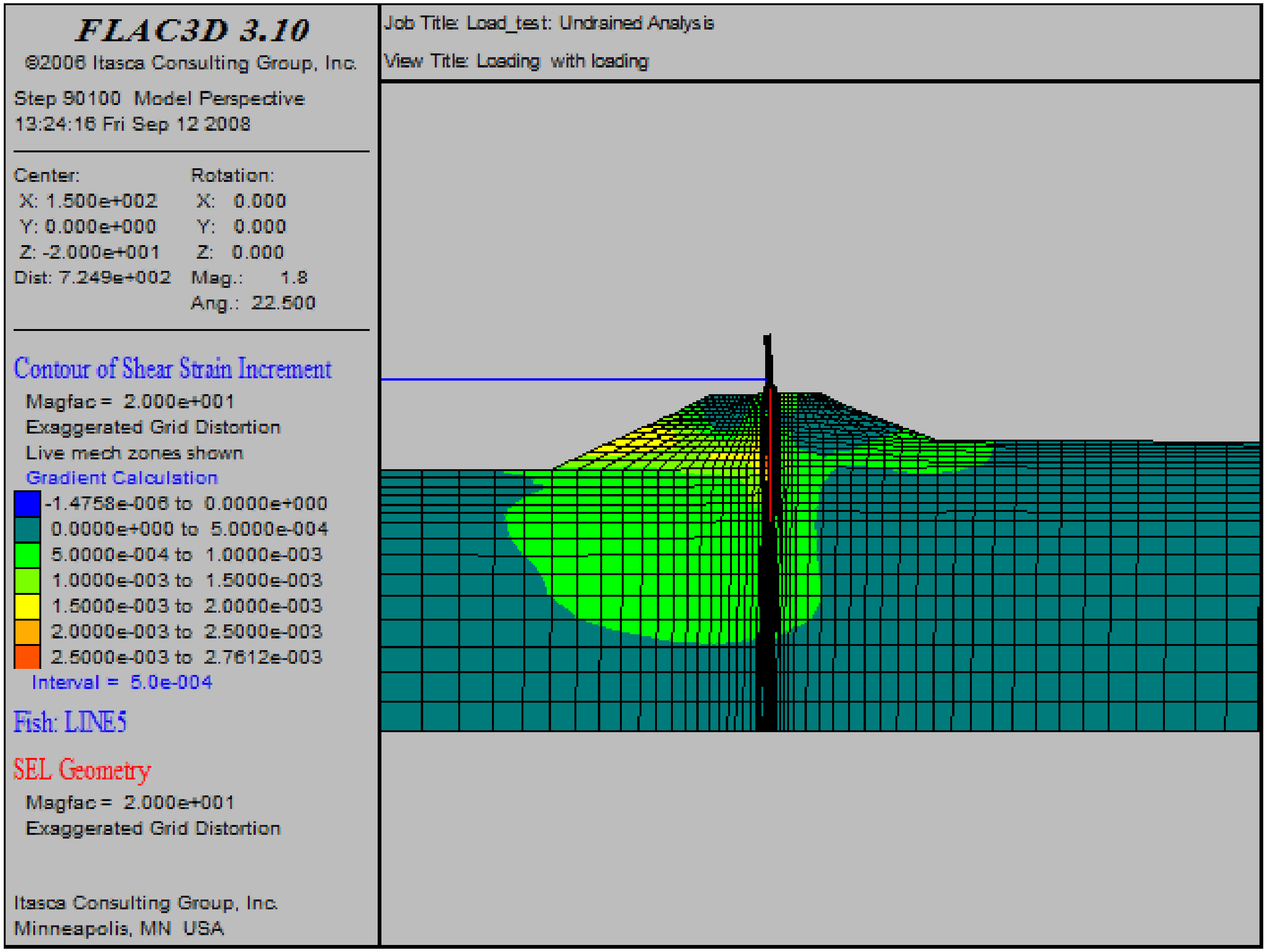


To match the full scale test data, moduli were doubled, and gap was introduced.

Task 3: Soil-structure-fluid coupled analysis : Analysis of Full Scale I-wall using FLAC London Ave. Canal- Failure Simulation

