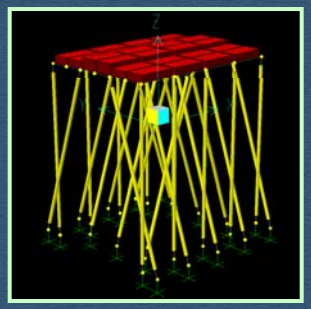

New ASCE Standard for Seismic Design of Piers and Wharves

Presented by:

Gayle Johnson
Halcrow, Inc.
Oakland, CA

October 20, 2010

Halcrow

Agenda

- Background / history of standards
- Why we are where we are
- What's coming
- Potential impact to the marine industry

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ASCE Standards Committee

- Formed in 2005
- National committee of > 40 professionals
- Owners, consultants, and academics
- Geographically diverse
- Heavy geotechnical emphasis
- Includes loading and design details specific to marine structures
- Funding by US Navy
- Our tribe: “We’re great” Building guys suck.

Halcrow

What will these new standards do?

- Codify current practice of performance-based seismic design
  - National consensus document
- Build on work done by others specifically for the marine industry
  - California State Land Commission (MOTEMS)
  - Port of Los Angeles
    Port of Long Beach
  - PIANC

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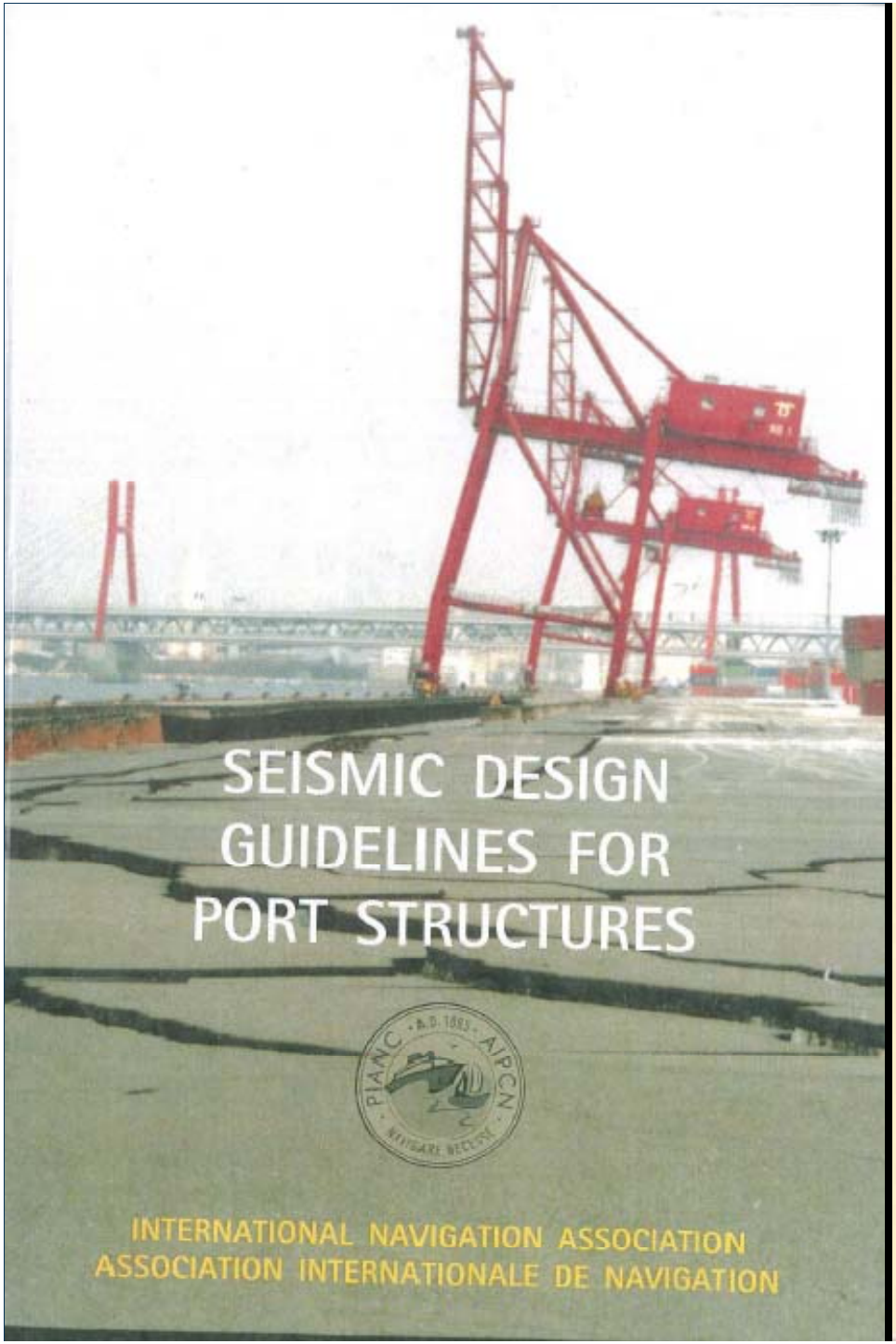

MARINE OIL TERMINAL ENGINEERING AND MAINTENANCE STANDARDS

CALIFORNIA STATE LANDS COMMISSION

MARINE FACILITIES DIVISION

May 2002

Why is this necessary ?

