Analysis of Seawall Concepts Using Yielding Soil Anchors

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Presentation Overview

• Project Overview
• Concept Development
• Lessons Learned
• Yielding Anchor Conclusions
• Project Update
Seattle Waterfront

- Alaskan Way Seawall
- Pier 70
- Pier 48
Plan of Alaskan Way Seawall

- North Seawall
- Central Seawall
- Type A wall
- Type B wall
- Other walls

Key Points:
- 8016’ (2443m)
- Pier 70
- Pier 48
- Myrtle Edwards Park
- Bell Harbor Conference Center
- Waterfront Park
- Colman Dock

LOGOS: Building on the Past, Respecting the Future

PORTS 2010
Typical 1934 Type A Seawall

- **Face panel**: 47’ (14.3m)
- **Timber relieving platform**: 13’ (4 m)
- **Sheet pile wall**: MLLW to MHHW
- **Liquefiable soil**
- **Non-liquefiable soil**
Typical 1934 Type B Seawall

- Face panel: 67’ (20.4m)
- MHHW
- MLLW
- Master pile wall length varies
- Timber relieving platform
- Liquefiable soil
- Non-liquefiable soil
- Alaskan Way Viaduct
Concept Development Process

- Preliminary static analysis

- Concepts were screened to two
  - Secant pile wall
  - Soil Improvement

- 2 – dimensional (2D) DSSI FLAC analysis
Design Earthquake Ground Motions

Central Seawall
RE-2500 (~2500-year ground motion return period)

North Seawall
RE-1000 (~1000-year ground motion return period)
RE$_{2500}$ Time History Input

Velocity pulse 0.91 m/sec

End of shaking at 32 seconds
Two Replacement Concepts Studied

Secant Pile Wall

Secant pile wall

Faceing

Soil Improvement

Jet Grout

Facing
Secant Pile Wall Construction
Jet Grouting
Global 2D Dynamic FLAC Model

- Silent boundary for dynamic loading
- Free-field boundary for dynamic loading

Seawall

Quiet boundary for dynamic loading

Free-field boundary for dynamic loading
Static Pushover Analysis Used to Calibrate FLAC Model Prior to Seismic Runs

Static load used to develop pushover plot of relieving platform
Summary of Preliminary Results on Secant Pile Wall – Type A

- Response dominated by velocity pulse from the nearby Seattle fault
- Relieving platform provided minimal benefit
- Reinforcement required in every shaft
Bracing Concepts

Relieving Platform

Brace Piles

Soil Anchors
The Yielding Anchor Concept for the Braced Secant Pile Wall (BSP)
## Comparison of Cantilever Wall Versus Wall Braced with Yielding Soil Anchors

<table>
<thead>
<tr>
<th></th>
<th>Cantilever Wall with All Shafts Reinforced</th>
<th>Yielding Soil Anchors with Every Other Shaft Reinforced</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak Displacement</td>
<td>11 inches (280mm)</td>
<td>5 inches (125 mm)</td>
</tr>
<tr>
<td>Displacement at End of Shaking</td>
<td>4 inches (100 mm)</td>
<td>1 inch (25 mm)</td>
</tr>
<tr>
<td>Peak Shaft Bending Moment</td>
<td>25,400 k-ft/shaft (33,200 kN-m) Shafts @ 7.5’ (2.3m)</td>
<td>15,000 k-ft/shaft (20,300 kN-m) Shafts @ 15’ (4.6m)</td>
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</tbody>
</table>
Application of Yielding Anchors to Soil Improvement Concept

- The yielding anchor concept was applied to the Type A and B Soil Improvement Concepts and renamed the “Anchored Soil Improvement Concept” (ASI)

- The Type A Wall is shown
Lessons Learned

• Continuous dialogue between structural and geotechnical team members is important

• Perform a static pushover analysis in FLAC to verify behavior of complex structure before proceeding with time-history analysis

• Provide FLAC output in different formats (i.e. graphs, deflected shapes, stress contours) was found to facilitate understanding of the analysis by the team
Plot of Anchor Stress vs. Time for Braced Secant Pile Wall (BSP)

This plot was used to verify the anchors were yielding at the peaks in ground motion response as intended.

Anchors yield

78 ksi (537 kPa)

1 ksi = 6.89 kPa
Displacement Plots for Anchored Soil Improvement

Type A
- Sheetpile deformation
- Soil-cement deformed shape

Type B
- Master pile deformation
- Soil-cement deformed shape
Plot of Principal Stresses in Jet Grout

Earthquake

Internal compression struts in soil-cement

Principal Stress Contours (ksf)

0

17.5 ksf (740 kg/m²)

Master pile

Soilcrete block

Soil anchor in tension
## Summary of Concept Performance

<table>
<thead>
<tr>
<th>Wall Type</th>
<th>Earthquake</th>
<th>Peak $\Delta$</th>
<th>Final $\Delta$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type A - ASI</td>
<td>RE-1000</td>
<td>8” (200mm)</td>
<td>8” (200mm)</td>
</tr>
<tr>
<td>Type A - BSP</td>
<td>RE-1000</td>
<td>5” (125mm)</td>
<td>1” (25mm)</td>
</tr>
<tr>
<td>Type B – ASI</td>
<td>RE-2500</td>
<td>4” (100mm)</td>
<td>3” (75mm)</td>
</tr>
<tr>
<td>Type B - BSP</td>
<td>RE-2500</td>
<td>12” (300mm)</td>
<td>9” (230mm)</td>
</tr>
</tbody>
</table>
Yielding Soil Anchor Conclusions

• Yielding anchors were effective in reducing internal forces and displacements due to the large velocity pulse.

• The anchors and wall elements were sized to remain elastic for normal service loads and liquefied soil loading and yield under the velocity pulse.

• The yielding anchor concept may be useful for other seawall or bulkhead applications with large dynamic loads.

• The analysis method is consistent with the displacement based design approach used for piers and wharves.
Project Update

• City of Seattle advancing design

• Coordinating with Central Waterfront Design and Planning Process

• Project Goals
  • Effective protection for waterfront facilities and economic activities
  • Long term solution that meets seismic standards
  • Improve habitat outboard of the seawall