Jacksonville District

2005 Tri-Service Infrastructure Conference
St. Louis, Missouri 1-4 August 2005

Presentation for

Development of Design Criteria for the Rio Puerto Nuevo Contract 2D/2E Channel Walls

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The Rio Puerto Nuevo

Contract 2D/2E Channel Walls

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- Why is the Flood Control Project needed?
- What wall systems are used?
- How were the wall systems selected?
- What design criteria was used?
- How were the walls designed?

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Project Description

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- Includes 11.2 miles of channel improvements, using 8 different channel sections, through the middle of San Juan.
- Includes 30 bridge modifications and replacements, 2 debris basins, and 2 stilling basins.

Project Location

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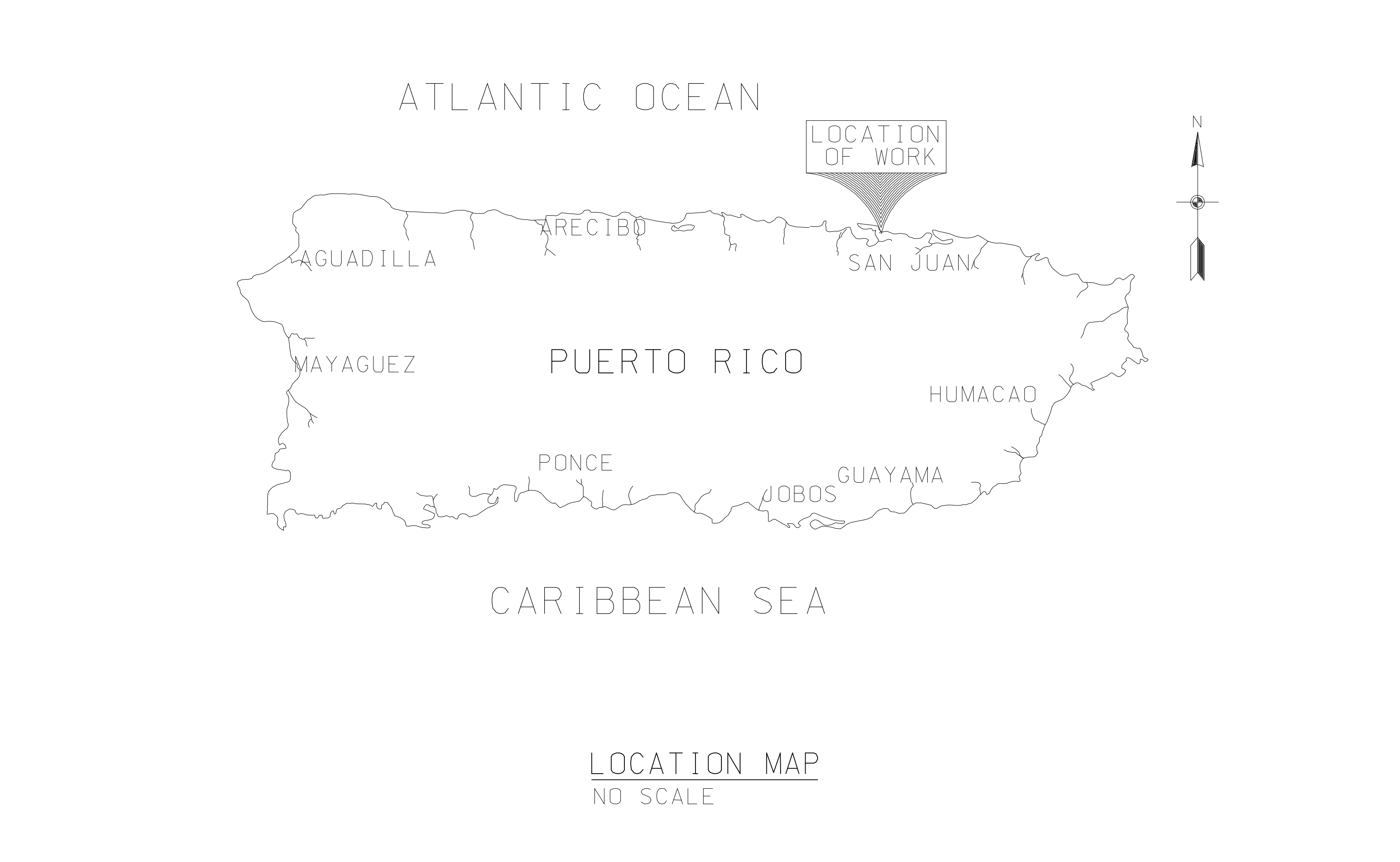

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Rio Puerto Nuevo Project

Jacksonville District

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Rio Puerto Nuevo Site Plan

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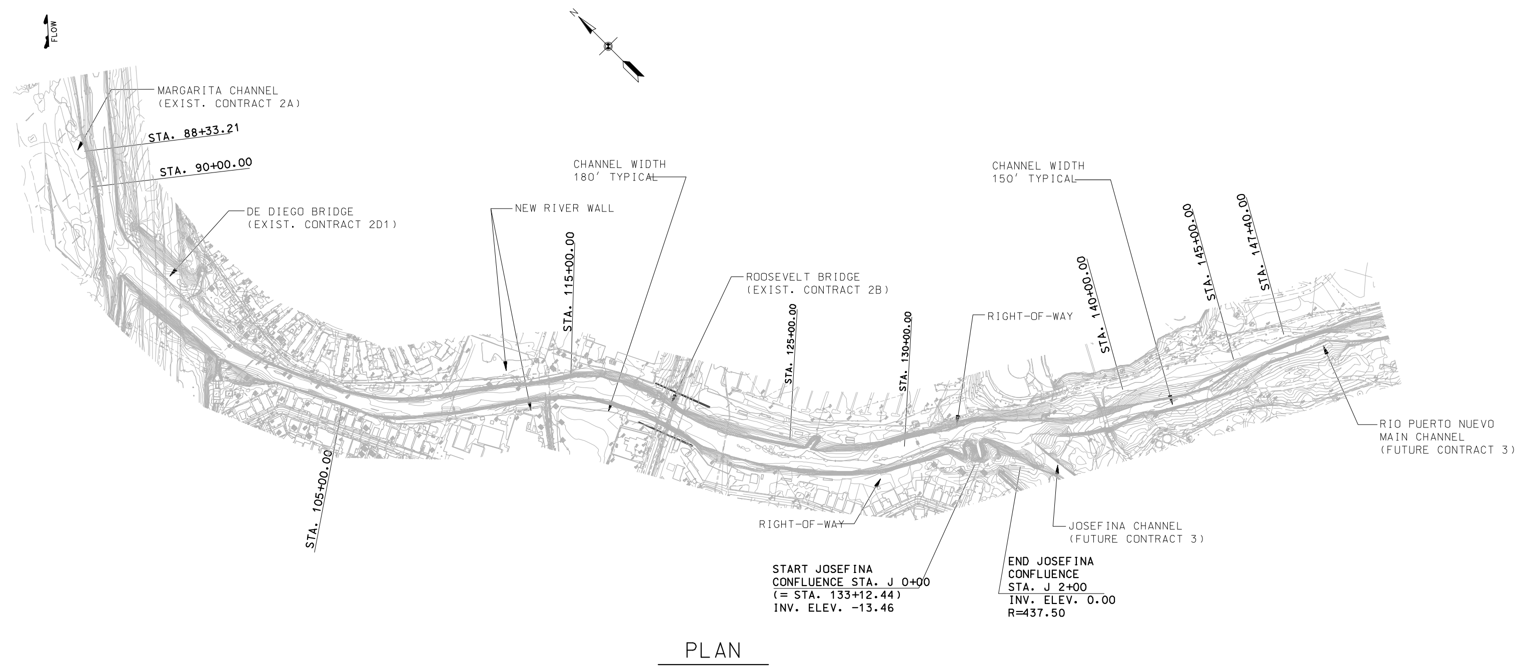