- Billions of dollars of construction in seismic regions
  - Performance-based design being used routinely on a project basis
- Existing marine codes have limited standing
- Conventional building codes still often take precedence
  - Enforcement by local building officials
- Conventional code development controlled by building designers
  - Major changes to those codes

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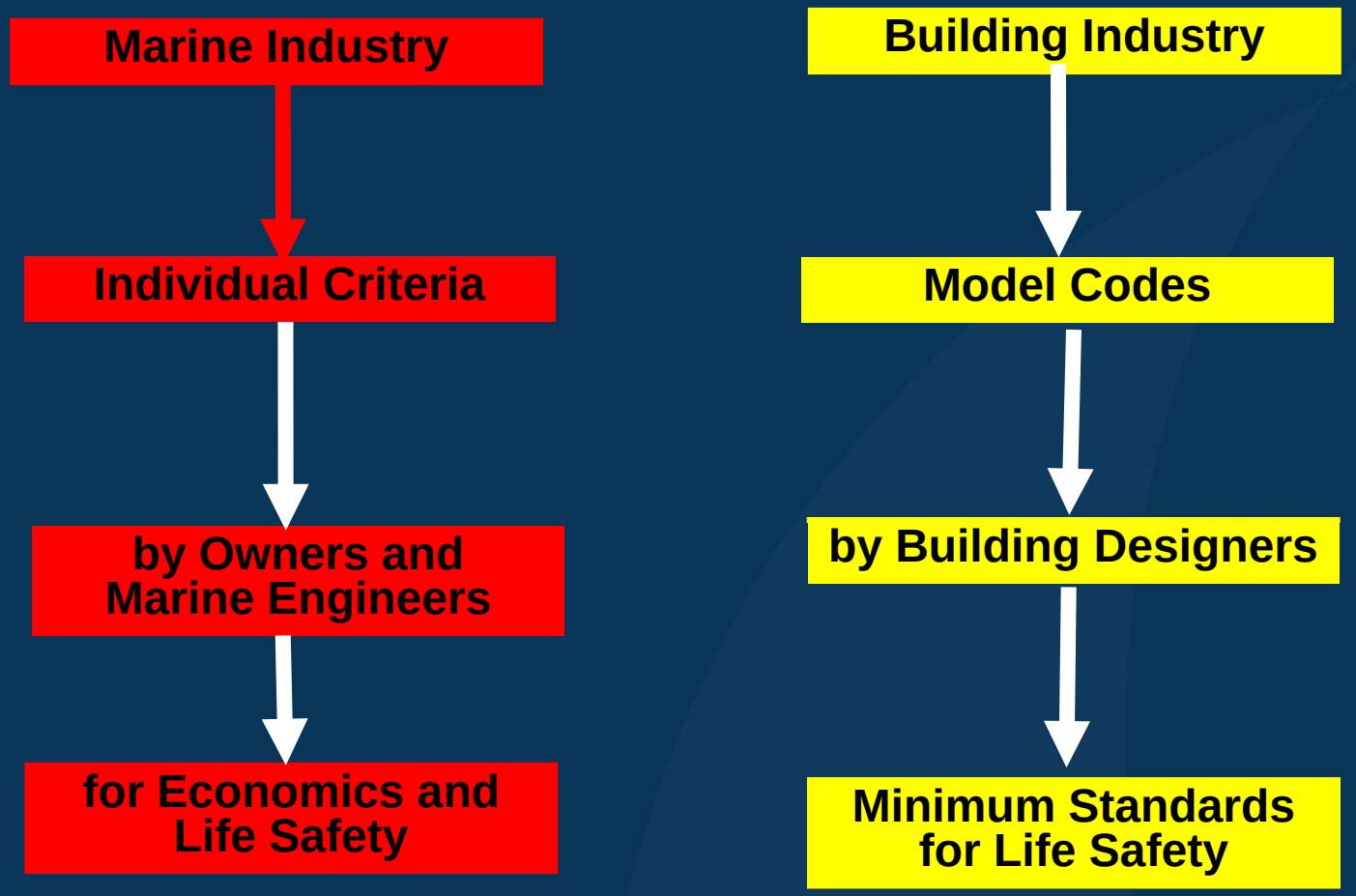
Code Development – 2 separate paths



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Marine Industry Historic Practice

- Through 1980's equivalent lateral force methods – mostly AASHTO based
- Lateral force often specified, not calculated for each project using R values, site factors, etc.
- Each major port (POLA, POLB, POAK) set their own criteria
  - POLA – 1981 used V = 0.12 W

Economics

BERTHS 216-218 POLA

DESIGN CRITERIA

JOB No. 7053-5-2 | SHEET No. 1

DESIGNED BY | DATE MAY 81

APPROVED

B. SEISMIC:

PSEUDO STATIC FORCE OF 0.12 g BOTH TRANSVERSE AND LONGITUDINAL DIRECTION.

g = TOTAL DEAD LOAD OF WHARF + CRANE DEAD LOAD.

