

# Analysis of Seawall Concepts Using Yielding Soil Anchors

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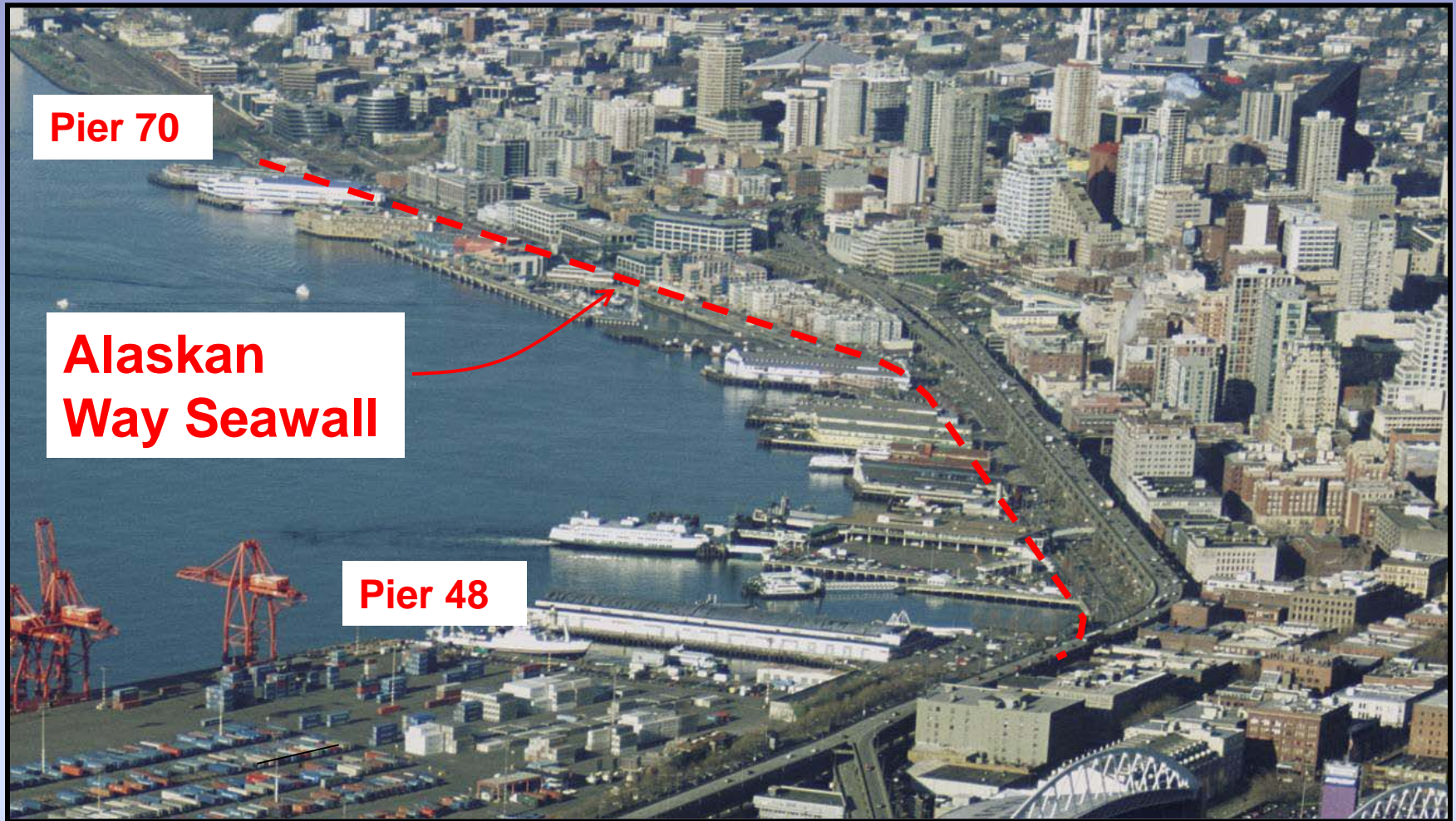
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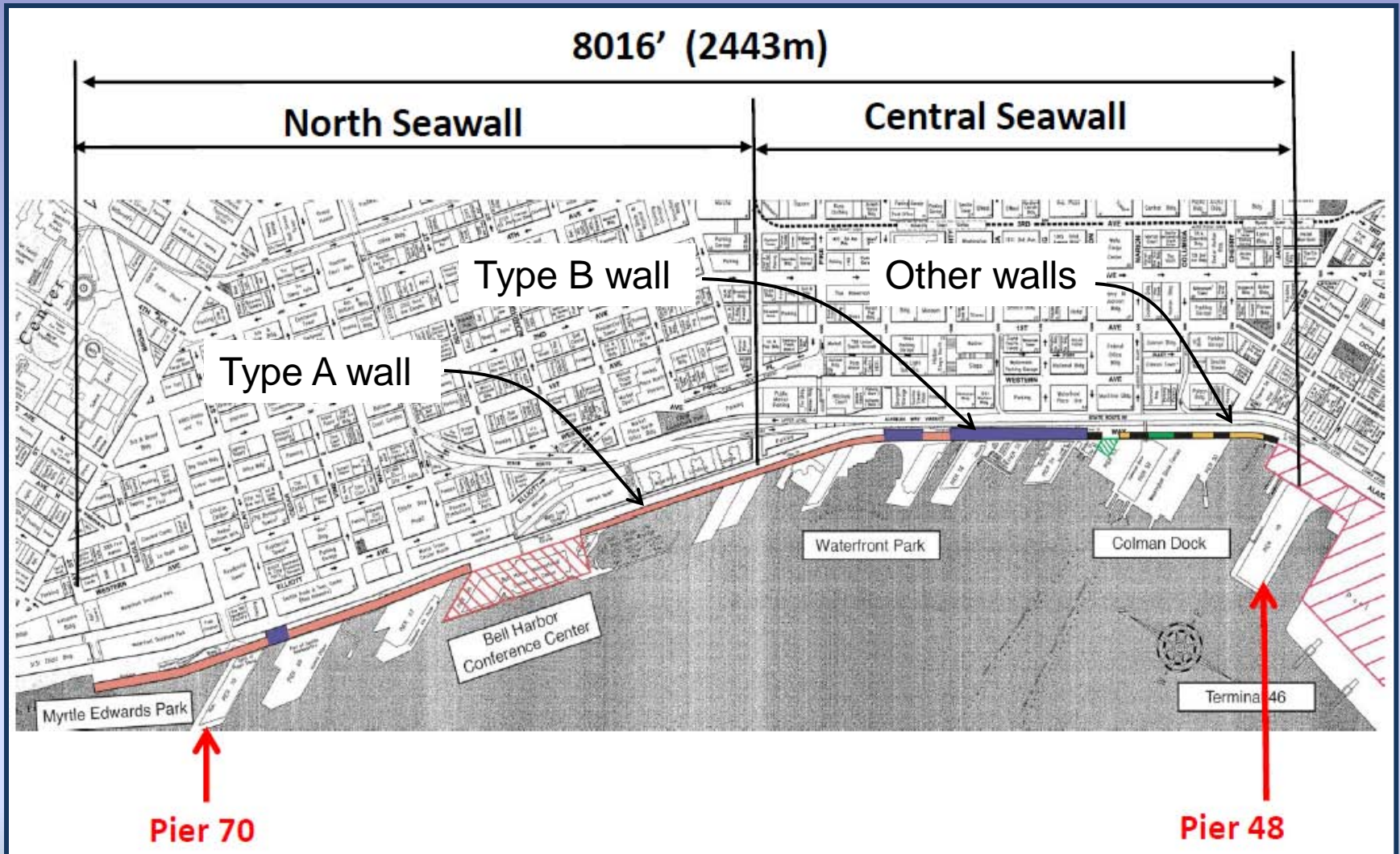
# Presentation Overview

