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

- 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?
Project Description

- 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

LOCATION MAP
NO SCALE
Rio Puerto Nuevo Project
Rio Puerto Nuevo Site Plan
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
Wall Design Goals

- 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

- 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

- **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.
Original & Revised Master Pile Wall

(Plan View)

Original

Revised
Drilled Shaft Wall (Plan View)
Geotechnical Site Issues

- 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
Geologic Profile Types
for Pile Design

<table>
<thead>
<tr>
<th>Geologic Profile Type</th>
<th>Top of Weathered Bedrock Elevation (feet)</th>
<th>Channel Reach Station Interval (Structural Design Reach)</th>
<th>Total Length of Channel Reaches (feet)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>-30</td>
<td>117+50 to 121+50 (A1) 132+50 to 139+00 (A2)</td>
<td>1050</td>
</tr>
<tr>
<td>B</td>
<td>-50</td>
<td>88+30 to 89+50 (B1) 95+50 to 117+50 (B2) 121+50 to 132+50 (B3)</td>
<td>3420</td>
</tr>
<tr>
<td>C</td>
<td>-80</td>
<td>89+50 to 95+50 (C1) 139+00 to 147+40 (C2)</td>
<td>1440</td>
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</tbody>
</table>
# Soil & Rock Properties

<table>
<thead>
<tr>
<th>Soil Layer</th>
<th>Stress State</th>
<th>Internal Friction Angle (degrees)</th>
<th>Cohesion (psf)</th>
<th>Total Unit Weight (pcf)</th>
<th>Saturated Unit Weight (pcf)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interlayered Silt &amp; Clay (CH)</td>
<td>Q</td>
<td>$\phi = 0$</td>
<td>$c = 720$</td>
<td>110</td>
<td>115</td>
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<tr>
<td></td>
<td>S</td>
<td>$\phi' = 25$</td>
<td>$c' = 0$</td>
<td>110</td>
<td>115</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>$\phi = 15$</td>
<td>$c = 400$</td>
<td>110</td>
<td>115</td>
</tr>
<tr>
<td>Weathered Bedrock</td>
<td>Q</td>
<td>$\phi = 0$</td>
<td>$c = 3,000$</td>
<td>125</td>
<td>125</td>
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<td>S</td>
<td>$\phi' = 35$</td>
<td>$c' = 0$</td>
<td>125</td>
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<td>R</td>
<td>$\phi = 15$</td>
<td>$c = 750$</td>
<td>125</td>
<td>125</td>
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</table>
## Subgrade Reaction Moduli

### Used for LPile Analysis

<table>
<thead>
<tr>
<th>Elevation (feet)</th>
<th>Geologic Profile Type</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>-15</td>
<td>16</td>
</tr>
<tr>
<td>-20</td>
<td>22</td>
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<tr>
<td>-75</td>
<td>200</td>
</tr>
<tr>
<td>-80</td>
<td>200</td>
</tr>
<tr>
<td>-85</td>
<td>200</td>
</tr>
</tbody>
</table>

**Subgrade Reaction Modulus, \( K_h \) (pci)**
**Design Philosophy**

*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.
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)
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
Design Procedure

- 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**
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
Pile Embedment

- 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

- 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
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

TYPICAL WALL GEOMETRY
Load Cases

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)
Load Case 1 Construction
Load Case 2A & 2B – Flood (Undrained & Drained)
Load Case 3A & 3B – Drawdown (Undrained & Drained)
Load Case 4A & 4B – OBE Seismic & MDE Seismic (Undrained)
### Design Results

#### Shear Forces and Bending Moments

#### Drilled Shaft Wall

<table>
<thead>
<tr>
<th>Design Reach B1</th>
<th>Vu</th>
<th>Static</th>
<th>241 k</th>
<th>Dynamic</th>
<th>94 k</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mu</td>
<td>Static</td>
<td>3791 k-ft</td>
<td>Dynamic</td>
<td>1643 k-ft</td>
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<tr>
<td>Design Reach C2</td>
<td>Vu</td>
<td>Static</td>
<td>242 k</td>
<td>Dynamic</td>
<td>115 k</td>
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<tr>
<td></td>
<td>Mu</td>
<td>Static</td>
<td>4166 k-ft</td>
<td>Dynamic</td>
<td>2089 k-ft</td>
</tr>
</tbody>
</table>
## Design Results