~~ASSUMED~~ CRANE DEAD LOAD = 1000 K

Performance-based design

- PSHA's common by mid-1980s
- Two level design

- Port of Oakland Example
- L1: **20% in 50 years (240 year RP)**
  - 7% damping
  - 0.35g PGA
  - 0.95g Spectral peak
  - Divide spectral peak by "risk factor" of 8
- L2: **50% in 50 years (72 year RP)**
  - 5% damping
  - 0.25g PGA
  - 0.65g Spectral peak
  - Use "risk factor" of 4 (ductility before spalling)
- Smaller L2 earthquake governs design (V = 0.16 W)

Halcrow

1994 Port of Oakland Design

EARTHQUAKE LEVEL	1	2
TYPE OF SEISMIC EVENT	EXTREME	MODERATE
PROBABILITY OF EXCEEDANCE IN 50 YEARS	20%	50%
PEAK GROUND ACCELERATION	0.35g	0.25g
% DAMPING	5	5
DUCTILITY/RISK FACTOR, Z	5	2
PEAK OF DAMPED SPECTRAL ACCELERATION (PDSA)	0.95 W	0.65 W

$$Vu = \frac{PDSA}{Z} W$$

Icrow

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

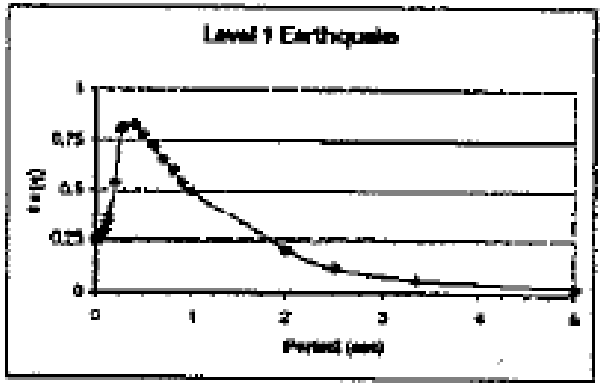
NOTE: PGA AND PDSA REPRESENT GROUND MOTION 10 FEET BELOW SURFACE FOR THE CDSM CONFIGURATION.

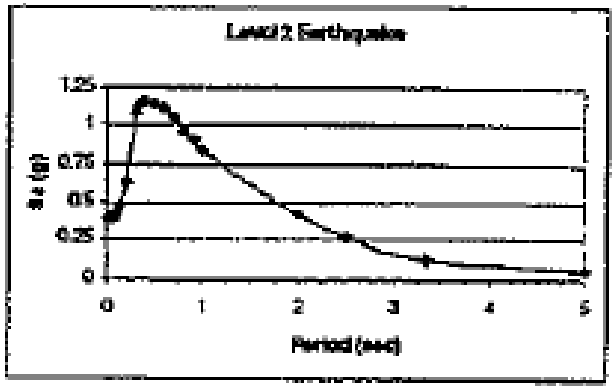
SEISMIC LOAD COMBINATIONS
(1) 1.4 DL + 1.0 EQ + 0.1 (VERTICAL LIVE LOAD FOR PILE DESIGN)
(2) 0.9 DL + 1.0 EQ

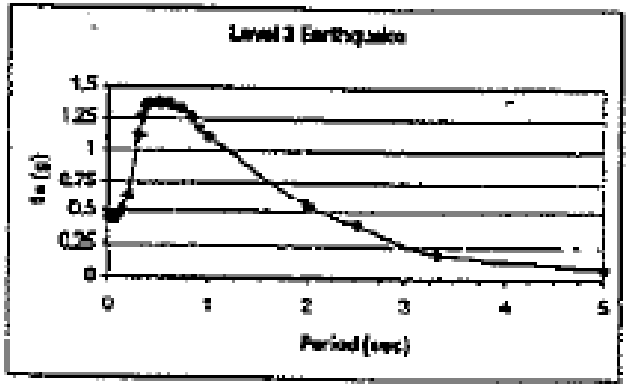
SITE-SPECIFIC RESPONSE SPECTRA HAVE BEEN DEVELOPED FOR THIS PROJECT BY SUBSURFACE CONSULTANTS, INC. MARCH 1998. FROM THESE SITE-SPECIFIC RESPONSE SPECTRA, THE FOLLOWING DESIGN RESPONSE SPECTRAS WERE DEVELOPED:

SLOPE DEFORMATION CRITERIA

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







2003 Port of Oakland Design

I. SEISMIC CRITERIA:

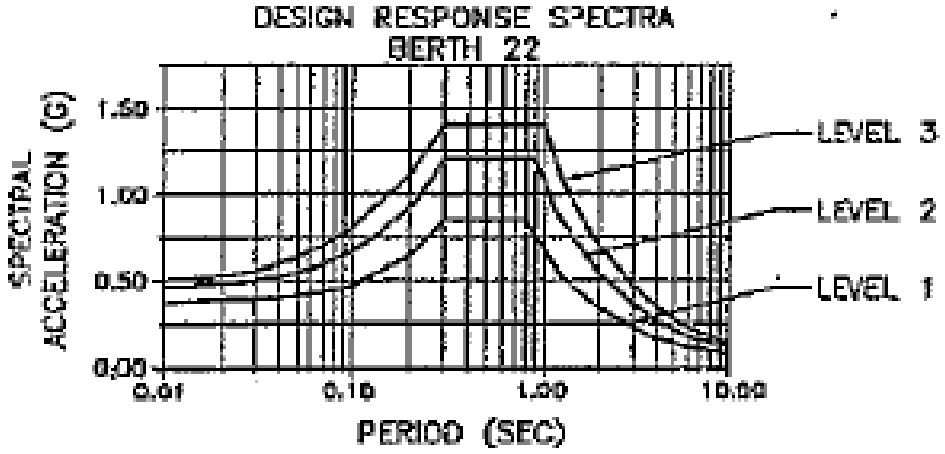
EARTHQUAKE LEVEL	1	2	3
PROBABILITY OF EXCEEDANCE IN 50 YEARS	50%	20%	10%
% DAMPING	5%	5%	5%
RESPONSE MODIFICATION FORCE REDUCTION FACTOR, R:			
ABOVE GROUND PILE FORCE	2	4	5
IN-GROUND PILE FORCE	1	2	2
PEAK GROUND ACCELERATION (PGA)	0.37g	0.46g	0.50g
PEAK OF DAMPED SPECTRAL ACCELERATION (PDSA)	0.85g	1.20g	1.40g

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. JUNE 2002. 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"



Were the low return periods unconservative ???

- Compare mid-80s Oakland design to a design using 1985 UBC
- V = ZIKCSW
  - Z = Zone factor (1.0 is highest for Zone 4)
  - I = Importance factor (1.0)
  - K = Factor for building type (0.67 for ductile moment resisting frame)
  - CS – Coefficients where CS need not exceed 0.14
- Express as ultimate load by applying a 1.4 factor
- V = 0.13W
- **Less** than the smaller L2 earthquake using the Port of

Current marine industry seismic design practice

- Performance based design

  Ports of Los Angeles, Long Beach, Oakland

  – MOTEMS for California Oil Terminals (State Law in 2006)