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Contract 2D/2E Description

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- Convert an existing trapezoidal earthen ditch, the Rio Puerto Nuevo, into a 150 foot wide by 15 foot deep rectangular channel.
- Channel walls and bottom designed separately.

Typical Channel Cross Section

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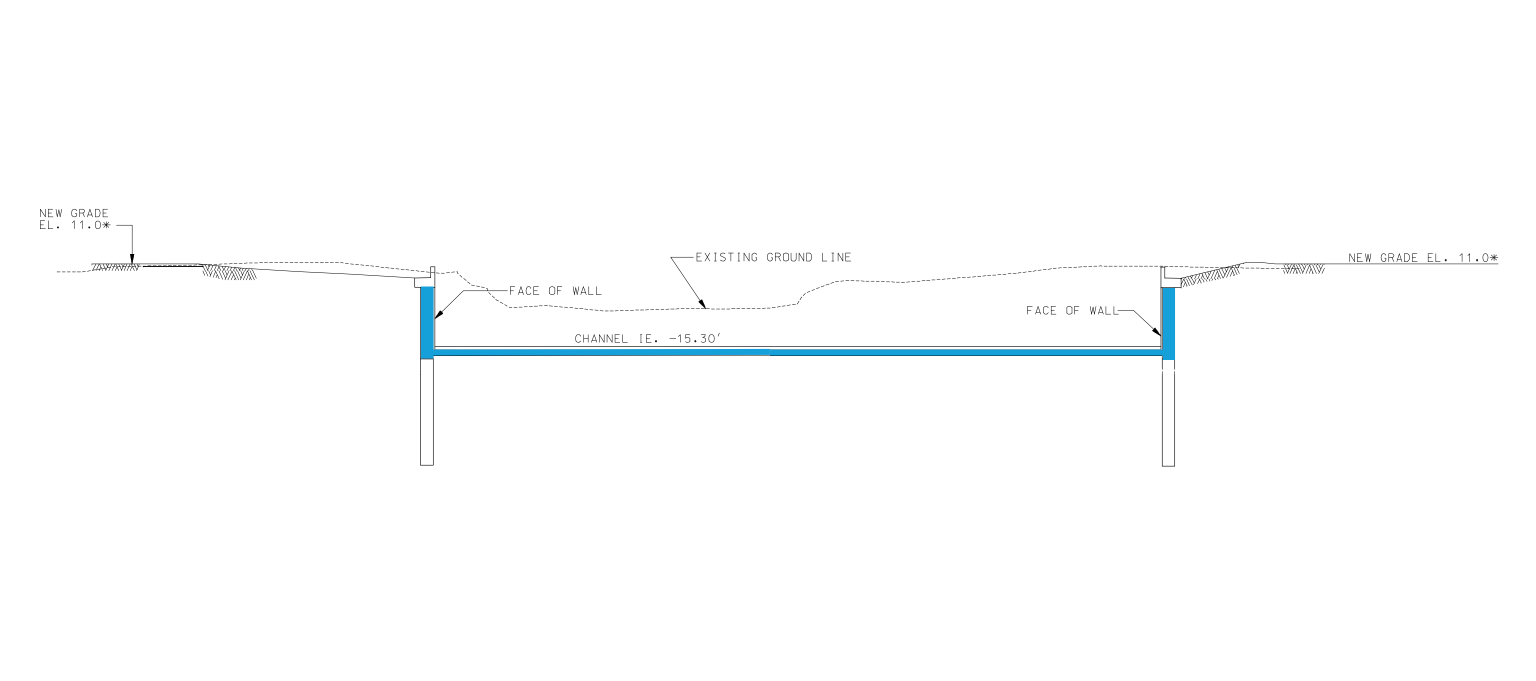

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Wall Design Goals

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- Develop least cost wall system for 10,700 lineal feet of channel wall with an average exposed face of 23 feet.
- Satisfy hydraulic design, real estate, and construction constraints.

Hydraulic Design Constraints

Jacksonville District

- Channel geometry must remain rectangular (i.e. vertical walls) for hydraulic and R/W acquisition reasons.
- Wall facing system must have a Manning's roughness constant consistent with finished concrete (I.e. 0.013)

Wall System Selection

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- **VE** selected 5 wall systems & 2 proprietary wall systems.

- **Further study** selected 2 wall types that were fully designed and detailed in the construction documents.

  - **Master Pile Wall.** The master pile wall consists of a series structural pipe piles alternating with lagging pipe piles.

  - **Drilled Shaft Wall.** The drilled shaft wall consists of initially installed lean concrete lagging piles with structural drilled shafts installed between and overlapping the lagging piles.