Water Level 10 ft. w. Gap

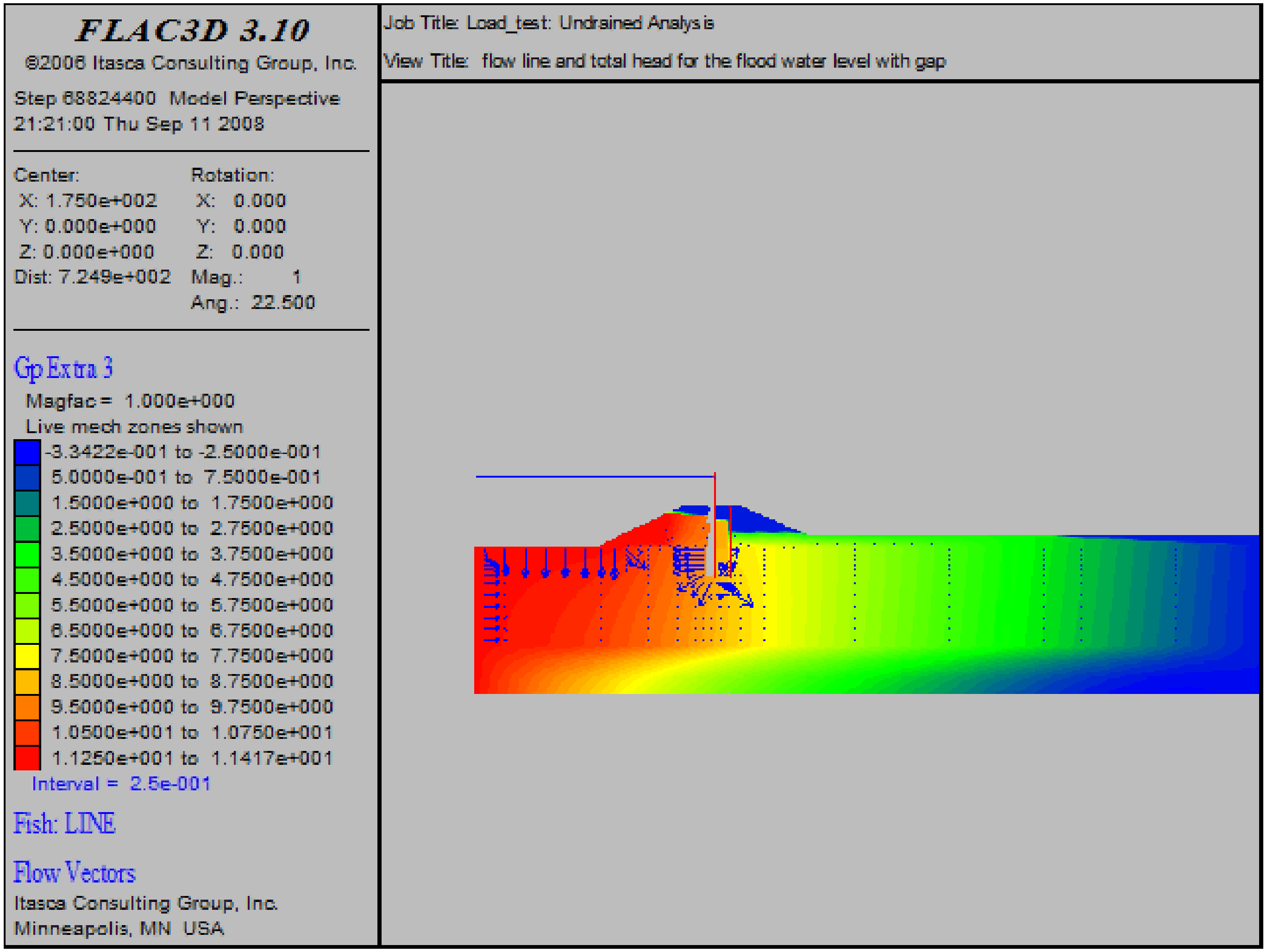
I-wall failed completely with gap development.



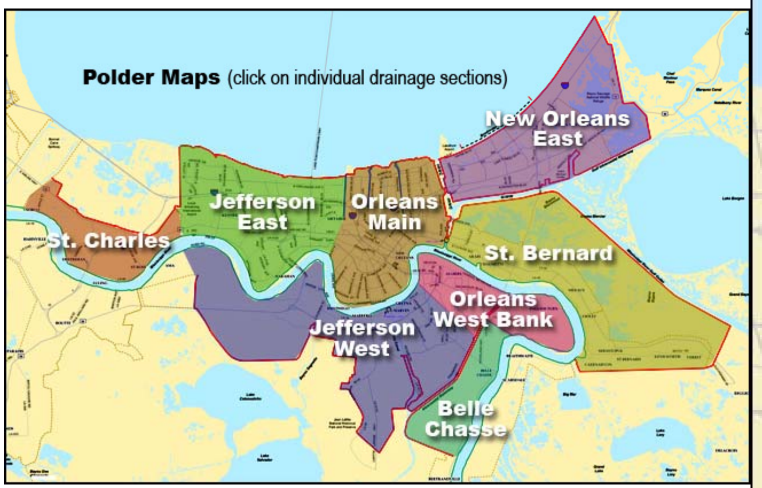
Task 3: Soil-structure-fluid coupled analysis : Analysis of I-wall Using FLAC London Ave. Canal- Seepage Analysis