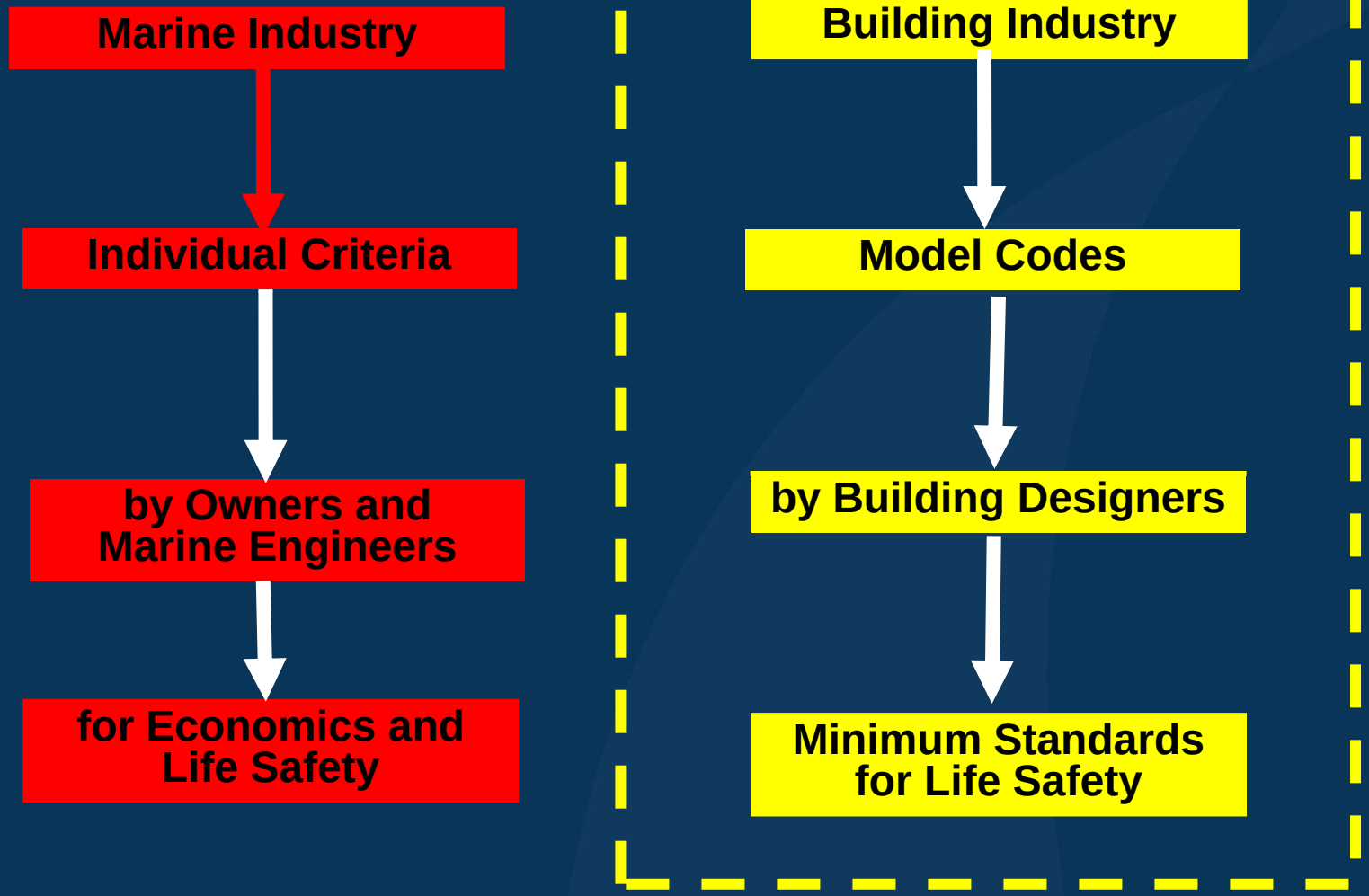
  – PIANC
- Two level earthquake

  – No damage level in small event

  – No collapse and repairable in large event
- Deformation based criteria
- Pushover analyses

Halcrow

Code Development – 2 separate paths



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Meanwhile:
Building Codes – "The Early Days"

- Through 1997:
  - Three model building codes adopted by building officials in US
    - Note: Not all ports subject to local building official jurisdiction
  - Dominated by UBC / SEAOC "Blue Book"
  - "Nonbuilding structures" added in 1988
  - No specific reference to piers and wharves

Halcrow

“World domination” by building designers

- Post 1997:
  - Consolidation of 3 US Model Building Codes into IBC
  - FEMA Sponsored National Earthquake Hazards Reduction Program (NEHRP)
  - ASCE 7 becomes focal point

  - Different sponsoring organizations

    Similar, but not identical, documents
  - Many of the same authors

Halcrow

Major changes to codes – not benign

- Some due to “lessons learned”, many changes for the sake of change
- Huge expansion of “nonbuilding structures”
  - Conflicts with existing industry practices and standards (not just piers and wharves)
- Major changes to ground motion definitions
  - Biggest effect outside of California

Halcrow

2000 NEHRP

14.6.6 Piers and Wharves:

14.6.6.1 General: Piers and wharves are *structures* located in waterfrcnt areas that project into a body of water or parallel the shore line.

14.6.6.2 Design Basis: Piers and wharves shall be designed to comply with the *Provisions* and approved standards. *Seismic forces* on elements below the water level shall include the inertial force of the mass of the displaced water. The additional seismic mass equal to the mass of the displaced water shall be included as a lumped mass on the submerged element, and shall be added to the calculated *seismic forces* of the pier or wharf *structure*. Seismic dynamic forces from the soil shall be determined by the registered design professional.

The design shall account for the effects of liquefaction on piers and wharfs as required.

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2003 NEHRP

- Task Committee of industry engineers
- Attempt to add performance-based design
- Crashed and burned

Ircrow

2003 NEHRP

14.3.3 Piers and wharves. Piers and wharves are structures located in waterfront areas that project into a body of water. Two categories of these structures are:

a. Piers and wharves with general public occupancy, such as cruise ship terminals, retail or commercial offices, restaurants, fishing piers and other tourist attractions.

b. Piers and wharves where occupancy by the general public is not a consideration and economic considerations (on a regional basis, or for the owner) are a major design consideration, such as container wharves, marine oil terminals, bulk terminals, etc., or other structures whose primary function is to moor vessels and barges.

These structures shall conform to the building or building-like structural requirements of the Provisions or other rational criteria and methods of design and analysis. Any methods used for design of these structures should recognize the unique importance of liquefaction and soil failure collapse mechanisms, as well as consider all applicable marine loading combinations, such as mooring, berthing, wave and current. Structural detailing shall be carefully considered for the marine environment.

14.3.3.1 Additional seismic mass. Seismic forces on elements below the water level shall include the inertial force of the mass of the displaced water. The additional seismic mass equal to the mass of the displaced water shall be included as a lumped mass on the submerged element, and shall be added to the calculated seismic forces of the pier or wharf structure.