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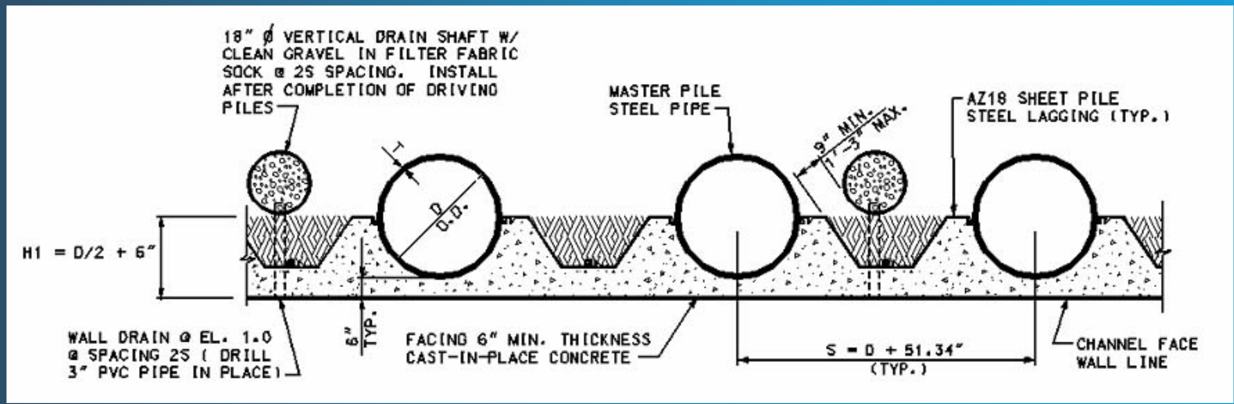
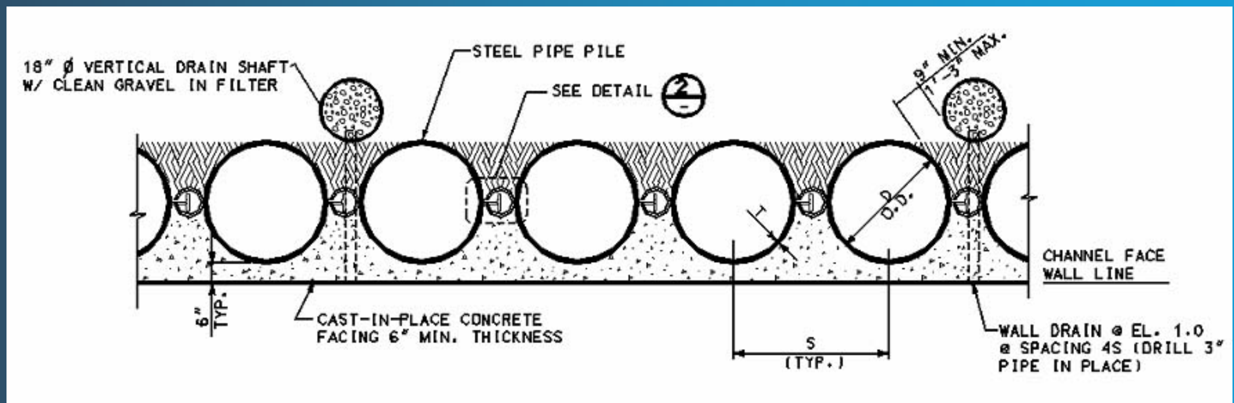
Original & Revised Master Pile Wall

(Plan View)



Original



Revised

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Drilled Shaft Wall (Plan View)

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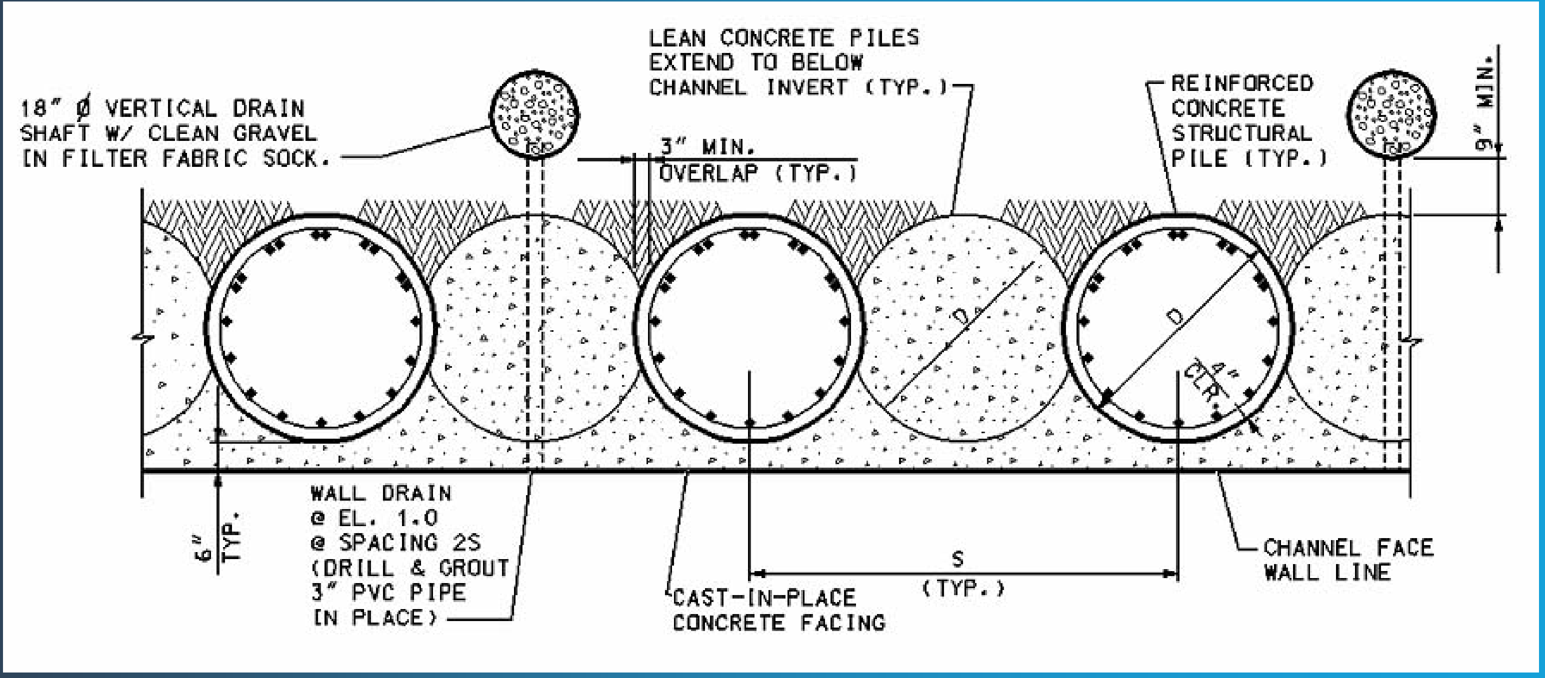

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Geotechnical Site Issues

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- Interlayered Silt and Clay overlies Weathered Bedrock. The top of weathered rock varies in elevation from -30 to -80.

- 3 different geographical profiles were idealized and used to analyze the different reaches of the channel.

