PBEE Research Needs in Port Structures

Gayle Johnson

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Agenda

- Brief History of PBEE Design for Port Structures

- Research Needs for Various Port Structures and Systems
  - Piers and Wharves
  - Container Storage Yards
  - Cranes
  - Tsunami Hazards

Evolution of Performance-Based Seismic Design of Ports

- Historically, always different than buildings

- Early 1980's
  - Single level earthquake
  - Equivalent lateral force
  - Specified acceleration
  - POLA used 0.12g

Evolution of Performance-Based Seismic Design of Ports

- Mid 1980's
  - PSHA's more common
  - 2 level earthquake
  - POAK used 72 yr and 240 year
  - Different "Risk Factor" for each earthquake
  - Lower level earthquake may govern

Evolution of Performance-Based Seismic Design of Ports

- Late 1990's
  - Three level earthquake (72, 240, 475)
  - Site-specific spectra
  - Different "R" factors for each earthquake
  - Different "R" factors for in-ground and above-ground piles
  - Slope deformation limits

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1999 Port of Oakland Design

SEISMIC CRITERIA:

EARTHQUAKE LEVEL	1	2	3
PROBABILITY OF EXCEEDANCE IN 50 YEARS	50%	20%	10%
% DAMPING	5%	5%	5%
TOP OF PILE FORCE REDUCTION FACTOR, R	2	4	5
IN-GROUND PILE FORCE REDUCTION FACTOR, R	1	2	2
PEAK GROUND ACCELERATION (PGA)	0.25g	0.37g	0.44g
PEAK OF DAMPED SPECTRAL ACCELERATION (PDSA)	0.82g	1.16g	1.38g

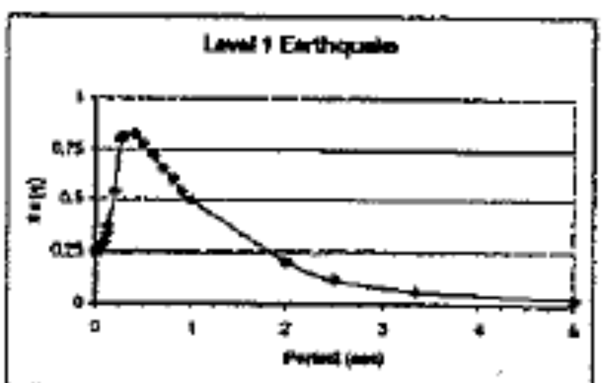
NOTE: PGA AND PDSA REPRESENT GROUND MOTION 10 FEET BELOW SURFACE FOR THE CDSM CONFIGURATION.

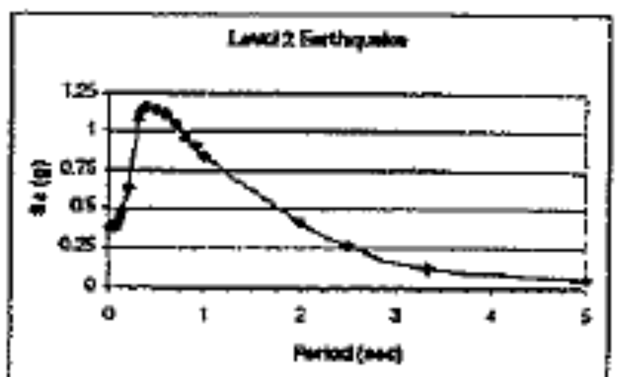
SEISMIC LOAD COMBINATIONS
(1) 1.4 DL + 1.0 EQ + 0.1 (VERTICAL LIVE LOAD FOR PILE DESIGN)
(2) 0.9 DL + 1.0 EQ