14.3.3.2 Soil effects. Seismic dynamic forces from the soil shall be determined by the registered design professional. The design shall account for the effects of liquefaction on piers and wharves, as appropriate.

ASCE 7-05

15.5.6 Piers and Wharves.

15.5.6.1 General. Piers and wharves are structures located in waterfront areas that project into a body of water or parallel the shoreline.

15.5.6.2 Design Basis. In addition to the requirements of Section 15.5.1, piers and wharves that are accessible to the general public, such as cruise ship terminals and piers with retail or commercial offices or restaurants, shall be designed to comply with this standard.

The design shall account for the effects of liquefaction and soil failure collapse mechanisms, as well as consider all applicable marine loading combinations, such as mooring, berthing, wave, and current on piers and wharves as required. Structural detailing shall consider the effects of the marine environment.

Why was performance-based design rejected ?

- Two level performance criteria
- Levels of shaking / return periods viewed as “unconservative”
  - Consistent risk vs. life-safety
- Displacement based design not understood
- Inconsistency in building code geotechnical requirements not appreciated, not a big deal for buildings

Halcrow

Performance Criteria

- ASCE 7 / IBC
  - Historically was single earthquake
    - 475 year return period
    - Life safety only
  - Now Maximum Considered Earthquake (MCE)
    - 2,500 year RP with deterministic cap
    - Allegedly for collapse prevention
  - Design Earthquake
    - 2/3 MCE
    - Life Safety
  - Really a single-level earthquake design for 2/3 MCE
  - Performance at higher level is presumed due to implied factors of safety for buildings

Halcrow

Why change the 475 year return period ?

- Increase ground shaking in Eastern US
  - 2% in 50 years
- Keep actual design values for California about the same
  - 2/3 factor
  - Justified by inherent 1.5 factor of safety