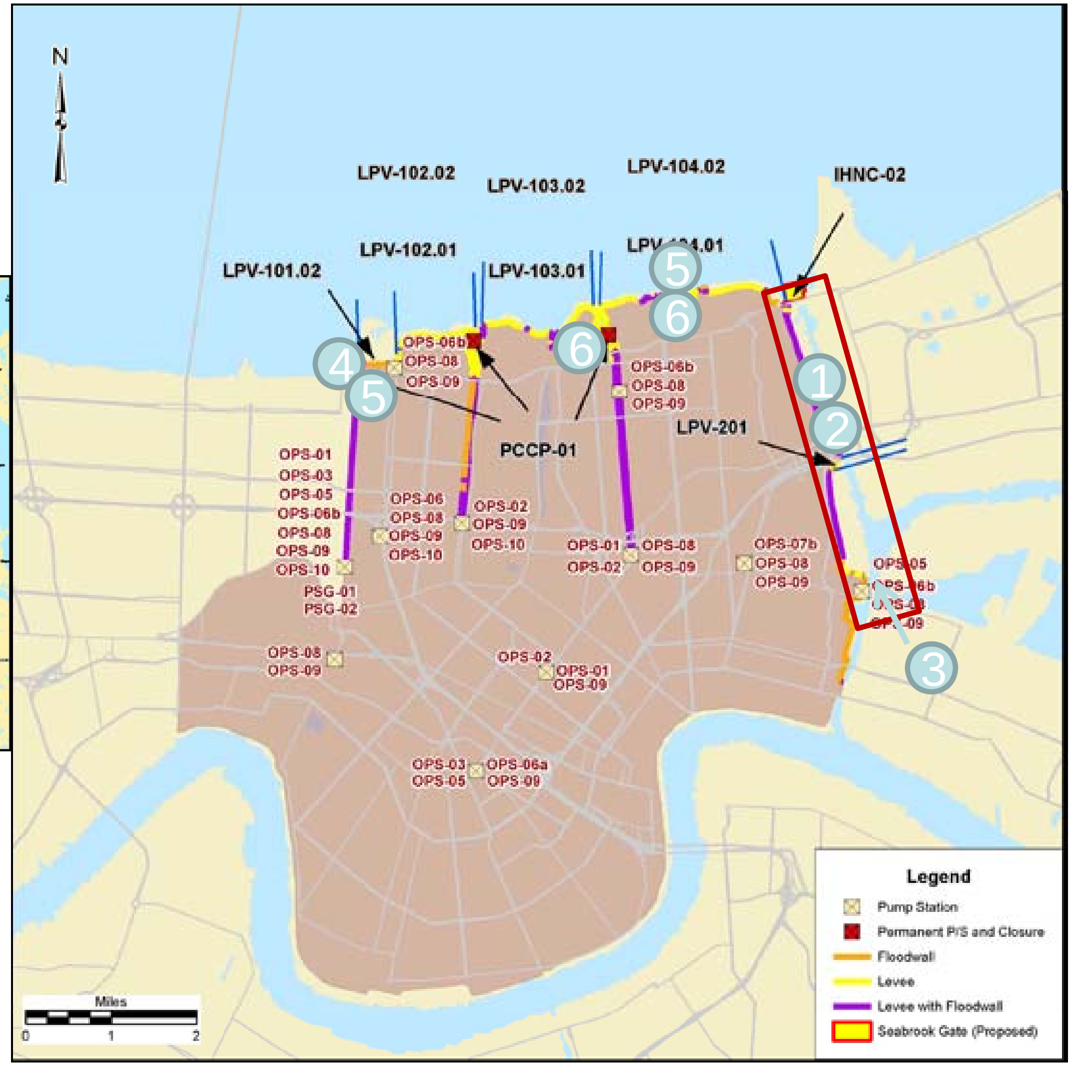
Water Level 10 ft. w/o Gap

Flow vectors are wide spread throughout the levee – healthy seepage condition.



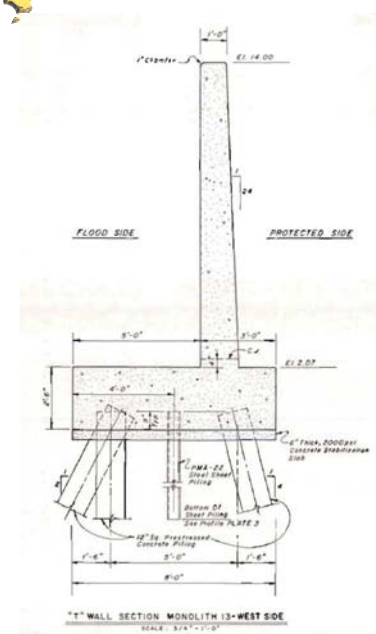
Task 3: Soil-structure-fluid coupled analysis : Distribution of T-wall Locations – Orleans District