- Project Overview
- Concept Development
- Lessons Learned
- Yielding Anchor Conclusions
- Project Update

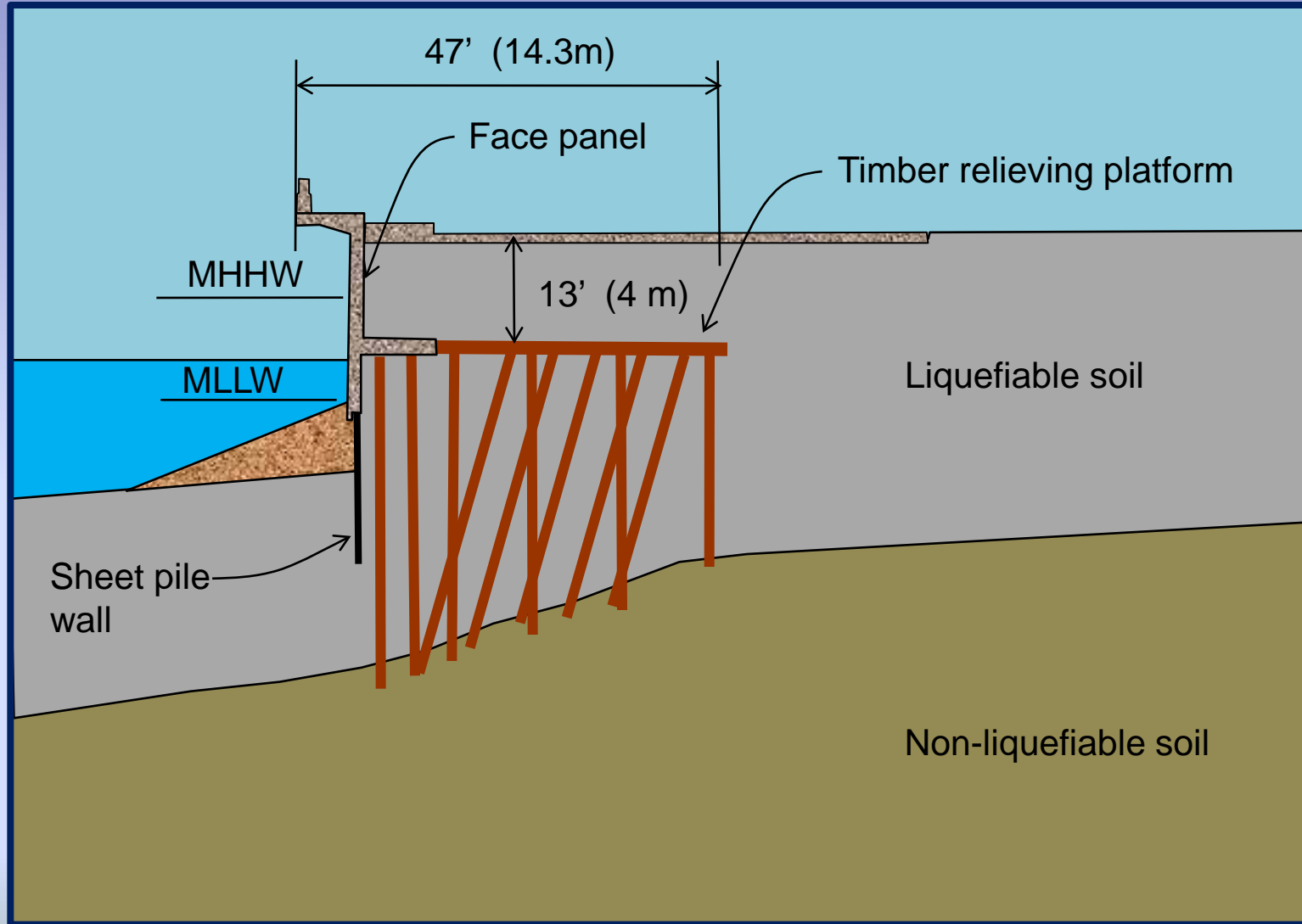
# Seattle Waterfront



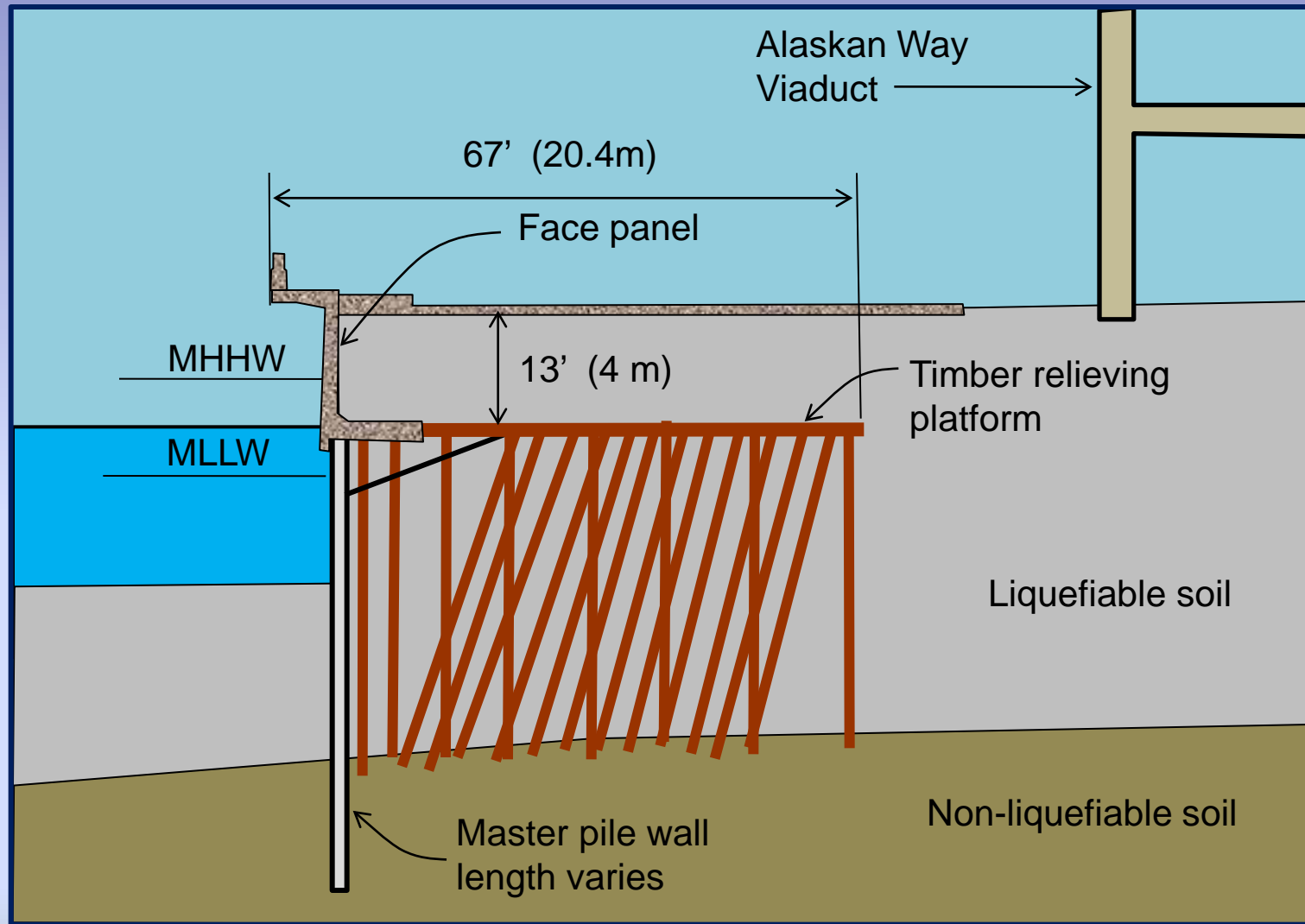
# Plan of Alaskan Way Seawall



# Typical 1934 Type A Seawall



# Typical 1934 Type