Typical Geologic Profile

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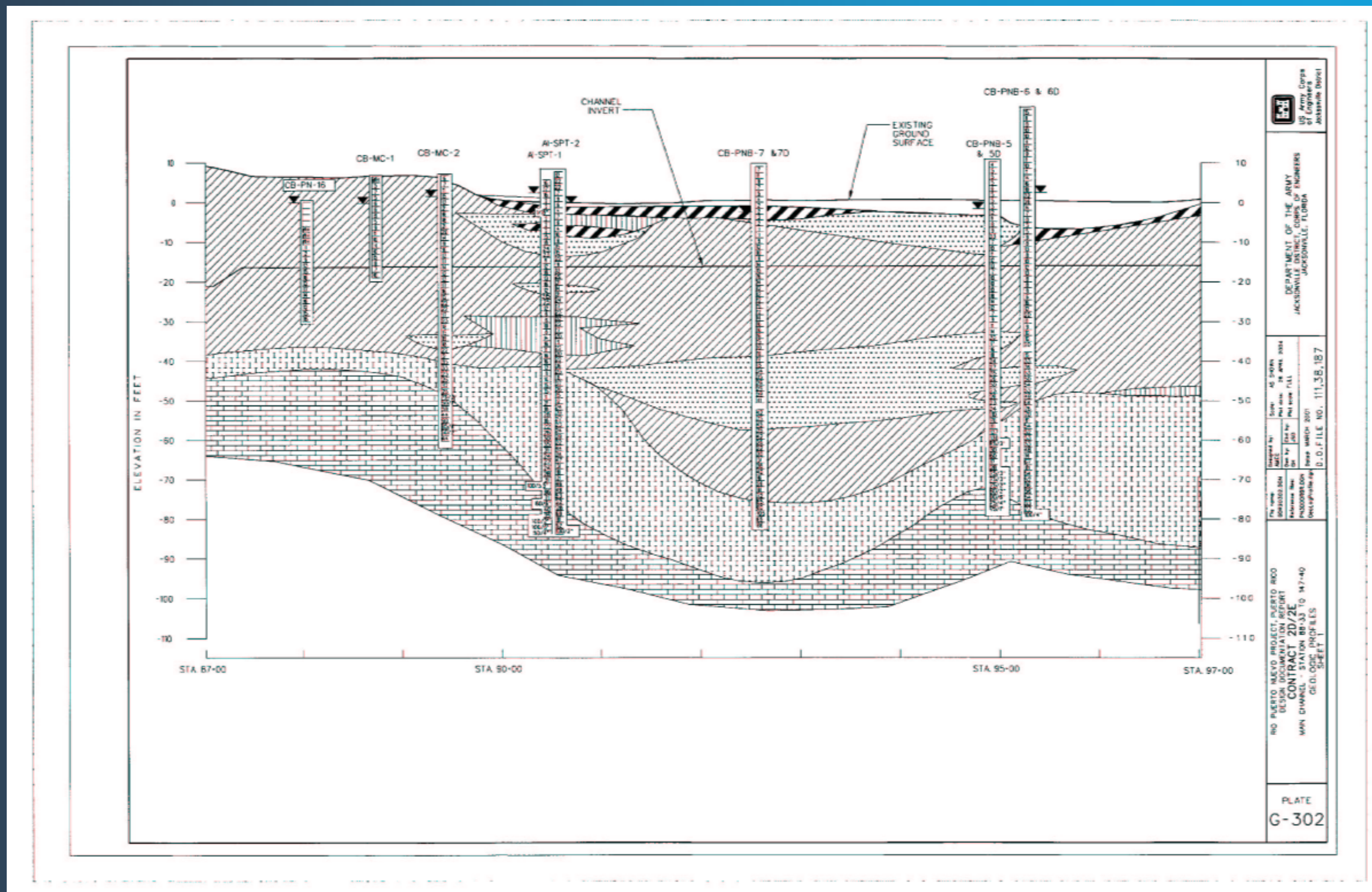

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Geologic Profile Types for Pile Design

Geologic Profile Type	**Top of Weathered Bedrock Elevation** *(feet)*	**Channel Reach Station Interval (Structural Design Reach)**	**Total Length of Channel Reaches** *(feet)*
A	-30	117+50 to 121+50 (A1) 132+50 to 139+00 (A2)	1050
B	-50	88+30 to 89+50 (B1) 95+50 to 117+50 (B2) 121+50 to 132+50 (B3)	3420
C	-80	89+50 to 95+50 (C1) 139+00 to 147+40 (C2)	1440

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Soil & Rock Properties

Soil Layer	Stress State	Internal Friction Angle *(degrees)*	Cohesion *(psf)*	Total Unit Weight *(pcf)*	Saturated Unit Weight *(pcf)*
Interlayered Silt & Clay (CH)	Q	$\phi = 0$	c = 720	110	115
	S	$\phi' = 25$	c’ = 0	110	115
	R	$\phi = 15$	c = 400	110	115
Weathered Bedrock	Q	$\phi = 0$	c = 3,000	125	125
	S	$\phi' = 35$	c’ = 0	125	125
	R	$\phi = 15$	c = 750	125	125

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Subgrade Reaction Moduli Used for LPile Analysis

Elevation *(feet)*	Geologic Profile Type — Subgrade Reaction Modulus, K_h *(pci)*		
	A	B	C
-15	16	16	16
-20	22	22	22
-25	30	30	30
-30	200	43	43
-35	200	61	61
-40	200	76	76
-45	200	93	93
-50	200	200	103
-55	200	200	111
-60	200	200	120
-65	200	200	128
-70	200	200	138
-75	200	200	148
-80	200	200	200
-85	200	200	200

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Design Philosophy

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Working Stress vs. Ultimate Strength Design

- The Master Piles were designed using working stress design.
- The Drilled Shafts were designed using the ultimate strength, load factor design.

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Serviceability Design

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- Design for serviceability addresses the concerns related to displacements of the loaded structure, both global stability and deflection.
- For a diaphragm wall there are three stability concerns
  - **Global rotation** (deep-seated failure)
  - **Rotational failure** (due to inadequate penetration)
  - **Flexural failure** (structural inadequacy)

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Rotational Failure

Rotational failure is due to inadequate penetration and is prevented by long pile action

- Good practice to ensure long pile action
  - Have 2 zero-deflection points
  - Have nearly zero deflection at the pile tip.