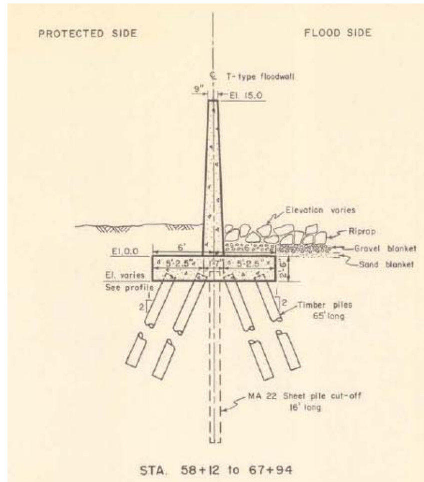


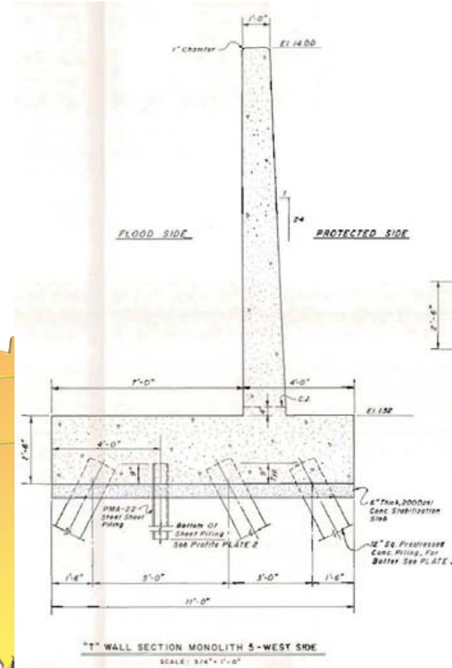


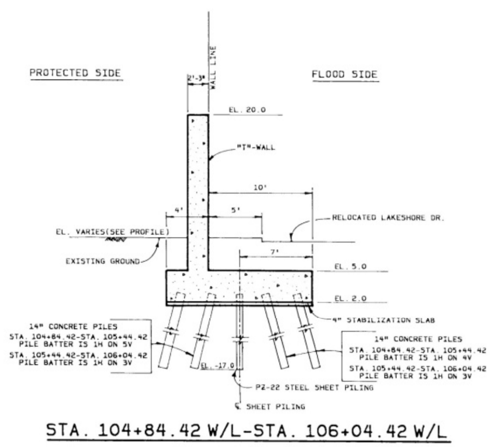
1. Orleans East Bank

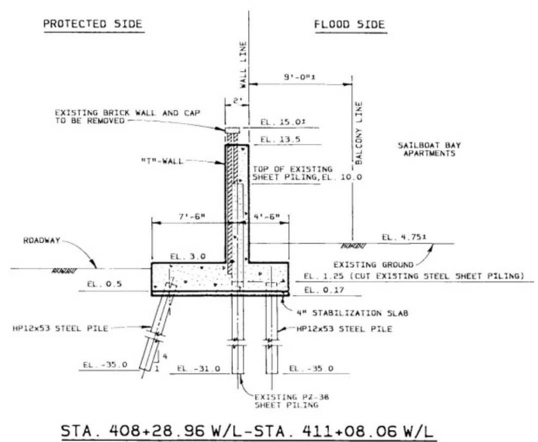
Task 3: Soil-structure-fluid coupled analysis : **Typical section**











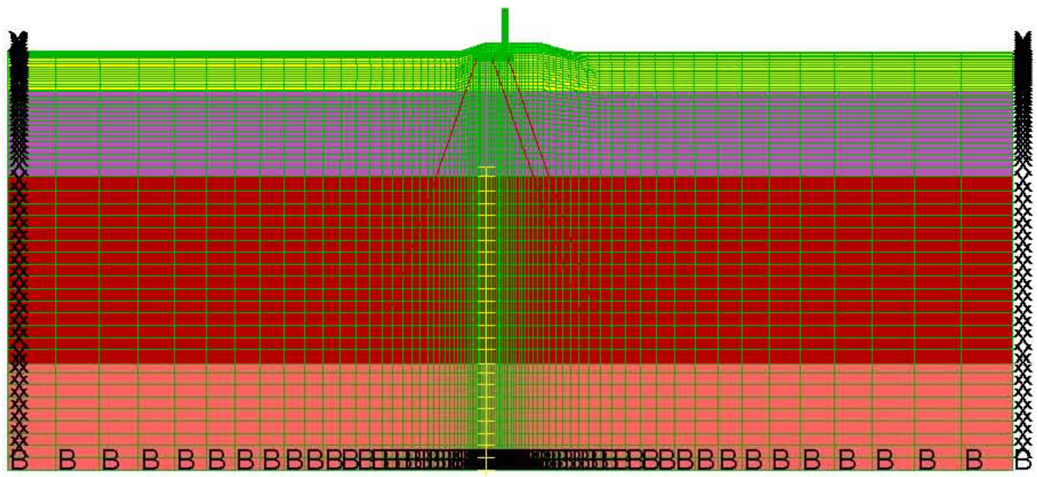
Various T-Walls in New Orleans

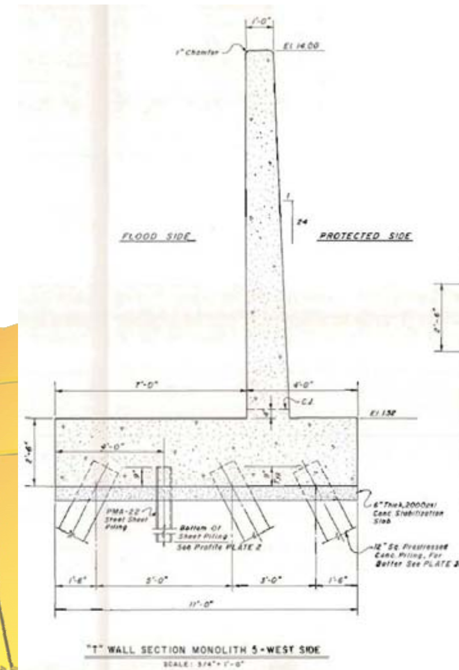
Summary of T-wall and various structures in New Orleans Area *Jinoh won*

No.	Area	IPET Page (III-)	Reference	IPET Ref#	Year	T-Wall	Gate	Pump st.	Flood wall	ETC	CAL
1	Orleans East Bank	51	DM19	4	1988			PW4			CAL
2	Orleans East Bank	56	DM13	7	1987	TW2S					
3	Orleans East Bank	67	DM2	12	1967	TW2S	GWR2S				CAL
4	Orleans East Bank	70	DM2_SUP5	13	1978		GWS2S			JOINT	CAL
5	Orleans East Bank	72	DM22	14	1993	TW2S	GWS2S			GATE MONOLITH, sluice gate	
6	Orleans East Bank	74	DM13	6	1984	TW2S, TW2AS, TW4S	GWBR2S, GWS2S			JOINT	
7	Orleans East Bank	86	DM2_SUP8	9, 10	1968, 1971	TW2S, TW3S, TW4S	GWR2S			JOINT	CAL
8	Orleans East Bank	108	DM2_SUP8A	36	1997	TW3S	GWBR2S, GWBR2AS, GWBR3S, GWS2S			GATE RAMP, JOINT	CAL
9	Orleans East Bank	115	DM4	37	1980	TW2S, TW3S	GWR3S, GWS2S			HEAD WALL, several struct	CAL
10	New Orleans East	158	DM2_SUP5A	17	1976	TW2S	GWS2S, GWR2S			JOINT	CAL
11	New Orleans East	167	DM2_SUP4	23	1971	TW2S	GWR2S, GWS2S	PW2, PW3		JOINT, Struct (3 sections), ? (86)	CAL
12	New Orleans East	171	DM2	24	1967	TW2S	GWR2S				CAL
13	New Orleans East	174	DM2_SUP8	9	1968	TW2S	GWR2S				
14	St. Bernard	226	DM3_SUP3	41	1966	TW4S				DRAINAGE	
15	Jeperson East Bank	263	DM17	45	1987	TW2S, TW3S	GWBR2S	PW3S. PW6S		JOINT, good figure	
16	Jeperson East Bank	267	DM7A	46	1987	TW2S, TW3S (GEOTECSTILE), TW4S (EXISTING)				**Long T-wall**, several section	
17	St. Charles East Bank	288	DM18	47	1989	TW2S, TW2AS (3 TYPES)	GWS2S			JOINT, Long T-Wall, Sluice gate	CAL
18	New Orleans to Venice	314	DM1_SUP5	52	1987	TW2S				JOINT	CAL
19	New Orleans to Venice	319	DM1_GEN	53	1971	TW2S		PW2S	GFW4S		CAL
20	New Orleans to Venice	324	DM1_SUP4	50	1972	TW2S		PW2S			CAL
21	New Orleans to Venice	333	DM2	54	1970				GFW4S, GFW6S	PUMP STRUCTURE	CAL
22	WEST BANK AND VICINITY	383	TECH REP	39	1996	TW2S	GWS2S			PUMP ST, JOINT	
23	WEST BANK AND VICINITY	398	DM1_GEN	32	1989	TW2S, TW3S	GWS2S, GWBR2S	PW2S		JOINT	