B Seawall



# 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

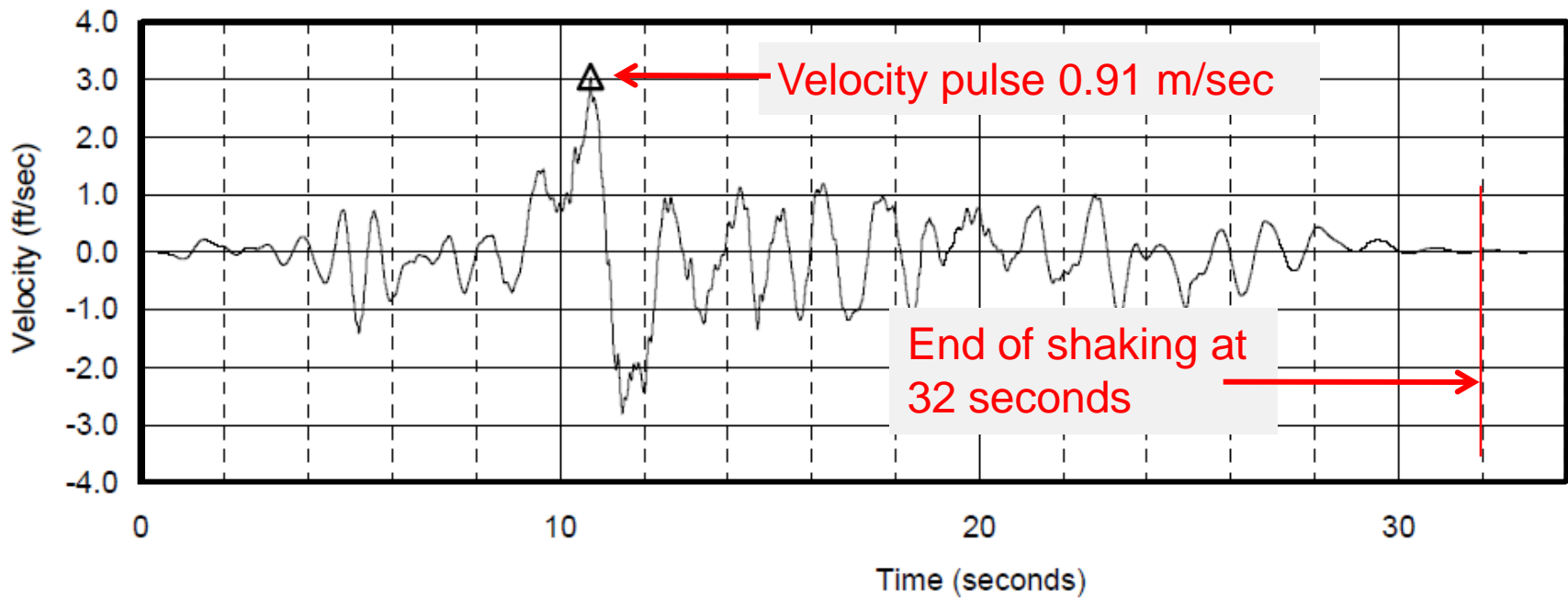
## Central Seawall

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

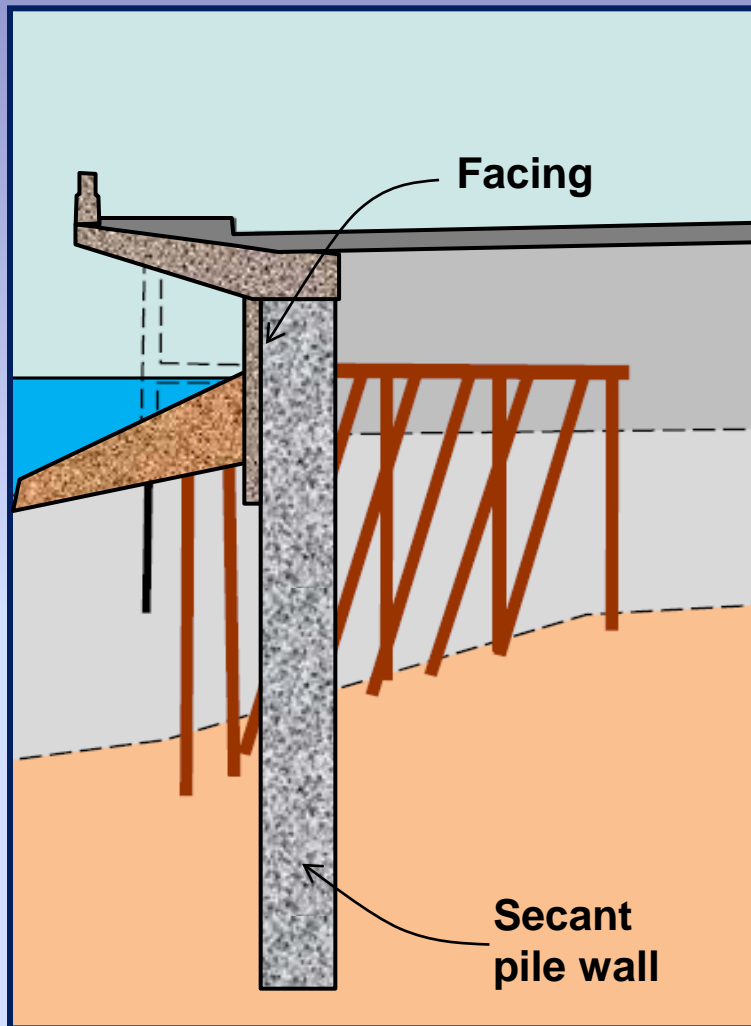
## North Seawall

RE-1000 (~1000-year ground motion return period)