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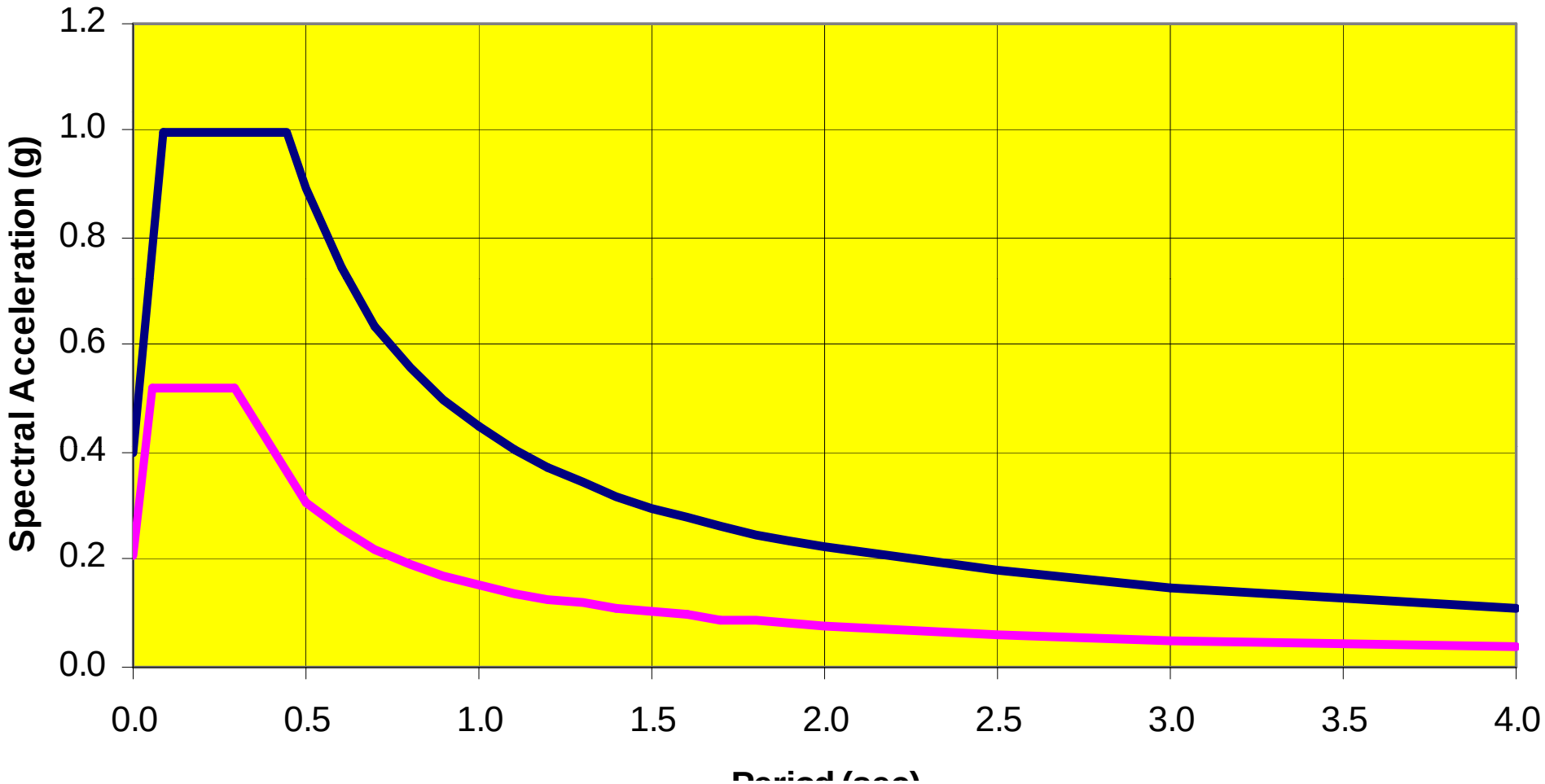
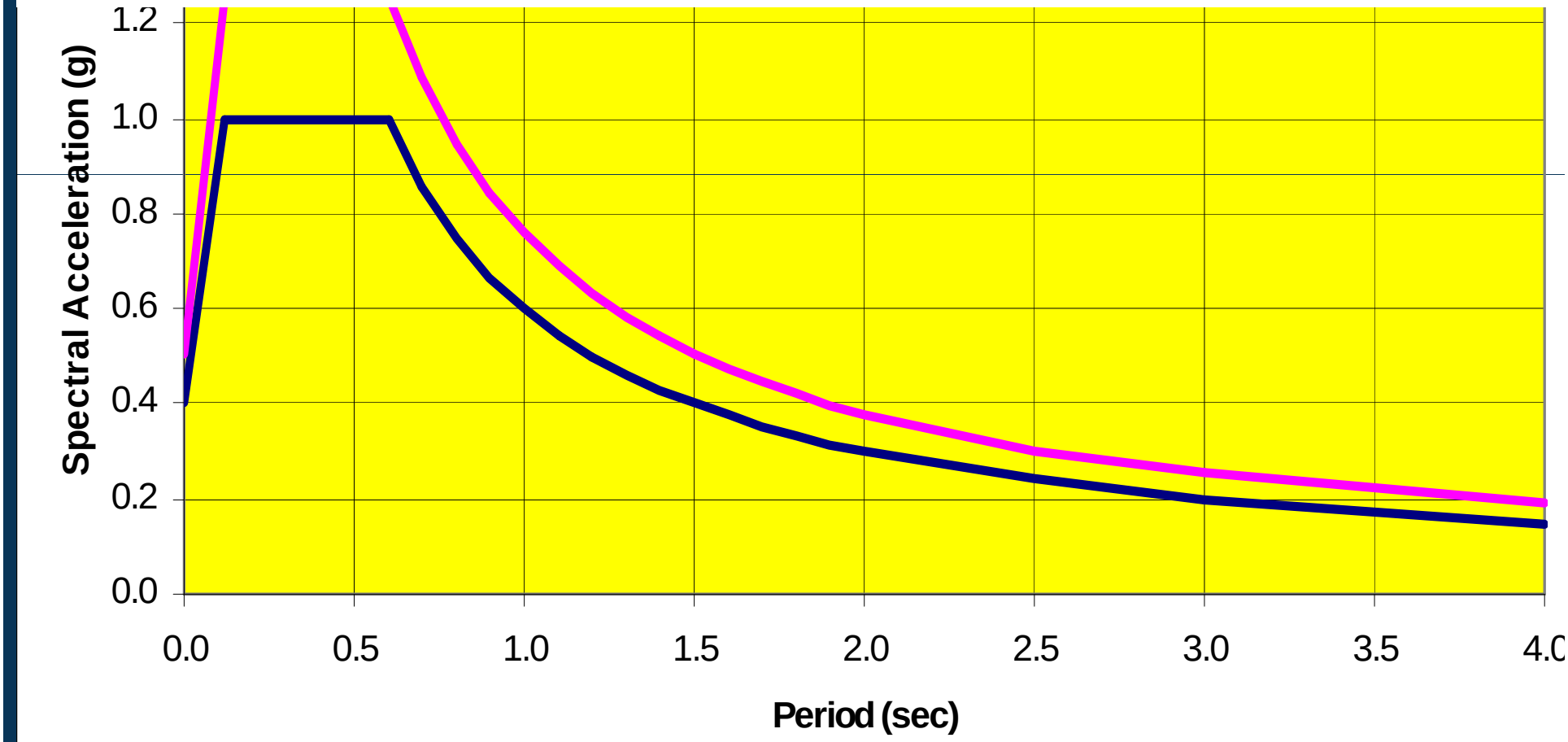

Spectral Acceleration (g)
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0


Spectral Acceleration (g)
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
Period (sec)

Port industry issues with changes

- Accelerations / forces can be scaled, displacements are not linear
- Massive ground failures occur in 2,500 year event that don't occur at 500 years
  - Can't just scale those events by 2/3
- Hard to distinguish between damage states for life-safety and collapse prevention
  - Inherent 1.5 FS is only for buildings
  - Difference between life-safety and collapse is meaningless
  - Life safety hasn't been an issue
- Never have addressed lessons learned in ports