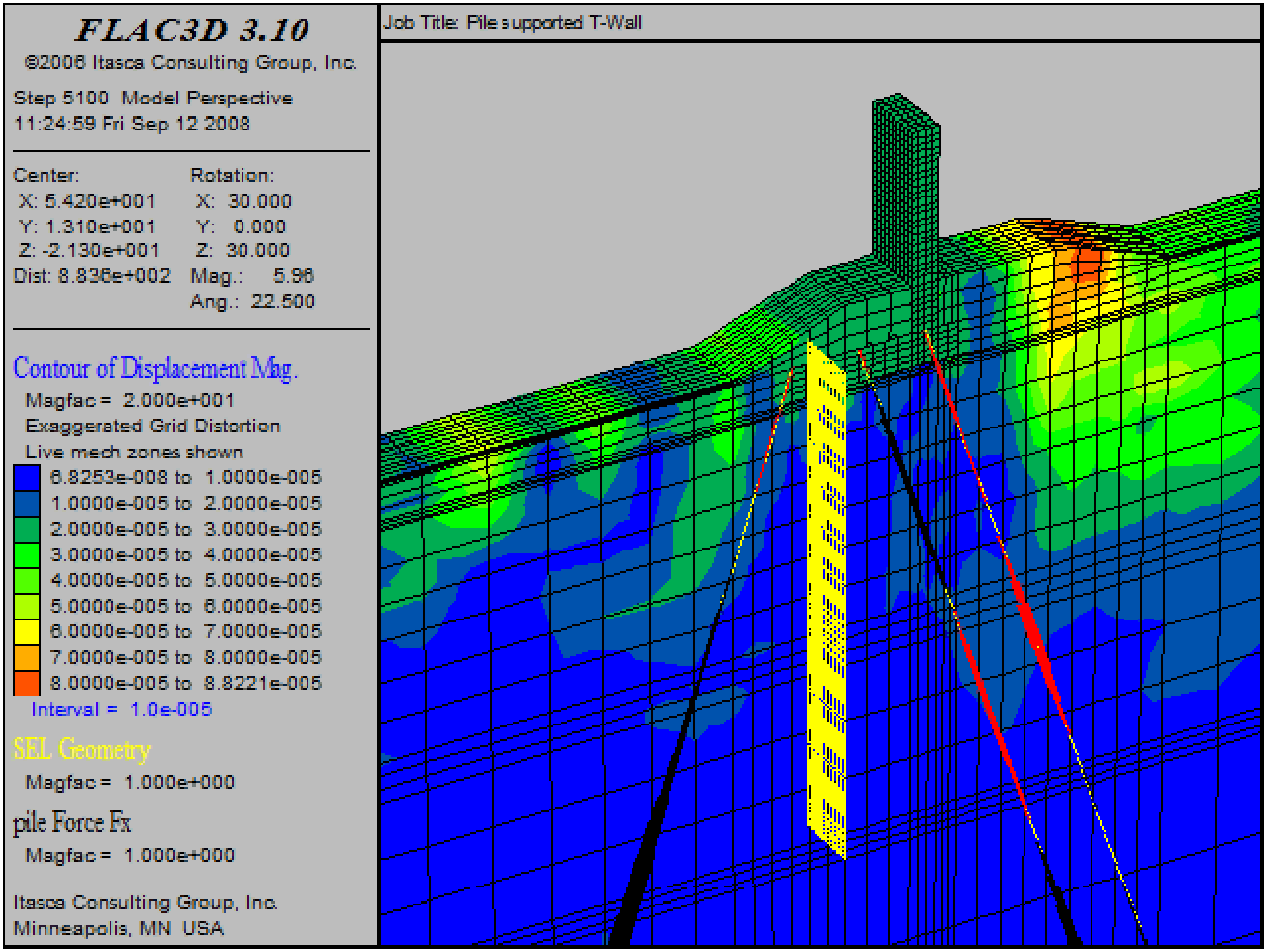
Year	T-Wall	Gate	Pump st.	Flood wall
60S: 5	TW2S: 18	GWS2S: 10	PW2S: 3	GFW4S: 2
70S: 7	TW3S: 6	GWR2S: 6	PW3S: 1	FGW6S: 1
80S: 9	TW4S: 4	GWBR2S: 4		
90S: 3				
	TW2AS:2	GWR3S: 1	PW2: 1	
		GWBR2AS: 1	PW3: 1	
		GWBR3S: 1	PW4: 1	
			PW6S: 1	