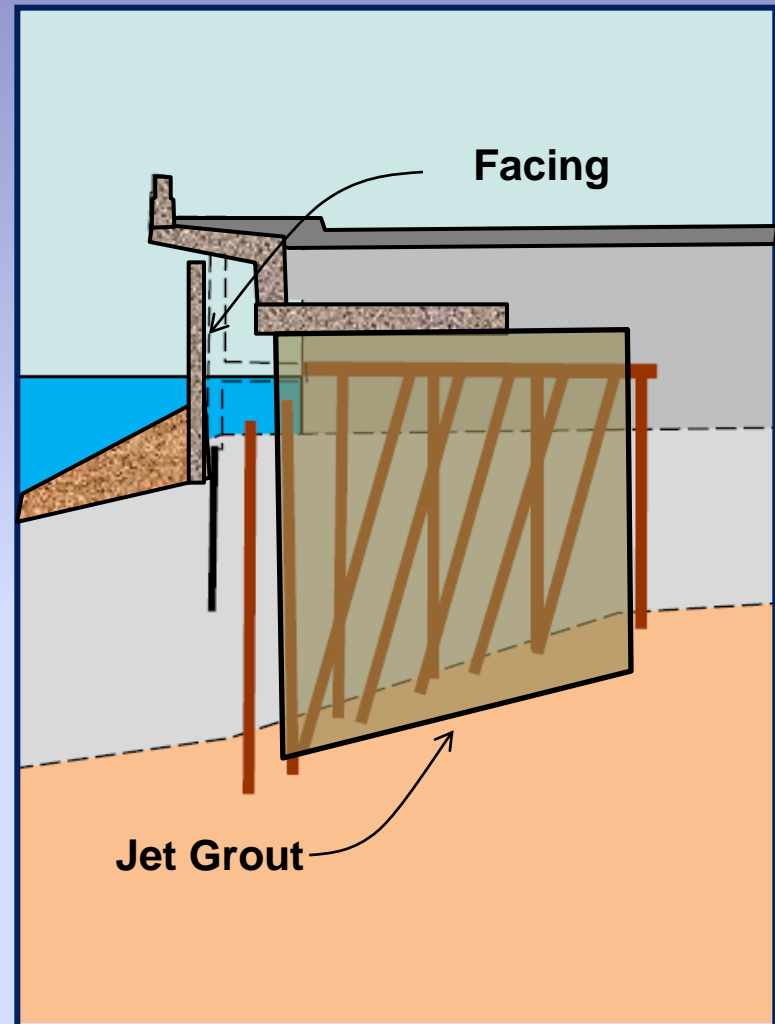
# RE<sub>2500</sub> Time History Input



# Two Replacement Concepts Studied



**Secant Pile Wall**

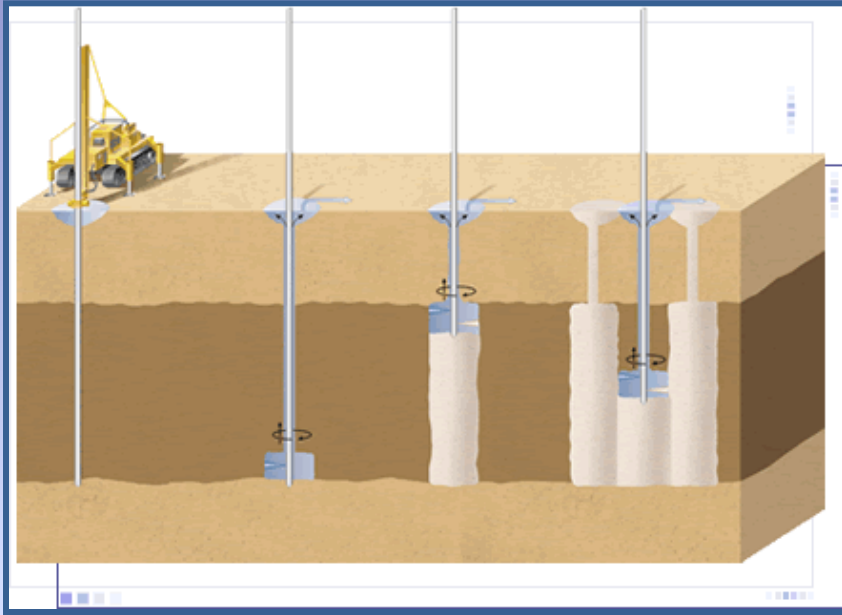


**Soil Improvement**

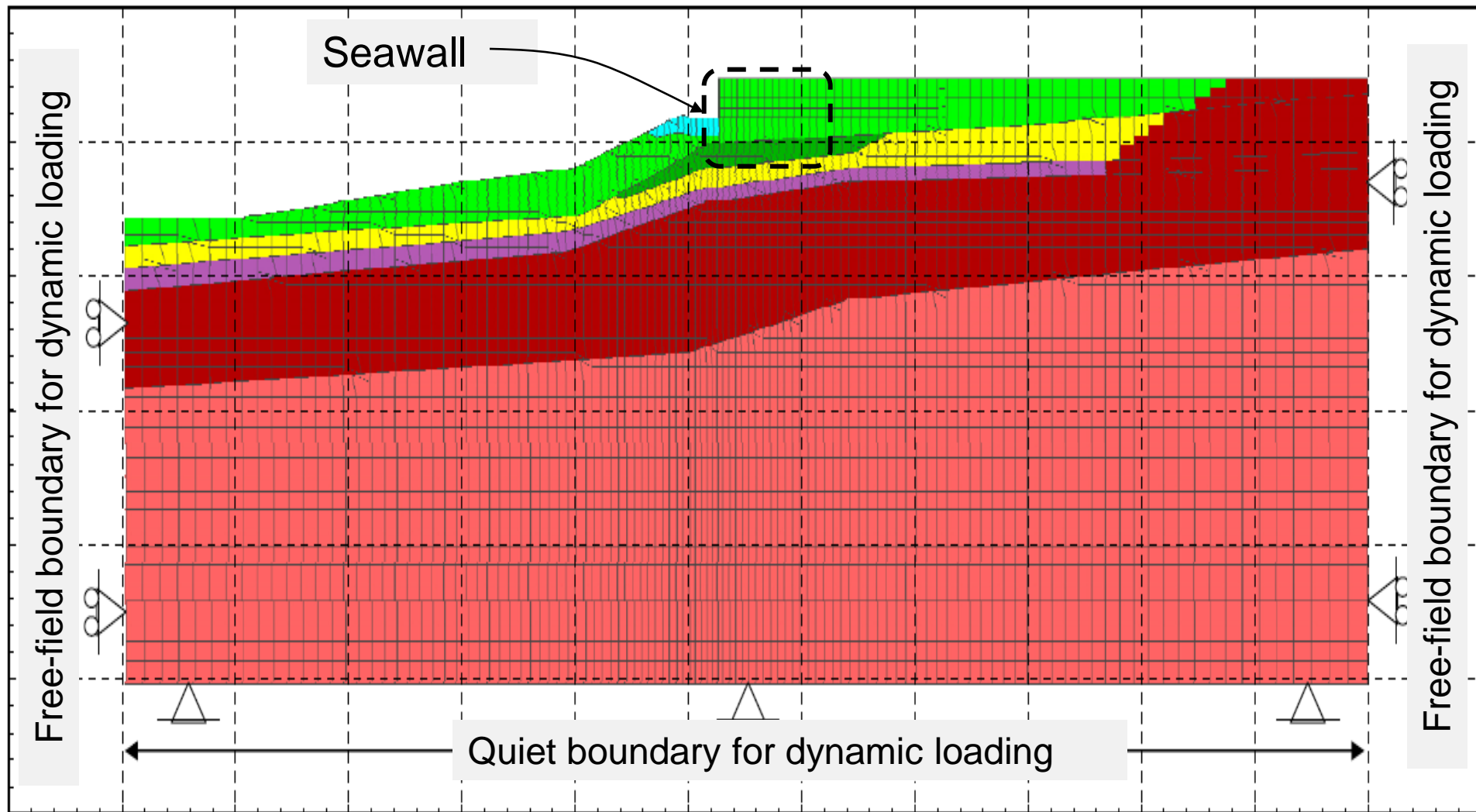
# Secant Pile Wall Construction



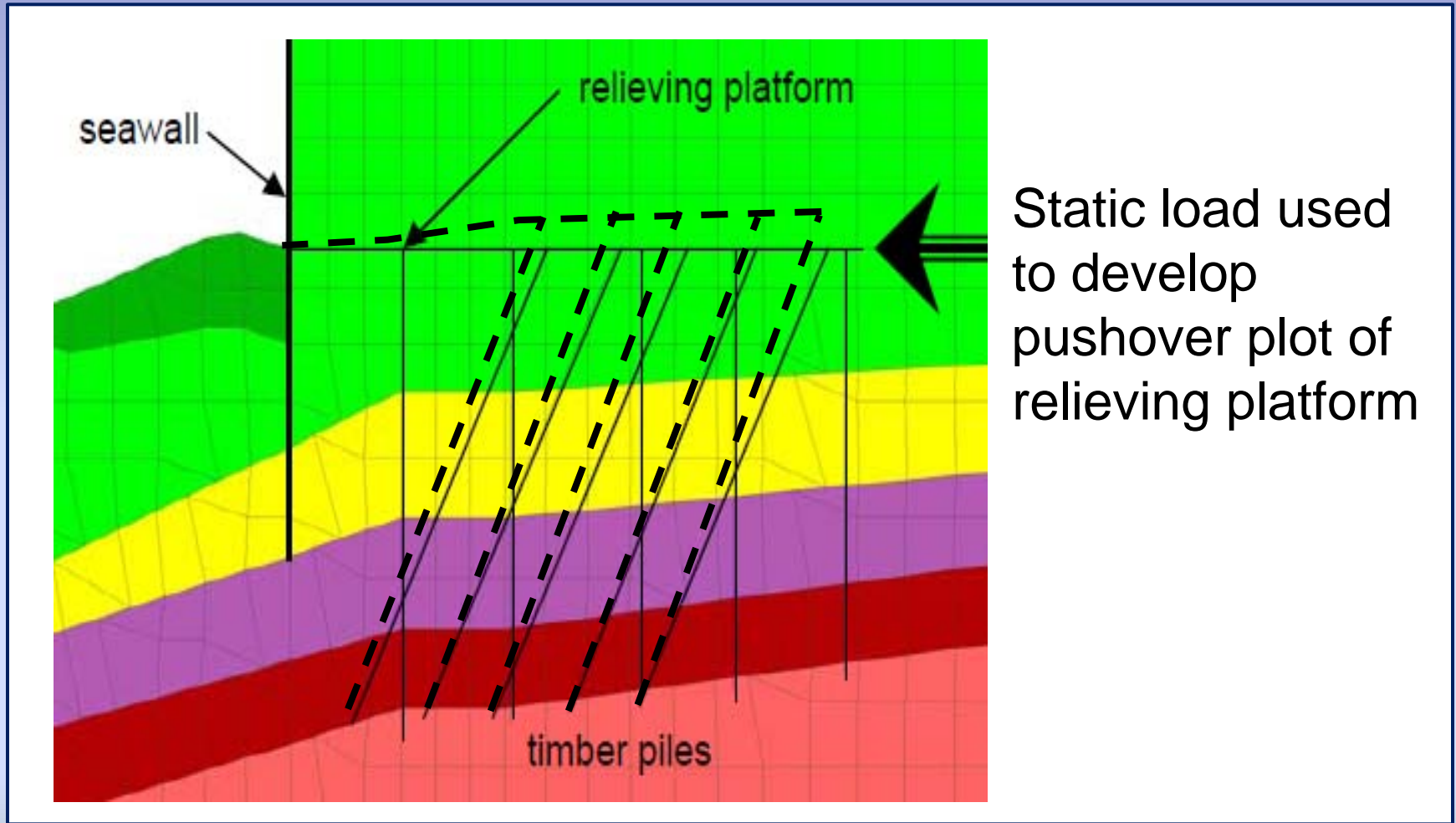