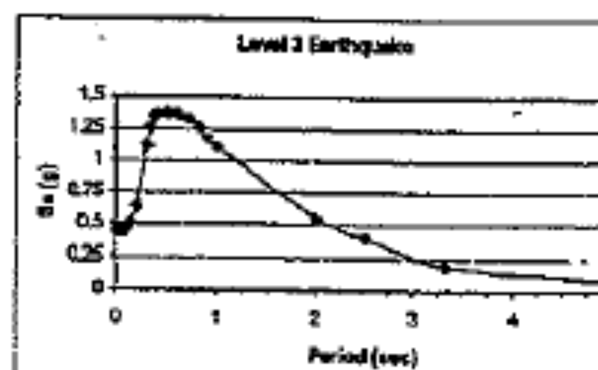
SITE-SPECIFIC RESPONSE SPECTRA HAVE BEEN DEVELOPED FOR THIS PROJECT BY SUBSURFACE CONSULTANTS, INC. MARCH 1998. FROM THESE SITE-SPECIFIC RESPONSE SPECTRA, THE FOLLOWING DESIGN RESPONSE SPECTRAS WERE DEVELOPED:

SLOPE DEFORMATION CRITERIA

SEISMIC EVENT	DEFORMATION LIMITS
POST-LEVEL 1	MINIMAL
POST-LEVEL 2	LESS THAN 6"
POST-LEVEL 3	LESS THAN 12"







1999 Port of Oakland Design

3 Levels

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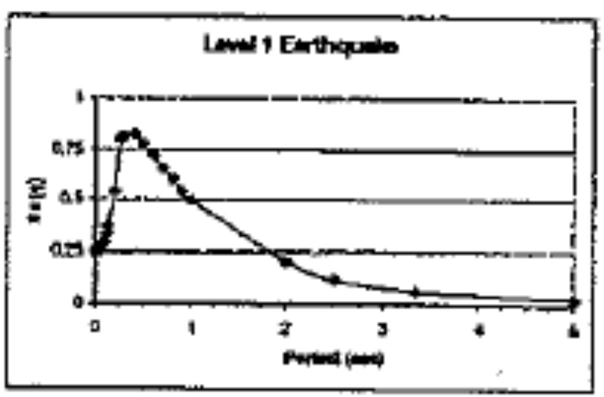
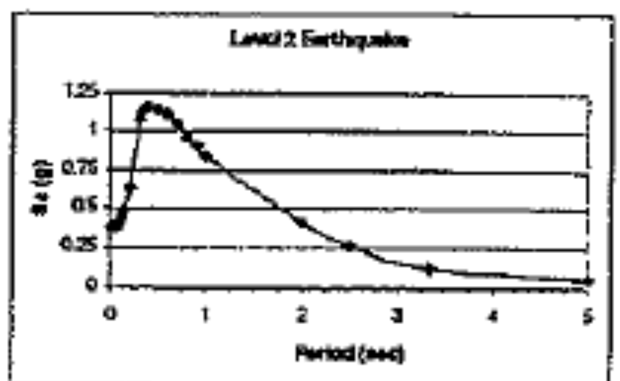
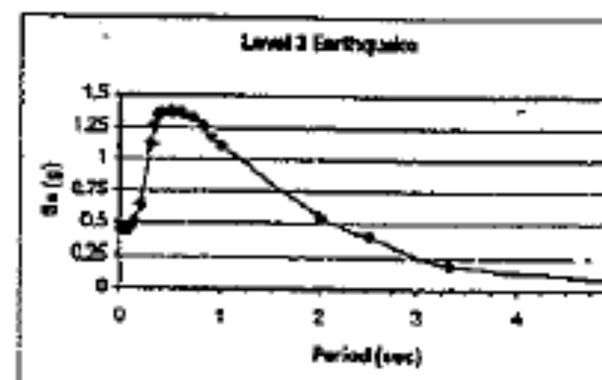
Site-specific, Not standard code shape







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Top of pile vs. In-ground

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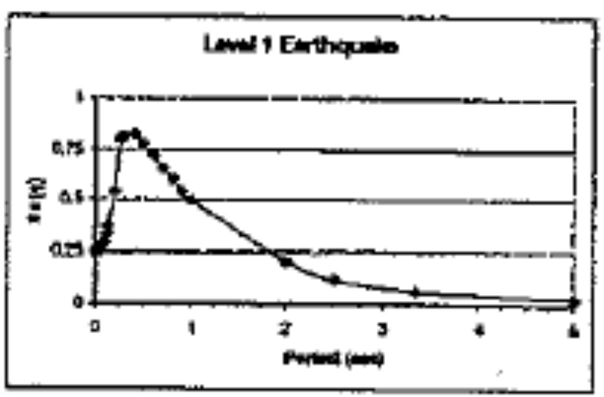