Task 3: Soil-structure-fluid coupled analysis : **Typical T-section**



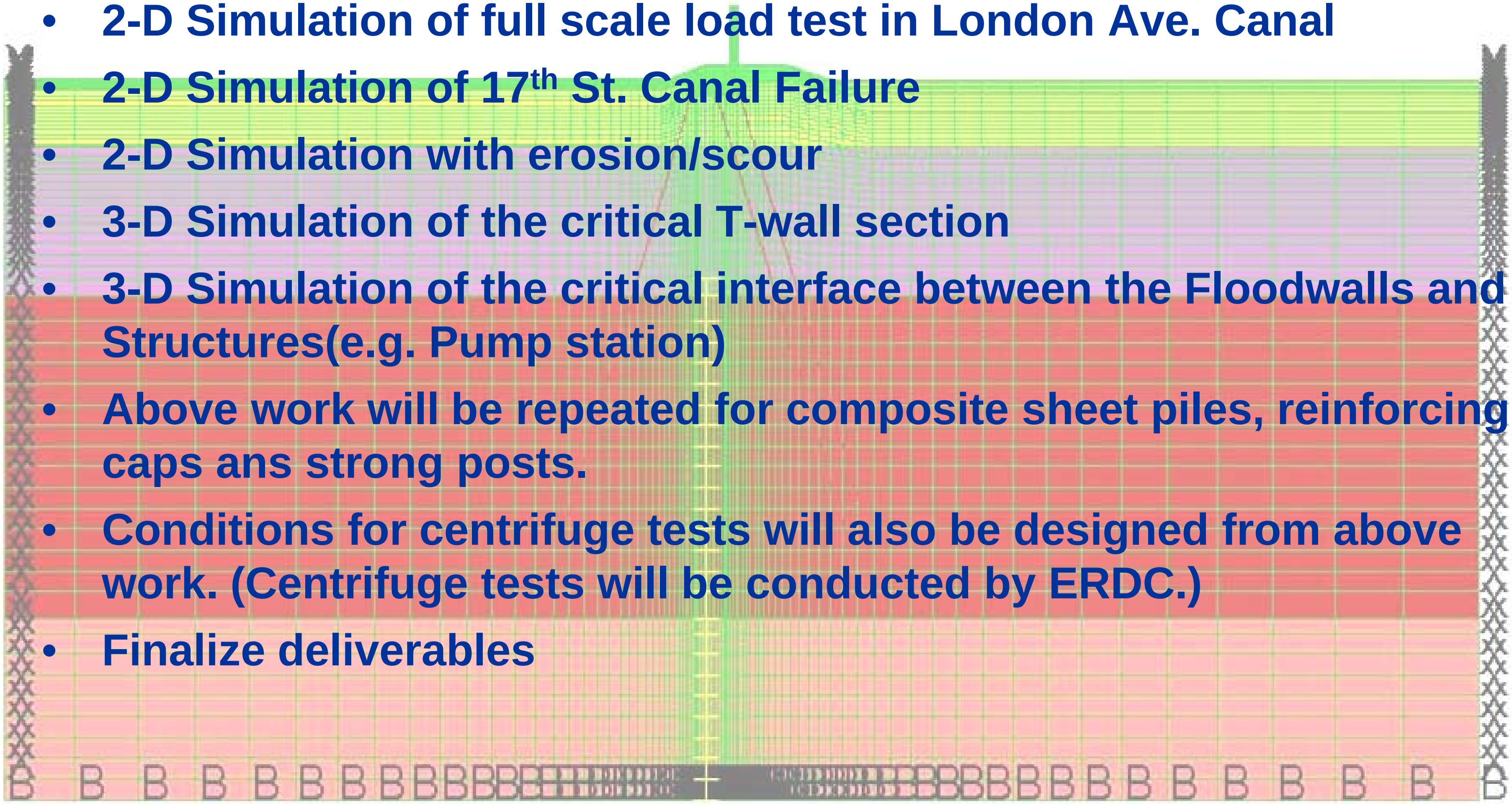


- Existing T-wall analysis is mostly 2-D analysis.
- 2-D analysis has limited flexibility in dealing with the frictional force that exist parallel to the mesh.
- By using 3-D FLAC simulation with advanced constitutive models, realistic 3-D simulation of soil-structure interaction for T-wall is conducted. (Click movie file to see 3-D results.)
- Similar 3-D simulation is also applied for floodwall and structure interfaces.


FLAC3D 3.10
©2006 Itasca Consulting Group, Inc.
Step 5100 Model Perspective
11:24:59 Fri Sep 12 2008
Center:
X: 5.420e+001
Y: 1.310e+001
Z: -2.130e+001
Dist: 8.836e+002
Rotation:
X: 30.000
Y: 0.000
Z: 30.000
Mag.: 5.96
Ang.: 22.500
Contour of Displacement Mag.
Magfac = 2.000e+001
Exaggerated Grid Distortion
Live mech zones shown
6.8253e-008 to 1.0000e-005
1.0000e-005 to 2.0000e-005
2.0000e-005 to 3.0000e-005
3.0000e-005 to 4.0000e-005
4.0000e-005 to 5.0000e-005
5.0000e-005 to 6.0000e-005
6.0000e-005 to 7.0000e-005
7.0000e-005 to 8.0000e-005
8.0000e-005 to 8.8221e-005
Interval = 1.0e-005
SEL Geometry
Magfac = 1.000e+000
pile Force Fx
Magfac = 1.000e+000
Itasca Consulting Group, Inc.
Minneapolis, MN USA
Job Title: Pile supported T-Wall