# Jet Grouting



# Global 2D Dynamic FLAC Model



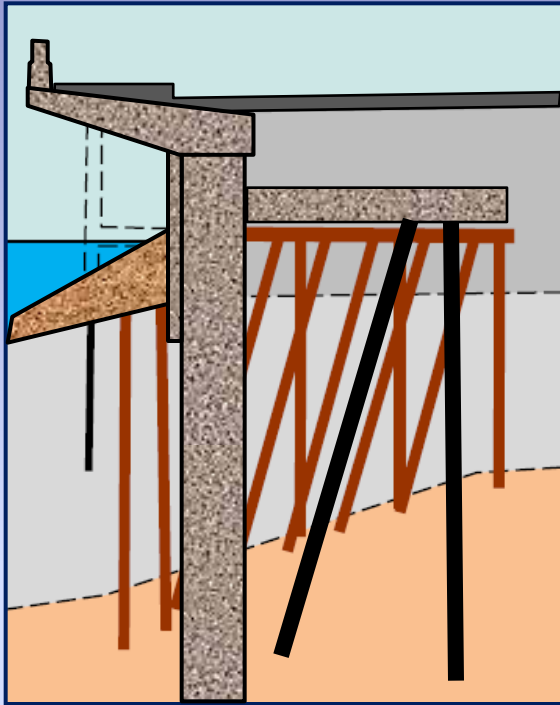
# Static Pushover Analysis Used to Calibrate FLAC Model Prior to Seismic Runs



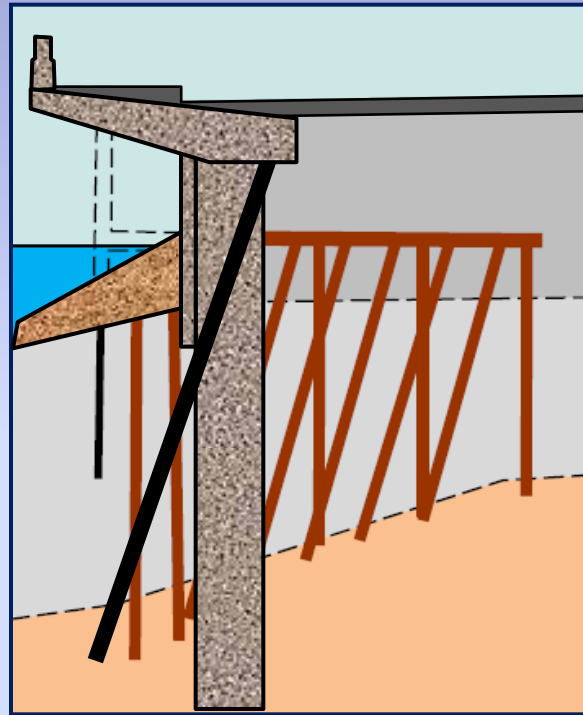
# Summary of Preliminary Results on Secant Pile Wall – Type A