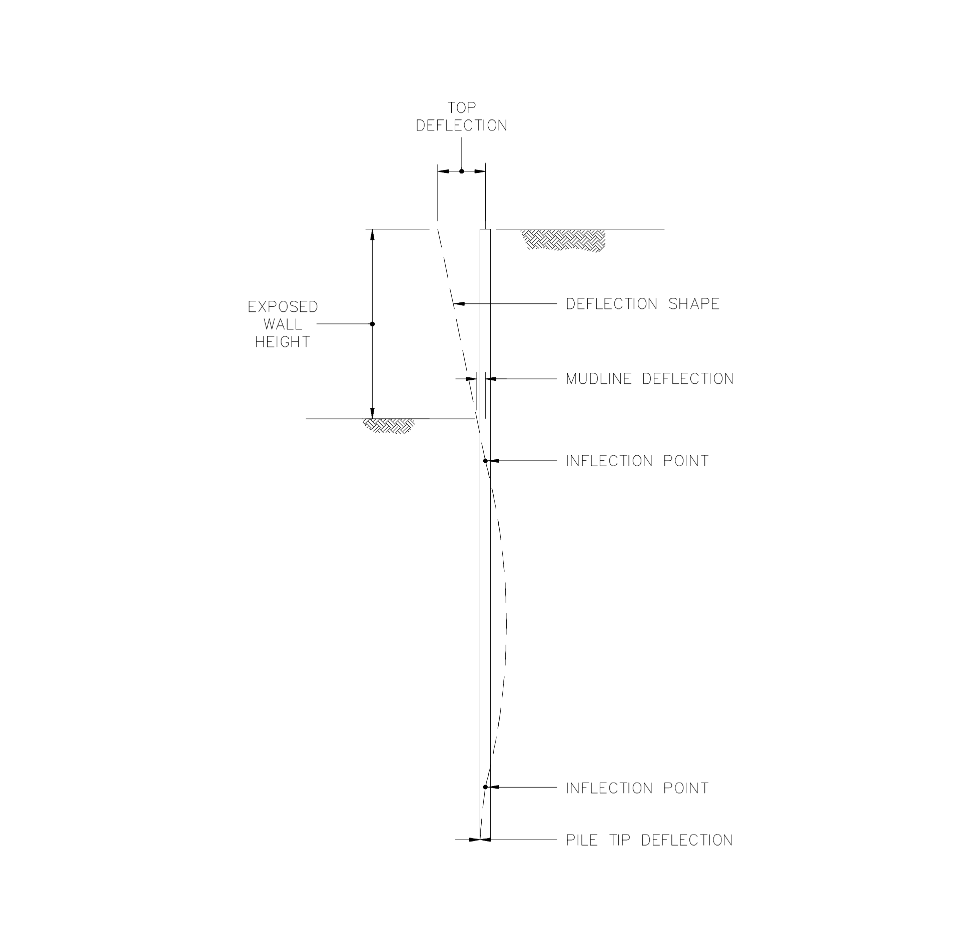
Deflection Criteria

- Good practice is to limit the wall deflection.

  Deflection criteria for the static load case has been developed (by team consensus not by EM) to limit the ratio of the top of wall deflection vs. the mudline deflection to 2% of the exposed wall face height.

- Seismic deflection does not have a limit, but this structure:
  - Must remain elastic during an OBE event
  - May be plastic during an MDE event, but no collapse is permitted

Pile Deflected Shape



Design Procedure

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- Determine the structural demand on the walls
- Calculate the depth of embedment necessary to produce long pile action
- Calculate the factor of safety for wall stability
- Calculate the structural capacity of the walls

Structural Demand

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- Calculate individual loads using classical soil mechanics and then combine results into load cases. The individual loads are:
  - Hydrostatic (channel side)
  - Porewater (landside)
  - Construction surcharge
  - Active condition soil
  - Wall inertia
  - Dynamic soil
  - Hydrodynamic porewater

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Pile Embedment

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- Determine embedment by using LPile
- Iterate to shorten pile in order to
  - Have barely 2 zero deflection points, and
  - Near zero tip rotation w/one zero deflection point near the tip

Stability Check

Jacksonville District

- Use EM 1110-2-2504 “Design of Sheet Pile Walls” for 3 failure modes
  - Deep seated failure
  - Rotational failure
  - Structural failure
- EM 1110-2-2504 is used since it’s for deep foundations

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Results

- Deep seated failure – Geotechnical analysis used Slope/W by Ensoft and determined that the walls, as designed, are stable

- Rotational failure – Wall as designed has long pile action so is stable for rotational failure

- Structural failure – Wall is designed to have adequate strength

Wall Geometry

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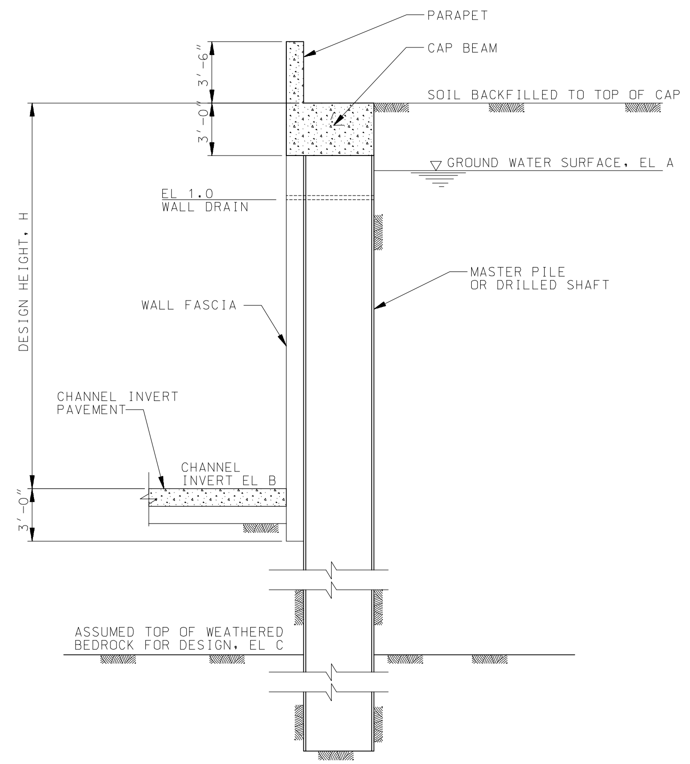

TYPICAL WALL GEOMETRY

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Load Cases

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- The load cases are as follows
  - Load Case 1 Construction
  - Load Case 2A – Flood (Undrained)
  - Load Case 2B – Flood (Drained)
  - Load Case 3A – Drawdown (Undrained)
  - Load Case 3B – Drawdown (Drained)
  - Load Case 4A – OBE Seismic (Undrained)
  - Load Case 4B – MDE Seismic (Undrained)

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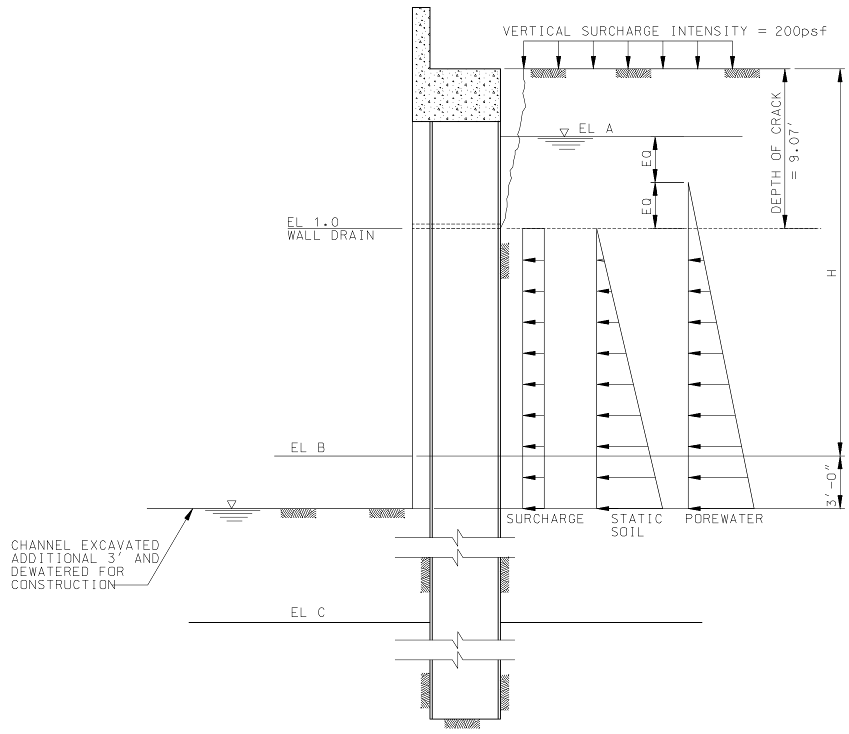
Load Case 1 Construction