Task 3: Soil-structure-fluid coupled analysis : Major Work

- **2-D Simulation of full scale load test in London Ave. Canal**
- **2-D Simulation of 17th St. Canal Failure**
- **2-D Simulation with erosion/scour**
- **3-D Simulation of the critical T-wall section**
- **3-D Simulation of the critical interface between the Floodwalls and Structures(e.g. Pump station)**
- **Above work will be repeated for composite sheet piles, reinforcing caps ans strong posts.**
- **Conditions for centrifuge tests will also be designed from above work. (Centrifuge tests will be conducted by ERDC.)**
- **Finalize deliverables**



Geotechnical Solutions

- Deliverables
  - A database of bentonite expansion coefficient under various moisture and confining stress condition
  - A design tool for bentonite curtain placement
  - A database for soil erodibility index against plunging impact, with recommendations
  - A correlation analysis with existing soil erodibility database
  - A computer model for two-dimensional soil-structure-fluid coupled analysis
  - Recommendation of retrofitting strategies based on the computer analysis

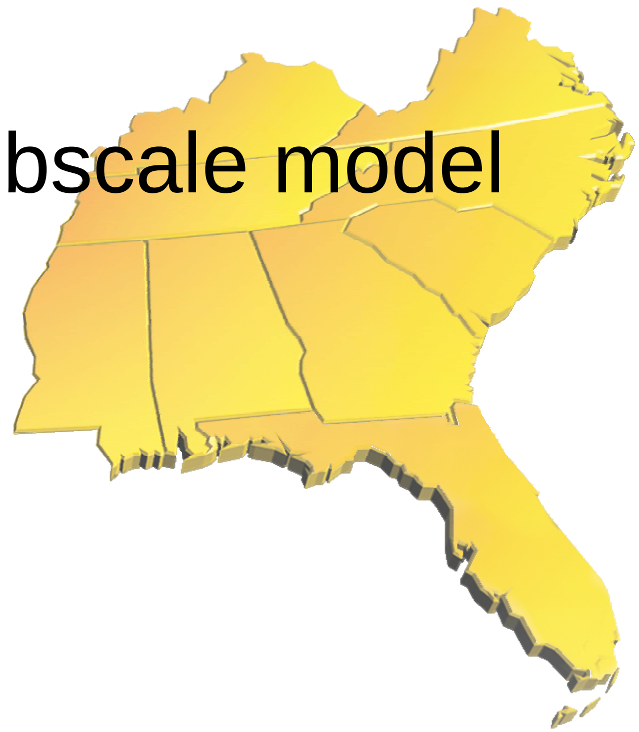
MATERIAL SOLUTIONS

Material Solutions

- Composite sheet pile
- Bentonite for seal-healing crack
- Plastisoil
- Nano particle reinforced polyurea spray

Deliverables-Materials

- Design analysis
- Two or three pieces of subscale model composite sheet piles
- Test result and analysis
- Patents if applicable