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

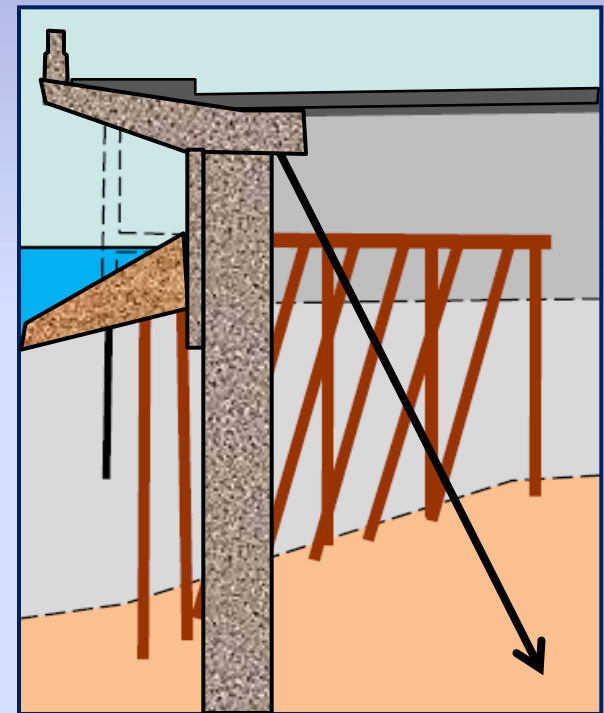
# Bracing Concepts



Relieving Platform

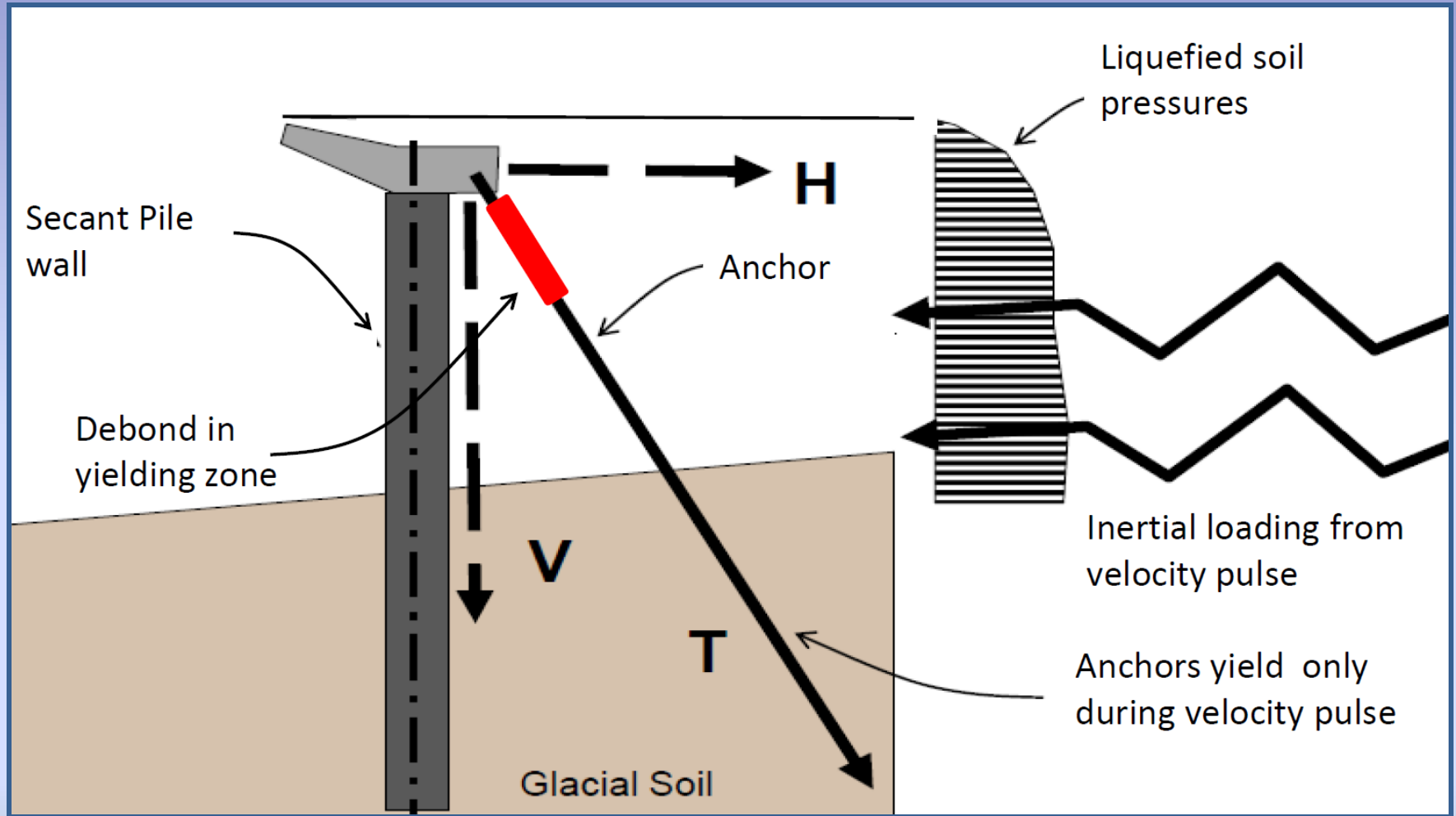


Brace Piles



Soil Anchors

# The Yielding Anchor Concept for the Braced Secant Pile Wall (BSP)

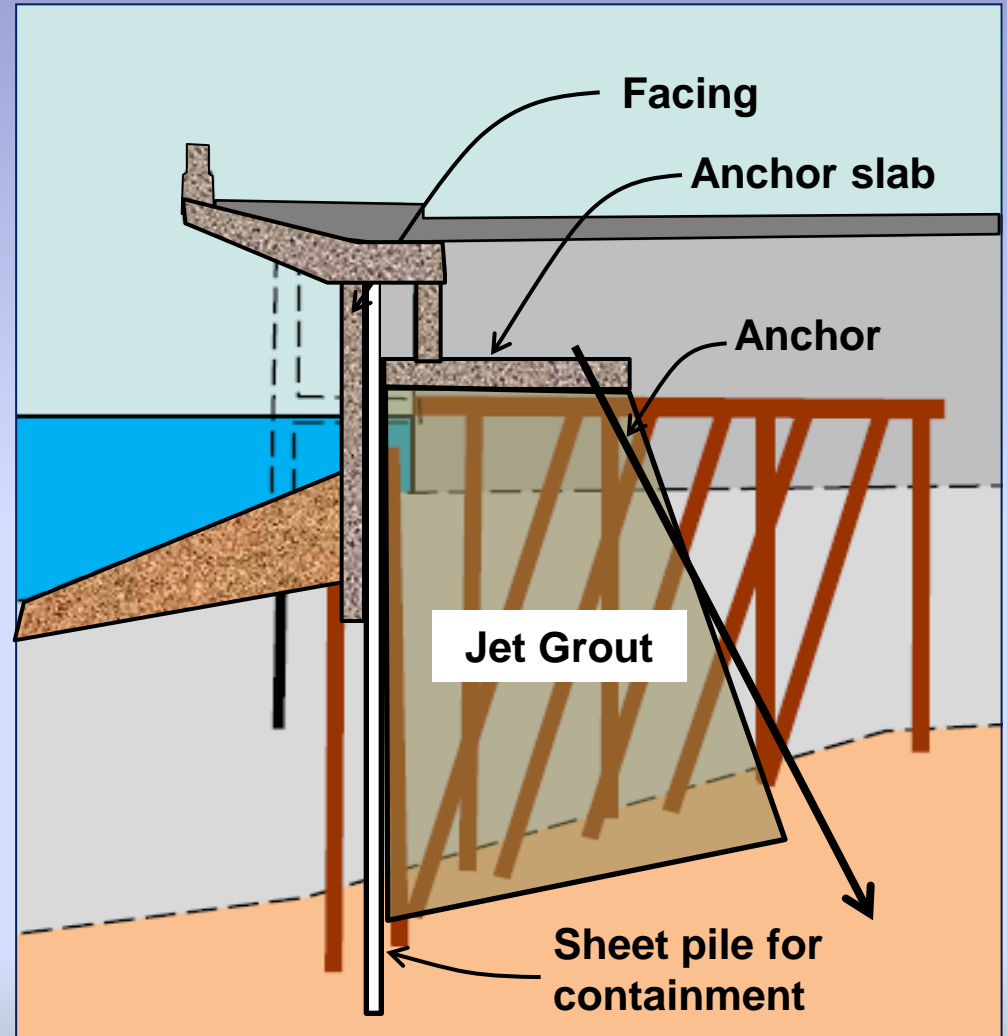


# Comparison of Cantilever Wall Versus Wall Braced with Yielding Soil Anchors

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