LOAD CASE 1: CONSTRUCTION

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Load Case 2A & 2B – Flood (Undrained & Drained)

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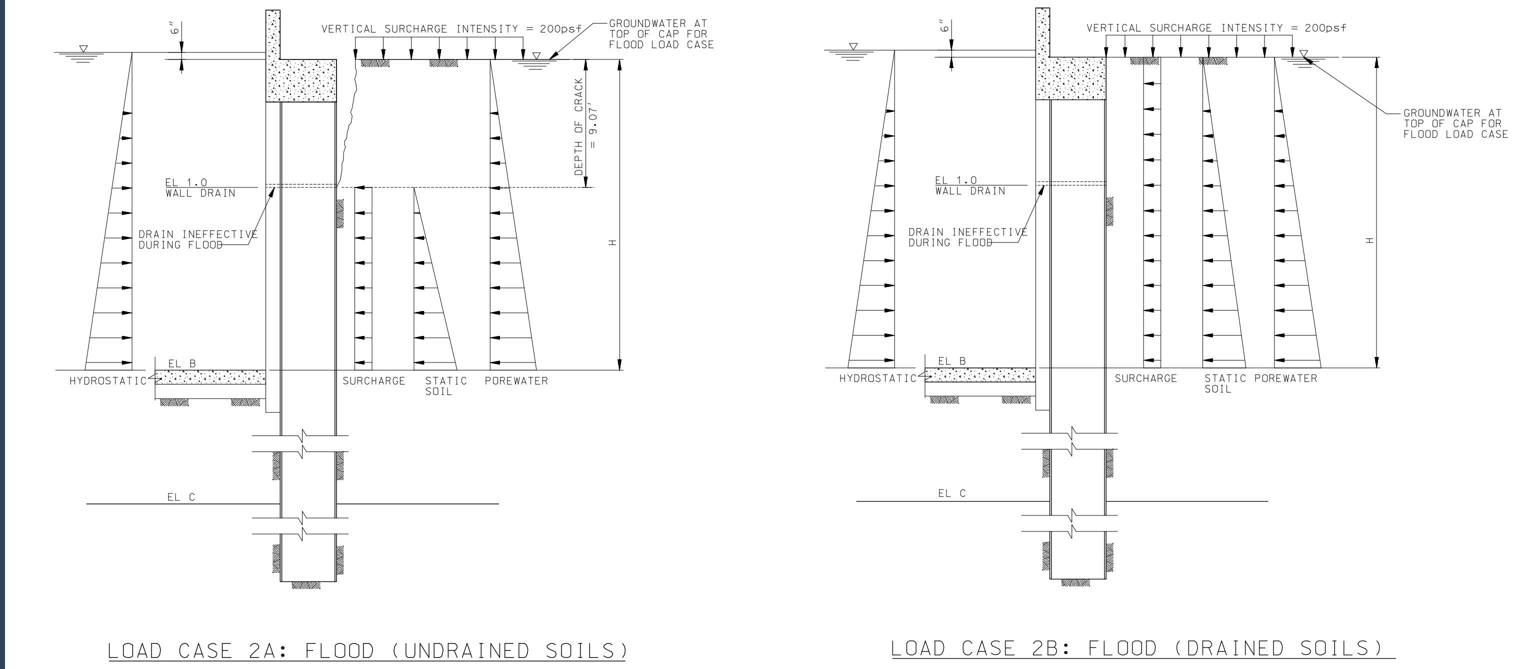

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Load Case 3A & 3B – Drawdown (Undrained & Drained)

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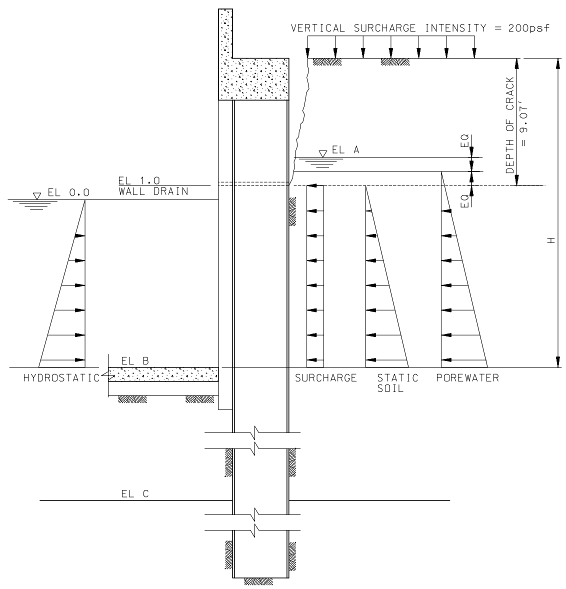
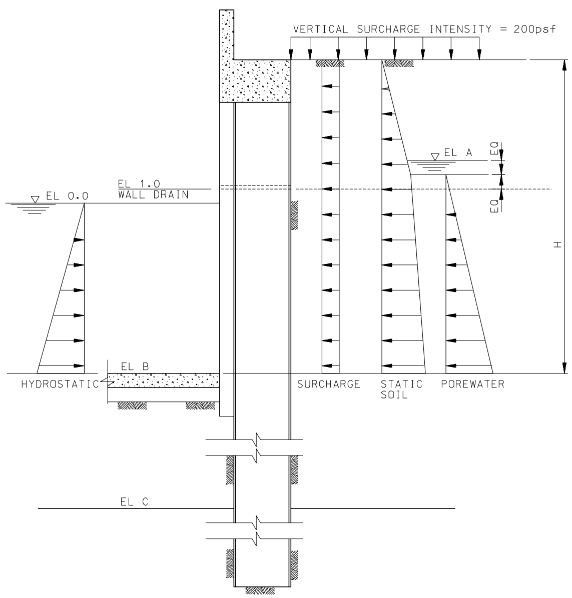


LOAD CASE 3A: DRAWDOWN (UNDRAINED SOILS)



LOAD CASE 3B: DRAWDOWN (DRAINED SOILS)

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Load Case 4A & 4B – OBE Seismic & MDE Seismic (Undrained)