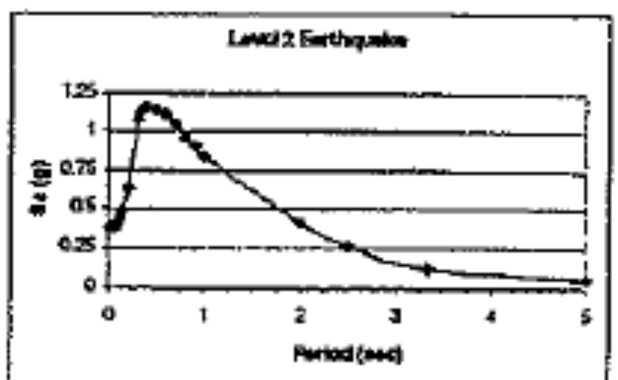

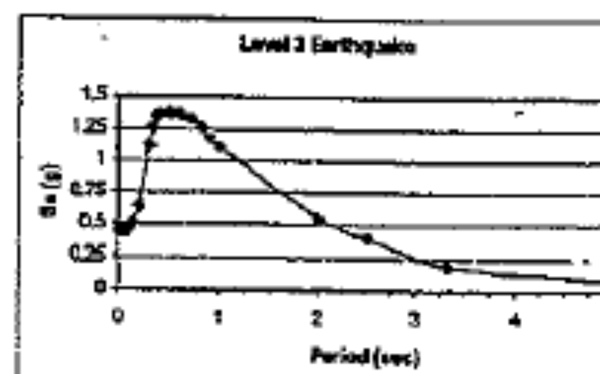

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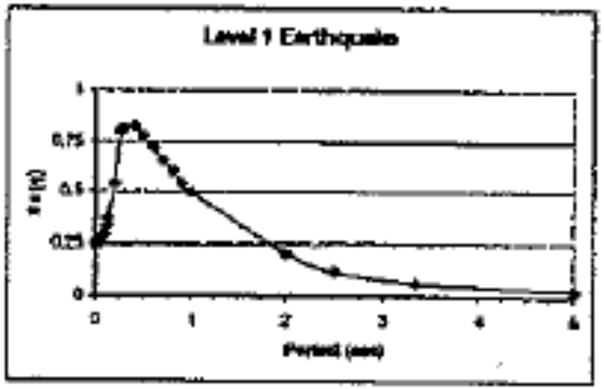
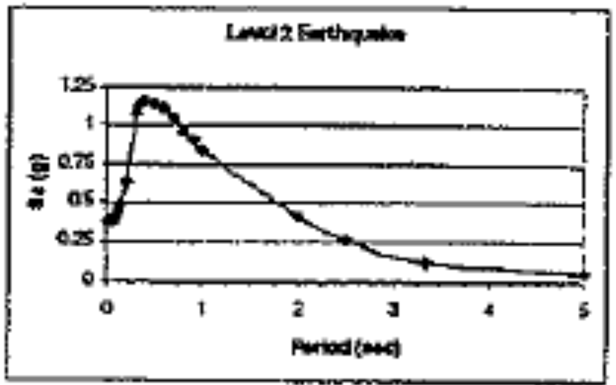
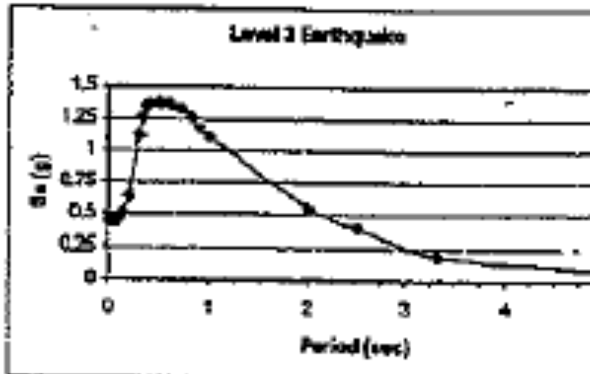
Deformation limits For each EQ level