# 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

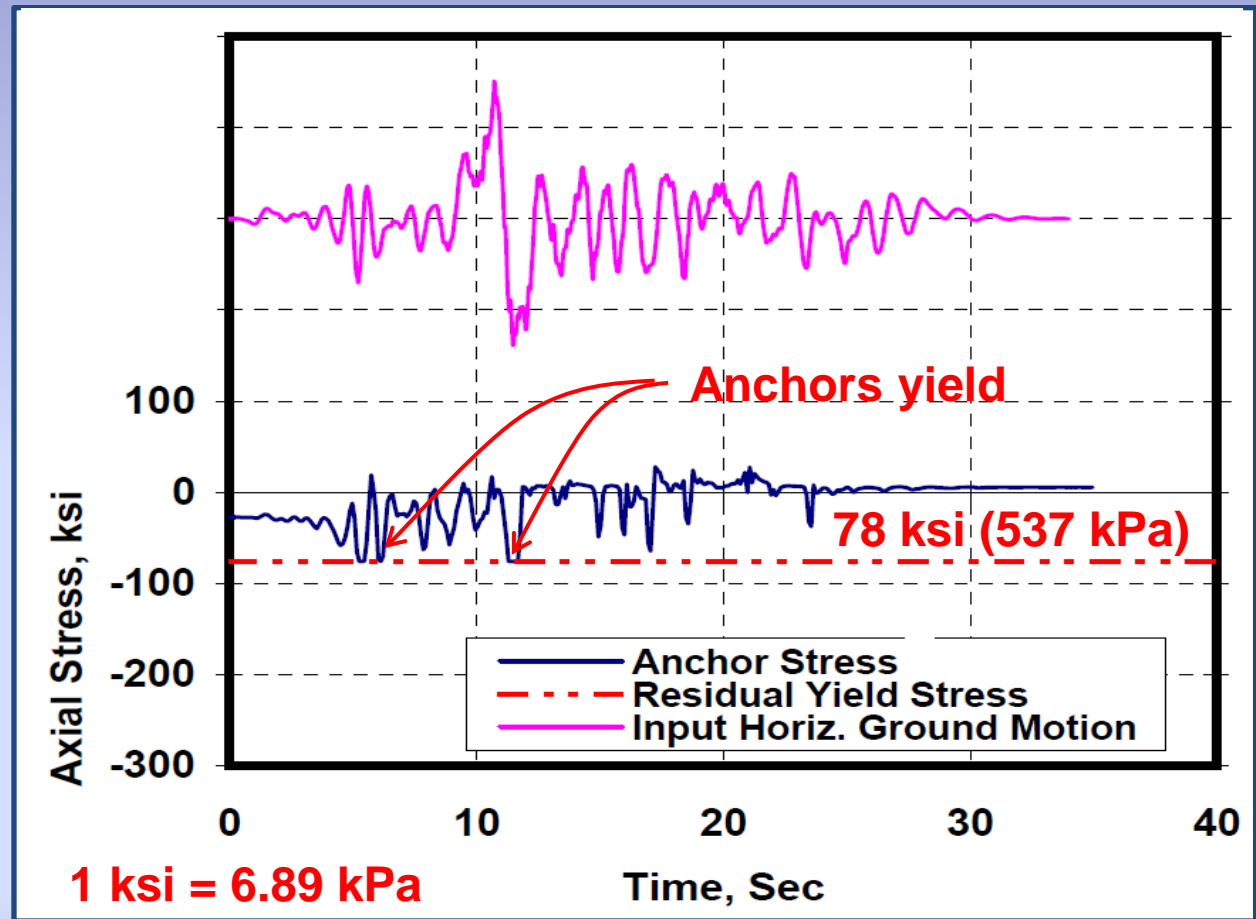


# Lessons Learned

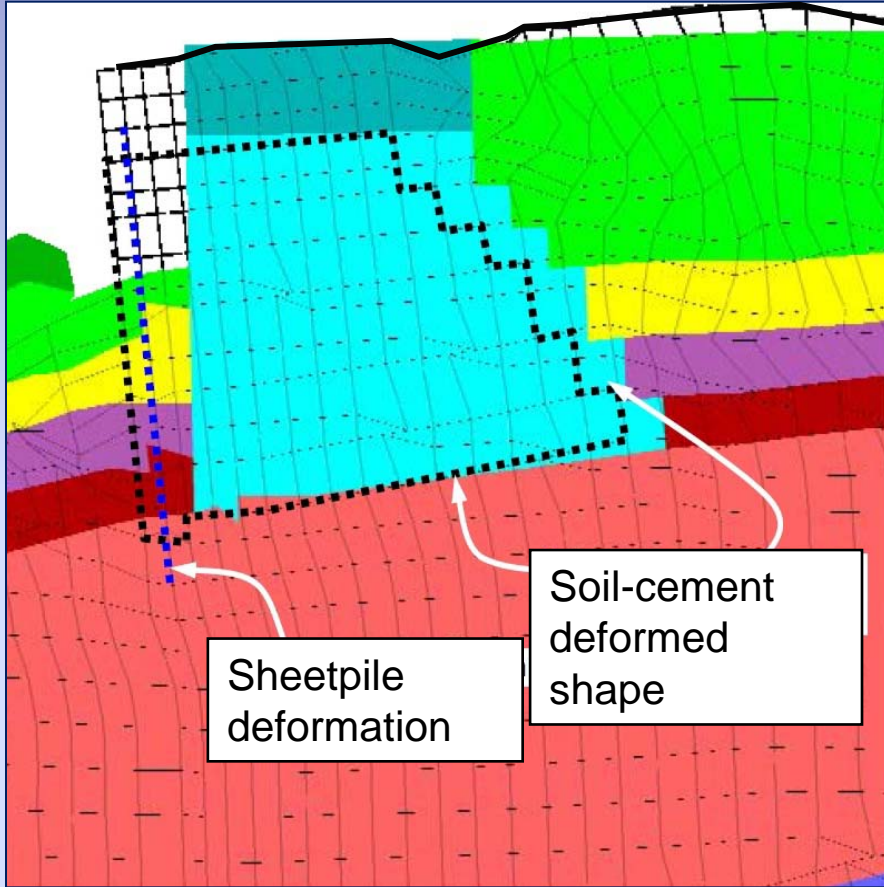
- Continuous dialogue between structural and geotechnical team members is important
- Perform a static pushover analysis in FLAC to verify behavior of complex structure before proceeding with time-history analysis
- Provide FLAC output in different formats (i.e. graphs, deflected shapes, stress contours ) was found to facilitate understanding of the analysis by the team