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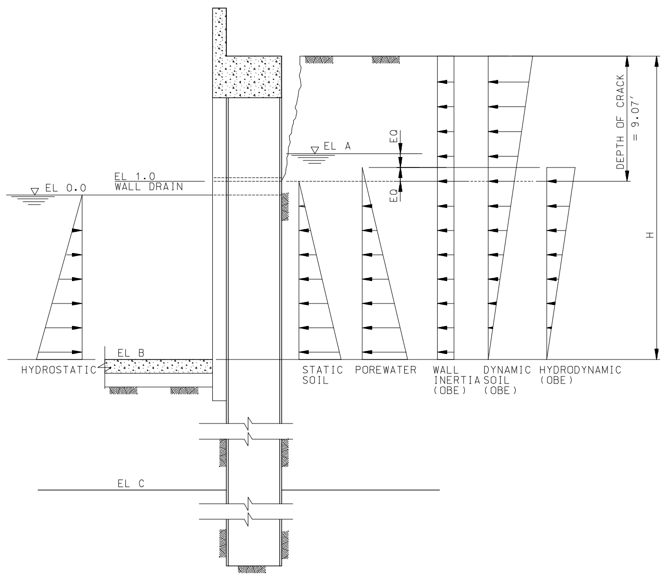
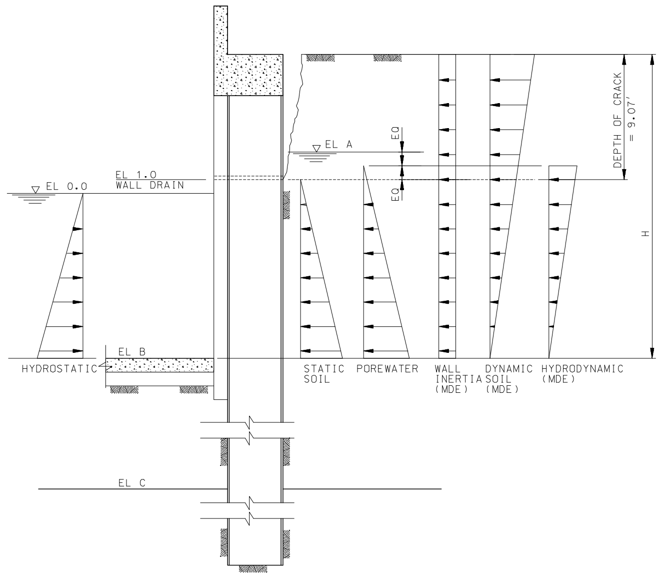


LOAD CASE 4A: OBE SEISMIC (UNDRAINED SOILS)



LOAD CASE 4B: MDE SEISMIC (UNDRAINED SOILS)

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Design Results

- Shear Forces and Bending Moments
  - Drilled Shaft Wall

Design Reach B1	Vu	Static Dynamic	241 k 94 k
	Mu	Static Dynamic	3791 k-ft 1643 k-ft
Design Reach C2	Vu	Static Dynamic	242 k 115 k
	Mu	Static Dynamic	4166 k-ft 2089 k-ft

Design Results

Jacksonville District

- Shear Forces and Bending Moments
  - Master Pile Wall

Design Reach B1	V	Static Dynamic	182 k 81 k
	M	Static Dynamic	2797 k-ft 1348 k-ft
Design Reach C2	V	Static Dynamic	151 k 101 k
	M	Static Dynamic	2280 k-ft 1728 k-ft

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Design Results

Jacksonville District

- The static load cases govern the wall design for all design reaches.
- The static shears and moments are approximately twice the dynamic shears and moments.
- Since the static cases govern, the seismic coefficient method is an acceptable procedure.

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Design Results

Jacksonville District

- Maximum Displacements
  - Drilled Shaft Wall

Design Reach	Location	Load Type	Displacement
B1	Top	Static	3.70 in
		Dynamic	2.34 in
	Mudline	Static	1.49 in
		Dynamic	0.78 in
C2	Top	Static	3.80 in
		Dynamic	3.21 in
	Mudline	Static	1.40 in
		Dynamic	1.00 in

Design Results

- Maximum Displacements
  - Master Pile Wall

Design Reach	Location	Load Type	Displacement
B1	Top	Static	6.02 in
		Dynamic	2.84 in
	Mudline	Static	2.42 in
		Dynamic	0.90 in
C2	Top	Static	5.54 in
		Dynamic	3.99 in
	Mudline	Static	1.95 in
		Dynamic	1.19 in

- Again, the static load cases govern the wall design for all design reaches.

Displacement Serviceability

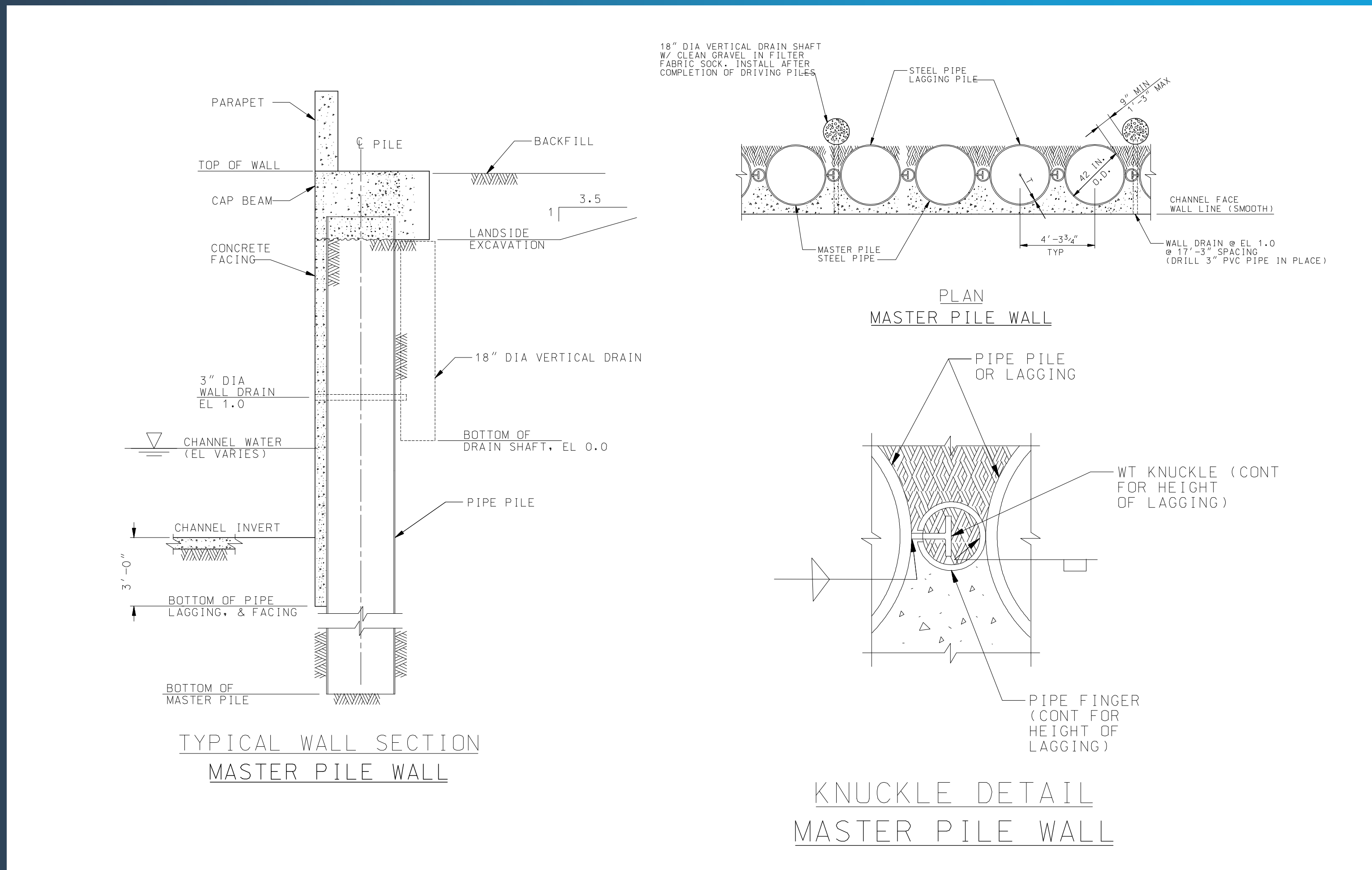
Jacksonville District

Design	Relative Displacement (%)	
Reach	Drilled Shaft	Master Pile
A1	0.7	1.1
A2	0.7	1.1
B1	0.8	1.4
B2	0.8	1.3
B3	0.9	1.3
C1	0.8	1.4
C2	0.8	1.2