Modern Performance Criteria

Design Classification	Seismic Hazard Level and Performance Level					
	Operating Level Earthquake (OLE)		Contingency Level Earthquake (CLE)		Design Earthquake (DE)	
	Ground Motion Probability of Exceedance	Performance Level	Ground Motion Probability of Exceedance	Performance Level	Seismic Hazard Level	Performance Level
High	50% in 50 years (72-year return period)	Minimal Damage	10% in 50 years (475-year return period)	Controlled and Repairable Damage	Design Earthquake per ASCE 7	Life-Safety Protection
Moderate	n/a	n/a	20% in 50 years (224-year return period)	Controlled and Repairable Damage	Design Earthquake per ASCE 7	Life-Safety Protection
Low	n/a	n/a	n/a	n/a	Design Earthquake per ASCE 7	Life-Safety Protection

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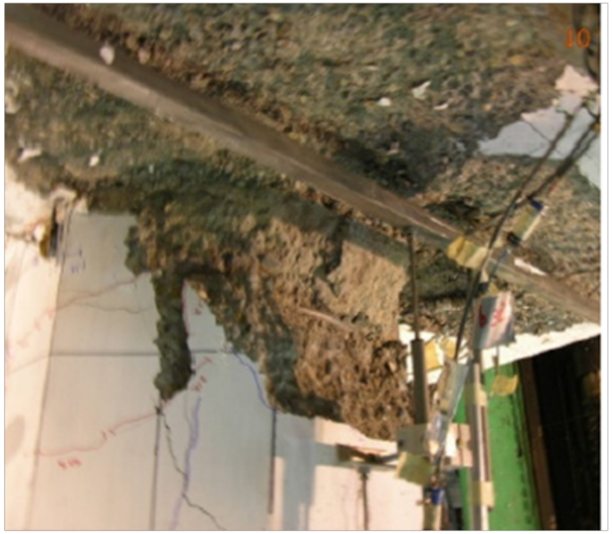
Physical Meaning of "Performance"

Minimal Damage OLE	Controlled and Repairable Damage CLE	Life Safety Protection DE
		
Initial cracking and spalling of the pile and/or deck	Substantial spalling of the pile exposing the spiral or substantial spalling in the deck to the depth of the embedded pile or that exposed the deck	Broken connection from either spalling into the core, fractured dowel bars or buckled strand.

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Strain limits describe "performance"

Table 3.1 Strain limits for "Minimal damage"

Pile Type	Component	Hinge Location		
		Top of pile	In-ground	Deep in-ground (>10D_p)
Solid Concrete Pile	Concrete	$e_c \leq 0.005$	$e_c \leq 0.005$	$e_c \leq 0.008$
	Reinforcing Steel	$e_s \leq 0.015$		
	Prestressing Steel		$e_p \leq 0.015$	$e_p \leq 0.015$
Hollow Concrete Pile [a]	Concrete	$e_c \leq 0.004$	$e_c \leq 0.004$	$e_c \leq 0.004$
	Reinforcing Steel	$e_s \leq 0.015$		
	Prestressing Steel		$e_p \leq 0.015$	$e_p \leq 0.015$
Steel Pipe Pile	Steel Pipe		$e_s \leq 0.010$	$e_s \leq 0.010$
	Concrete	$e_c \leq 0.010$		
	Reinforcing Steel	$e_s \leq 0.015$		

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Tests at U.C. San Diego

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POLA Experimental Program at UCSD