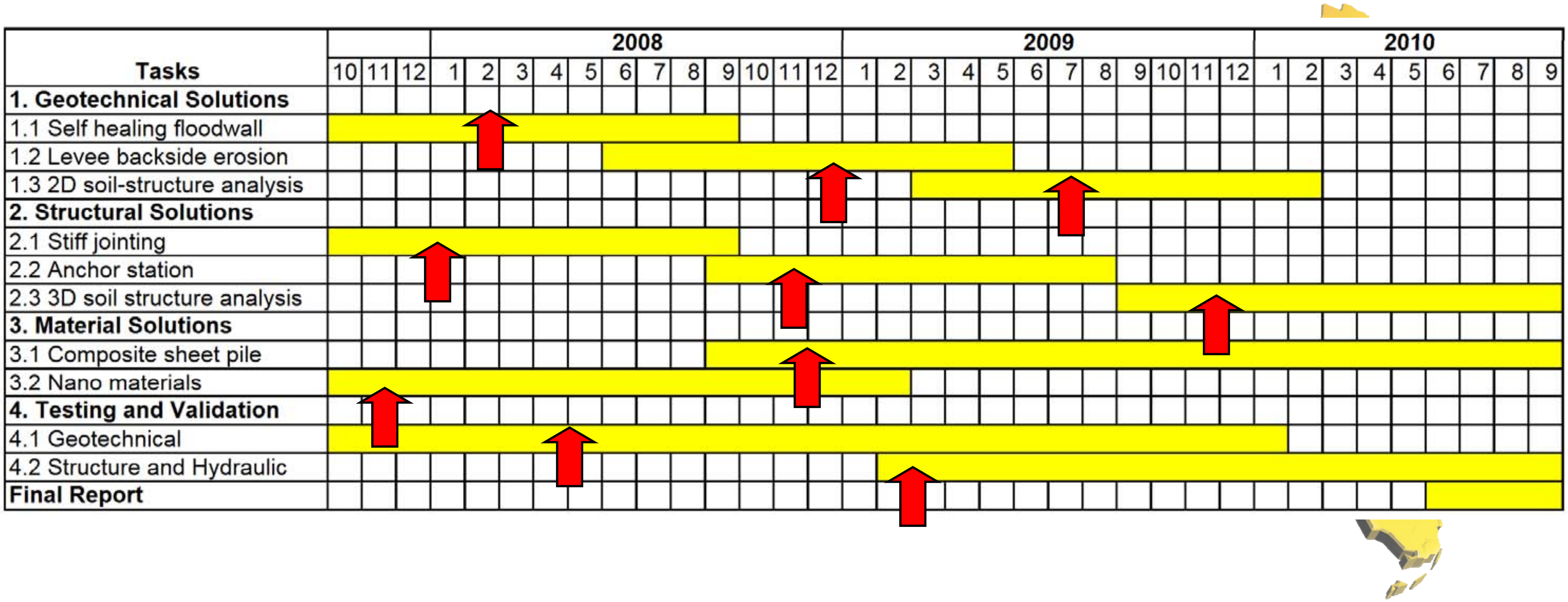
Budget Information

- Original amount: $1,959,537
- Amount spent to date: $368,000 (as of 9/8/08).
- Project end date: 12/31/2010.

Collaborative Opportunities

- Corps of Engineers, New Orleans District.
- ERDC, Vicksburg
- USDA, Dam and Levee Erosion Lab.
- USDA National Sedimentation Lab
- NCCHE, University of Mississippi
- Mississippi State University Projects

Project Timeline



Commercialization Progress

- None so far.

IP STATUS

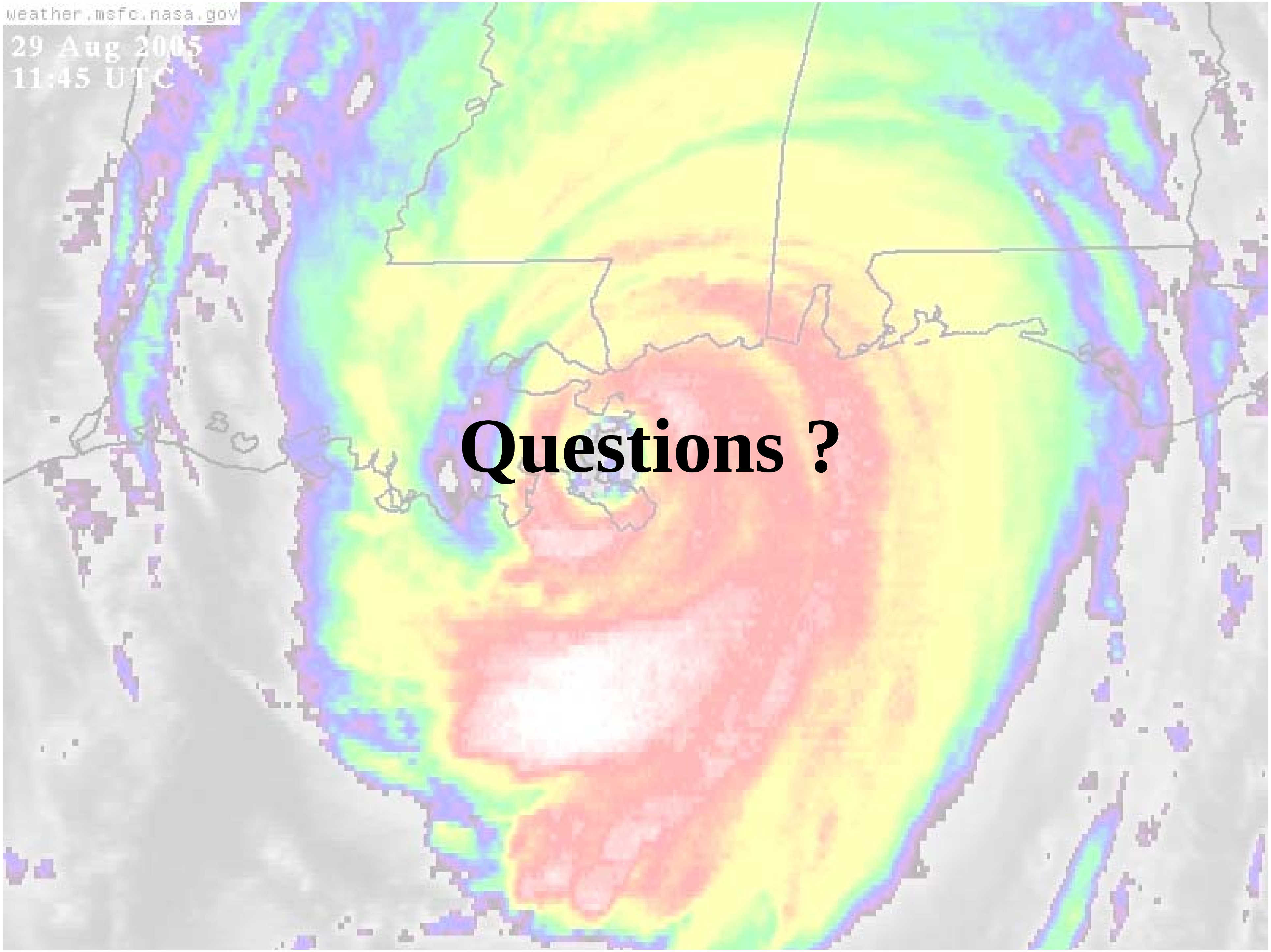
- None so far.

Educaitnal Component

- Ph.D. Students supported
  - Sudarshan Adhikari
  - Wongil Jang
  - Jin-Won Kim
  - Weidong Wu (Ph.D. degree awarded)

Summary & Conclusions

- Research is well underway.
- The schedule for various tasks has been adjusted.
- The overall schedule is on time.
- In The direct communication with Corps of Engineers, New Orleans District, one of the ultimate users of the project.



Questions ?