# Plot of Anchor Stress vs. Time for Braced Secant Pile Wall (BSP)

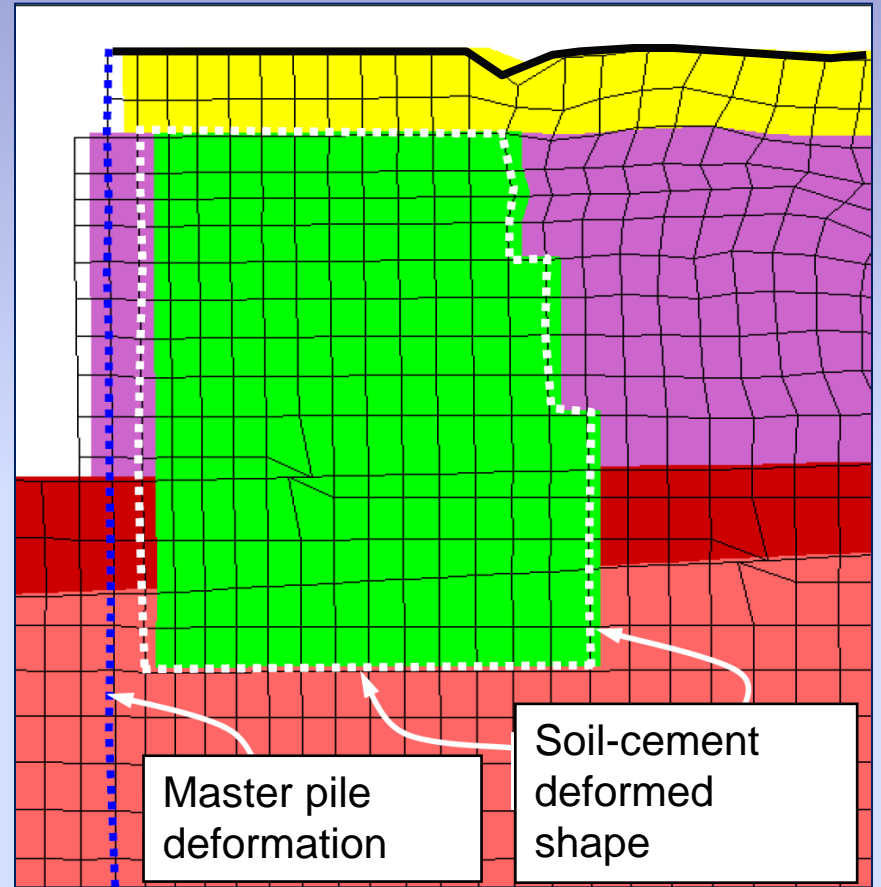
This plot was used to verify the anchors were yielding at the peaks in ground motion response as intended



# Displacement Plots for Anchored Soil Improvement

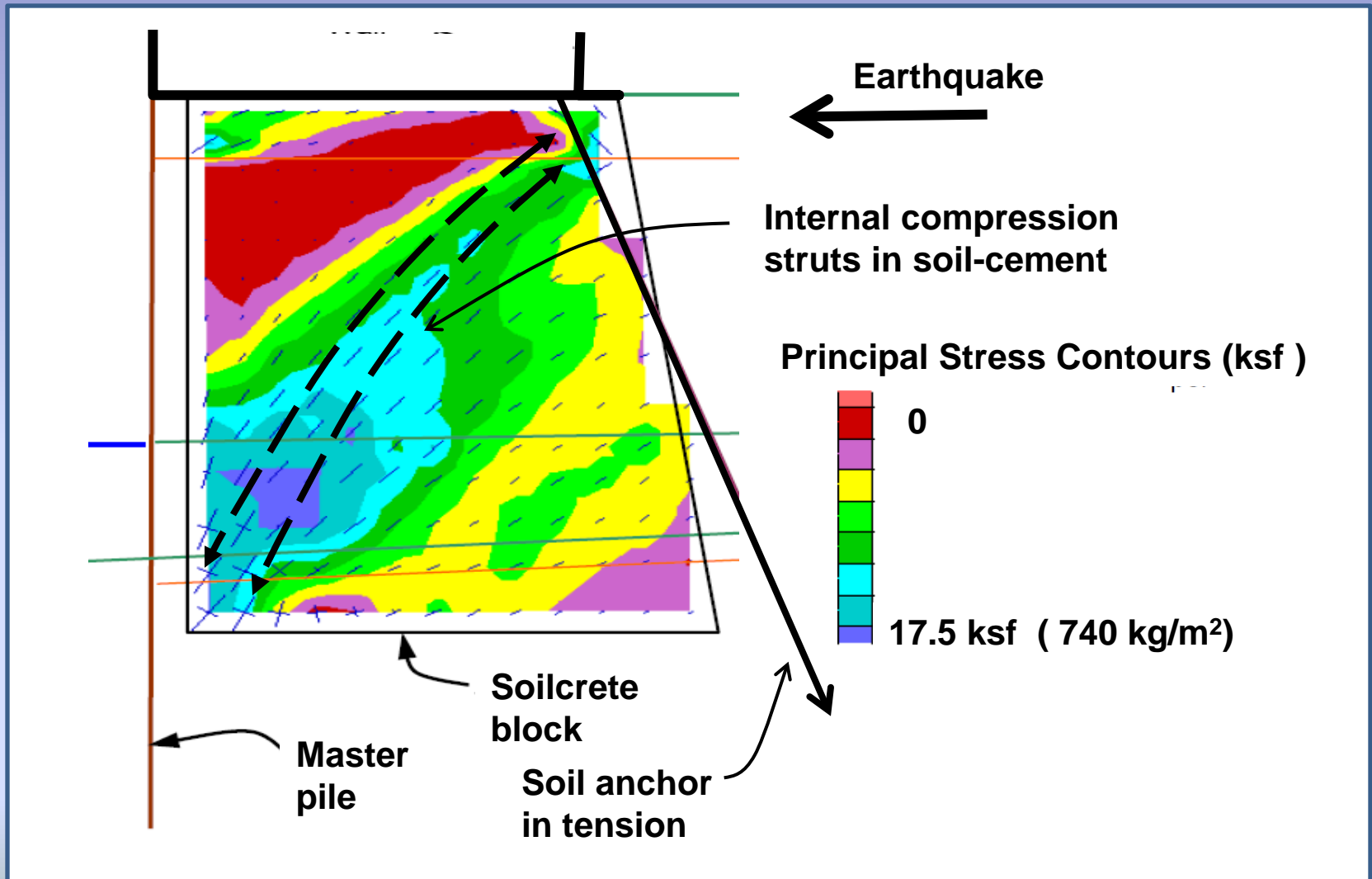


**Type A**



**Type B**

# Plot of Principal Stresses in Jet Grout



# Summary of Concept Performance

Wall Type	Earthquake	Peak $\Delta$	Final $\Delta$
Type A - ASI	RE-1000	8" (200mm)	8" (200mm)
Type A - BSP	RE-1000	5" (125mm)	1" (25mm)
Type B - ASI	RE-2500	4" (100mm)	3" (75mm)
Type B - BSP	RE-2500	12" (300mm)	9" (230mm)

# 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