Current Experimental Work – Phase I

Tests at University of Washington

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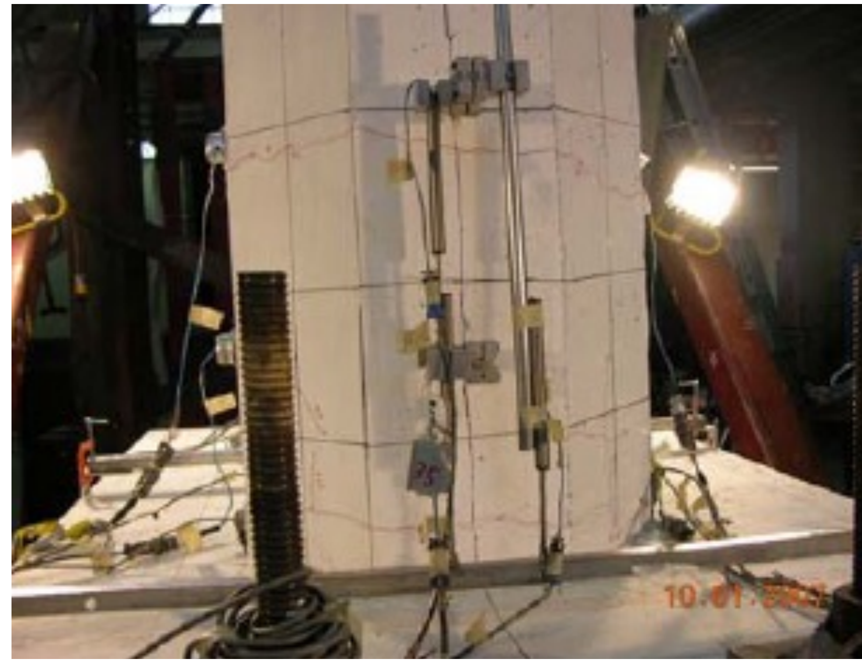
Tests at University of Washington

1.75 % Drift



9% Drift

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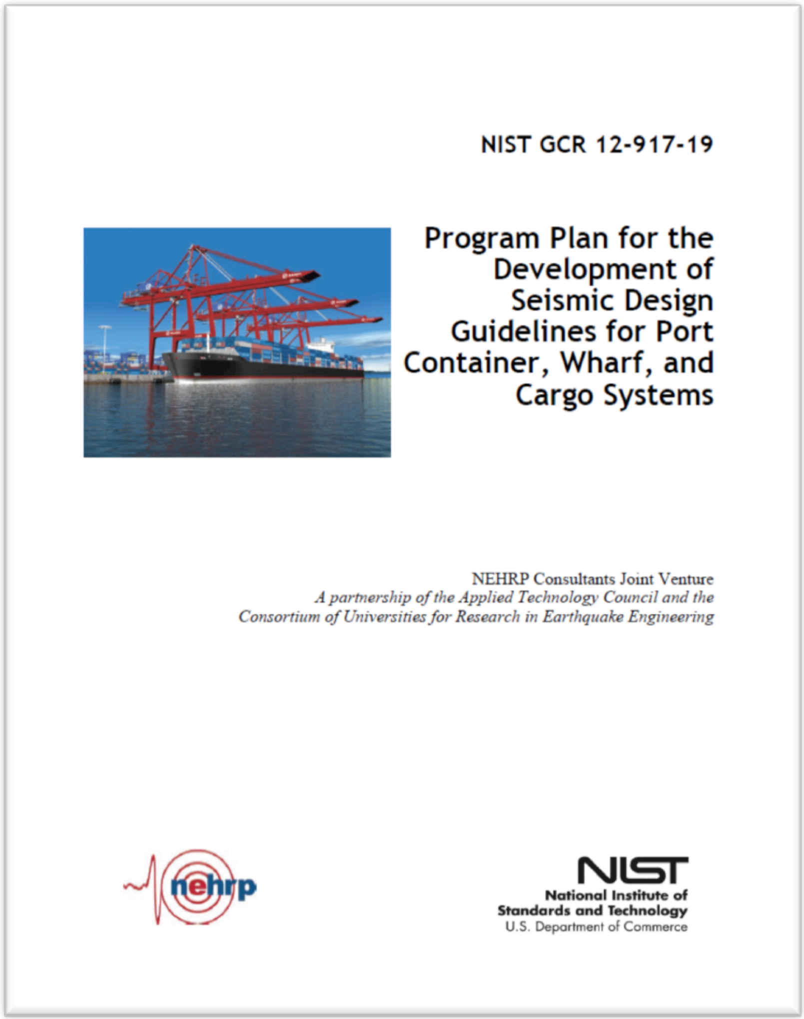
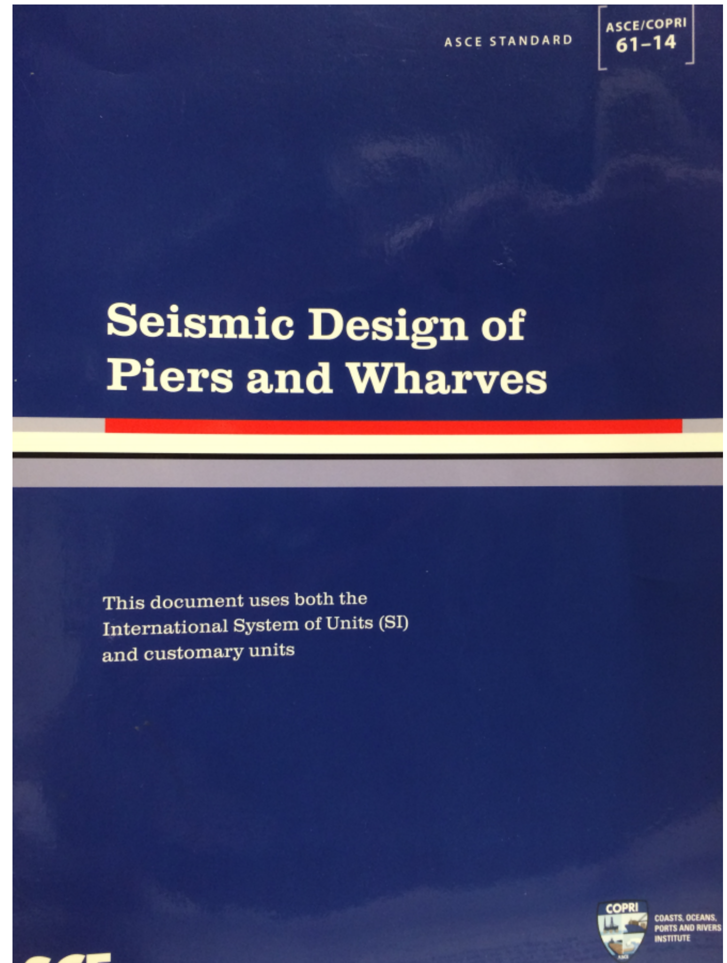
Basis of Research Needs