- All displacements meet the established deflection criteria.

Master Pile Wall

Jacksonville District



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Drilled Shaft Wall

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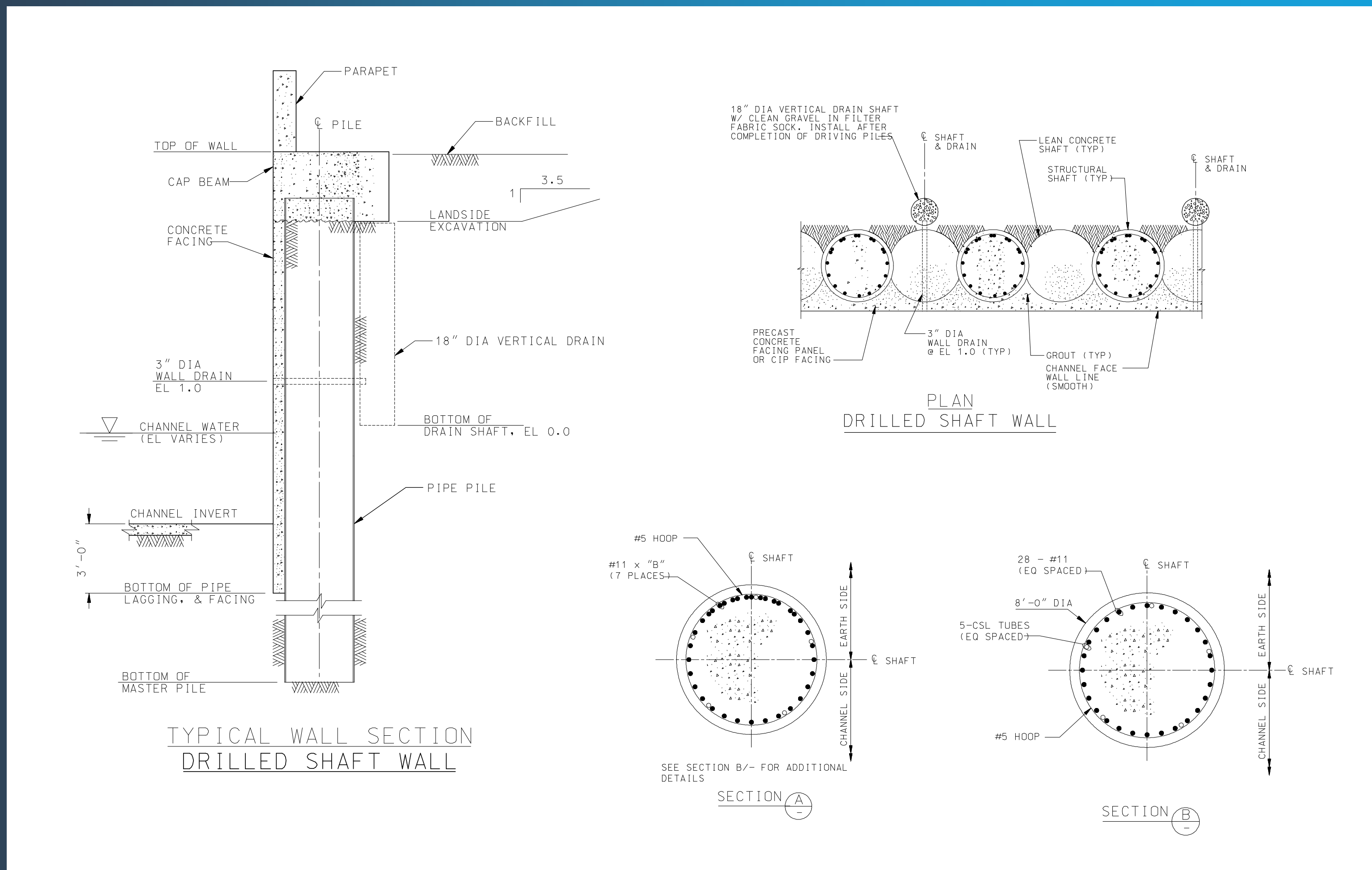

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Cost Comparison

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- 2003 MCACES Cost Estimate

Drilled Shafts w/Precast Facing	$94M
Drilled Shafts w/CIP Facing	$95M
Master Piles w/Precast	$66M
Master Piles w/CIP Facing	$71M

- Foreign Steel Makes Master Piles Cheaper
- Steel Prices Increased Significantly Since 2003

Conclusion

Jacksonville District

- Set idealized soil/rock parameters that can be used for long reaches of the project
- Set serviceability criteria for deflections
- Analyze and design to resist
  - Deep seated failure
  - Rotational failure
  - Structural failure
- Let the market determine the least cost solution – Foreign Steel price fluctuating

Master Pile Wall for Contract 2A

Jacksonville District

- 800 ft of wall installed
- 48” dia, 3/4” wall, ASTM A252, Gr 3 (fy = 45 ksi) pipe piles, with average pile length of 70 ft
- intermediate pair of AZ 18, ASTM A572, Gr 50, steel sheet piles, with an average length of 35 ft

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Drilled Shaft Wall at Bechara Industrial Area

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- 2000 linear feet of culvert
- Top down excavation
- Secant pile wall

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Drilled Shaft Walls at Bechara Industrial Area

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Drilled Shaft Walls at Bechara Industrial Area

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Drilled Shaft Walls at Bechara Industrial Area

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Drilled Shaft Walls at Bechara Industrial Area

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Drilled Shaft Walls at Bechara Industrial Area

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Drilled Shafts at De Diego Expressway Bridge

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Drilled Shafts at De Diego Expressway Bridge

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Drilled Shaft Walls at I-90 Mercer Island, Washington

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Drilled Shaft Walls at I-90 Mercer Island, Washington

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Drilled Shaft Walls at I-90
Mercer Island, Washington

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Drilled Shaft Walls at I-90 Mercer Island, Washington

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SR 526 Interchange / I-5 Northbound Ramp

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