### Shear Forces and Bending Moments

#### Master Pile Wall

<table>
<thead>
<tr>
<th>Design Reach B1</th>
<th>V Static</th>
<th>182 k</th>
<th>Dynamic</th>
<th>81 k</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M Static</td>
<td>2797 k-ft</td>
<td>Dynamic</td>
<td>1348 k-ft</td>
</tr>
<tr>
<td>Design Reach C2</td>
<td>V Static</td>
<td>151 k</td>
<td>Dynamic</td>
<td>101 k</td>
</tr>
<tr>
<td></td>
<td>M Static</td>
<td>2280 k-ft</td>
<td>Dynamic</td>
<td>1728 k-ft</td>
</tr>
</tbody>
</table>
Design Results

- 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.
## Design Results

### Maximum Displacements

#### Drilled Shaft Wall

<table>
<thead>
<tr>
<th>Design Reach</th>
<th>Location</th>
<th>Load Type</th>
<th>Displacement</th>
</tr>
</thead>
<tbody>
<tr>
<td>B1</td>
<td>Top</td>
<td>Static</td>
<td>3.70 in</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Dynamic</td>
<td>2.34 in</td>
</tr>
<tr>
<td></td>
<td>Mudline</td>
<td>Static</td>
<td>1.49 in</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Dynamic</td>
<td>0.78 in</td>
</tr>
<tr>
<td>C2</td>
<td>Top</td>
<td>Static</td>
<td>3.80 in</td>
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<tr>
<td></td>
<td></td>
<td>Dynamic</td>
<td>3.21 in</td>
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<tr>
<td></td>
<td>Mudline</td>
<td>Static</td>
<td>1.40 in</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Dynamic</td>
<td>1.00 in</td>
</tr>
</tbody>
</table>
Design Results

- Maximum Displacements
- Master Pile Wall

<table>
<thead>
<tr>
<th>Design Reach</th>
<th>Location</th>
<th>Load Type</th>
<th>Displacement</th>
</tr>
</thead>
<tbody>
<tr>
<td>B1</td>
<td>Top</td>
<td>Static</td>
<td>6.02 in</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Dynamic</td>
<td>2.84 in</td>
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<td></td>
<td>Mudline</td>
<td>Static</td>
<td>2.42 in</td>
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<td></td>
<td>Dynamic</td>
<td>0.90 in</td>
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<tr>
<td>C2</td>
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<tr>
<td></td>
<td>Mudline</td>
<td>Static</td>
<td>1.95 in</td>
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<tr>
<td></td>
<td></td>
<td>Dynamic</td>
<td>1.19 in</td>
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</table>

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

<table>
<thead>
<tr>
<th>Design</th>
<th>Drilled Shaft</th>
<th>Master Pile</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>0.7</td>
<td>1.1</td>
</tr>
<tr>
<td>A2</td>
<td>0.7</td>
<td>1.1</td>
</tr>
<tr>
<td>B1</td>
<td>0.8</td>
<td>1.4</td>
</tr>
<tr>
<td>B2</td>
<td>0.8</td>
<td>1.3</td>
</tr>
<tr>
<td>B3</td>
<td>0.9</td>
<td>1.3</td>
</tr>
<tr>
<td>C1</td>
<td>0.8</td>
<td>1.4</td>
</tr>
<tr>
<td>C2</td>
<td>0.8</td>
<td>1.2</td>
</tr>
</tbody>
</table>

- All displacements meet the established deflection criteria.
Master Pile Wall

**Typical Wall Section**

**Master Pile Wall**

**Knuckle Detail**

**Master Pile Wall**
Drilled Shaft Wall

Typical Wall Section
Drilled Shaft Wall
Cost Comparison

- 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

- 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

- 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
Drilled Shaft Wall at Bechara Industrial Area

- 2000 linear feet of culvert
- Top down excavation
- Secant pile wall
Drilled Shaft Walls at Bechara Industrial Area
Drilled Shaft Walls at Bechara Industrial Area
Drilled Shaft Walls at Bechara Industrial Area
Drilled Shaft Walls at Bechara Industrial Area
Drilled Shaft Walls at Bechara Industrial Area
Drilled Shafts at De Diego Expressway Bridge
Drilled Shafts at De Diego Expressway Bridge
Drilled Shaft Walls at I-90
Mercer Island, Washington
Drilled Shaft Walls at I-90
Mercer Island, Washington
Drilled Shaft Walls at I-90
Mercer Island, Washington
Drilled Shaft Walls at I-90
Mercer Island, Washington
SR 526 Interchange / I-5 Northbound Ramp
SR 526 Interchange / I-5 Northbound Ramp
SR 526 Interchange / I-5 Northbound Ramp