Research Needs – Piers / Wharves

- Development of models for nonlinear pile and bulkhead behavior and deck connections
  - Identification of appropriate strain levels consistent with typical performance criteria for commonly used deck connections
  - Incorporation of ductile structural elements for different pile types in analyses
  - Consensus on a robust effective stress soil model for liquefaction analyses
  - Procedures for identifying when kinematic and inertial coupling is required

Research Needs – Piers / Wharves (cont)

- Consensus on appropriate soil-pile coupling elements
- Establishment of conditions under which simplified analysis procedures may be used
- Development of tilt and displacement criteria and models for bulkheads consistent with performance criteria

Research Needs –Container Storage Yards

- Mitigation measures to reduce vertical and horizontal displacements during a seismic event to ensure a faster start up after the earthquake.
- Less expensive methods for soil stabilization for large acreage storage yards subject to liquefaction.
- Seismic design and performance guidelines and performance metrics do not exist for container storage yards.

Research Needs – Container Cranes

- Effect of vertical ground motions on crane response
- Understanding of crane-wharf interaction in terms of fundamental period of the two components and the impact to seismic performance
- Methods of crane design to resist excessive motion for new and existing cranes

Research Needs – Tsunami Hazards

- Probabilistic tsunami forecast hazard analyses for all critical ports and harbors in the U.S.
- Methods for the probabilistic analysis of debris strike potential, especially for ports with large container handling facilities in proximity to fuel storage tanks.
- Innovative mooring systems to allow for rapid sea level rise and high currents

Research Needs – Tsunami Hazards (cont.)

- Understanding and mitigation of tsunami induced liquefaction and enhanced scour below slab-on-grade pavements and behind wharf retaining wall systems.
- Design criteria for tsunami uplift of pile-supported piers and marginal wharves.

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Prior Funding Sources

- Major ports
  - Los Angeles
  - Long Beach
  - Oakland
- US Navy
- California State Lands Commission

PEER Annual Meeting

Thank You