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1989 Loma Prieta Earthquake

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1989 Loma Prieta Earthquake

1995 Kobe Earthquake

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1995 Kobe Earthquake

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1995 Manzanillo, Mexico Earthquake

1995 Manzanillo, Mexico Earthquake

1999 Turkey Earthquake

1999 Turkey Earthquake

2004 Indonesia Earthquake / Tsunami

New Standards

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 RP)	Minimal Damage	10% in 50 years (475 year RP)	Controlled and Repairable Damage	as per ASCE-7	Life Safety Protection
Moderate	n/a	n/a	20% in 50 years (225 year RP)	Controlled and Repairable Damage	as per ASCE-7	Life Safety Protection
Low	n/a	n/a	n/a	n/a	as per ASCE-7	Life Safety Protection

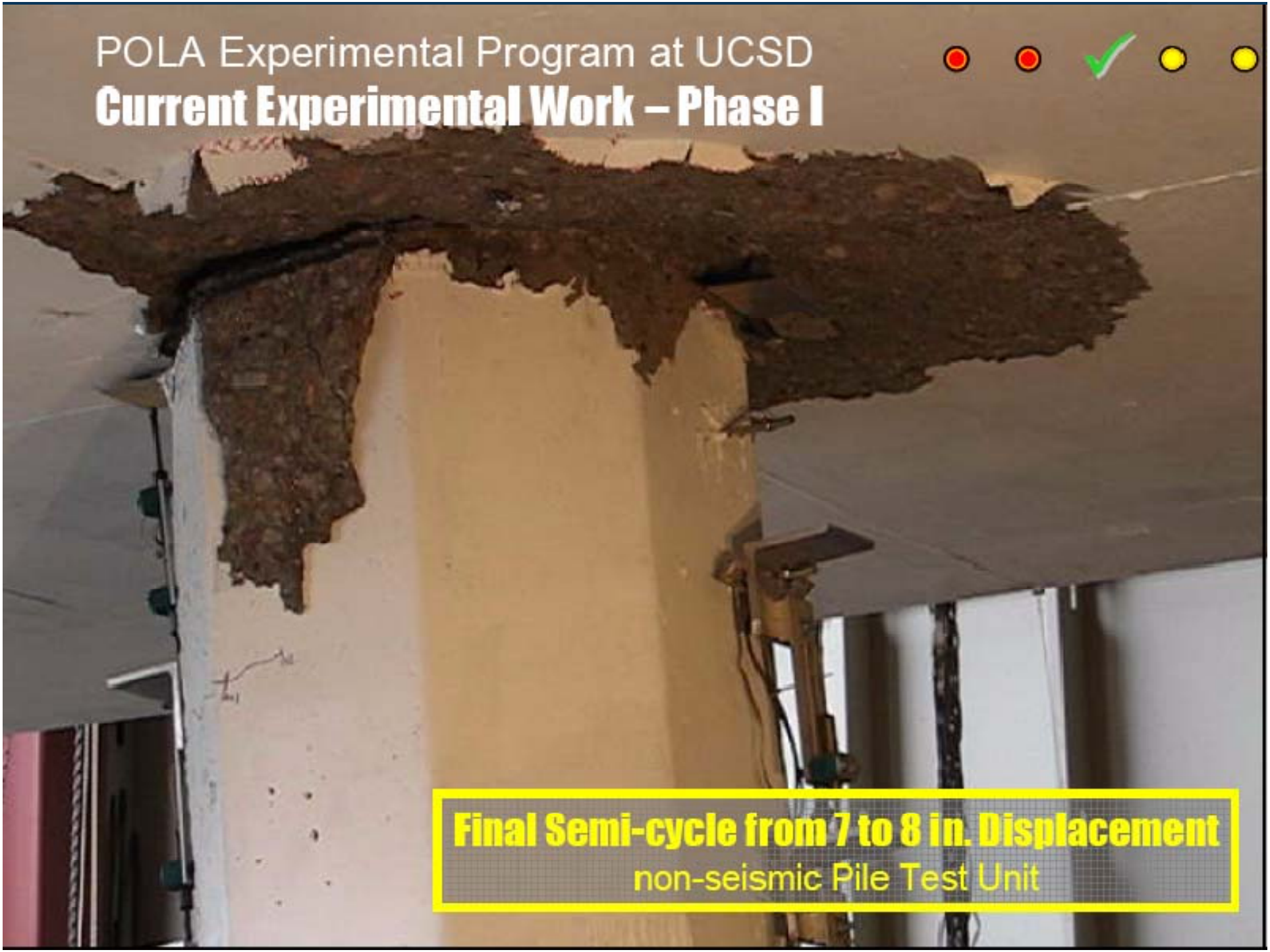
Does higher RP = more conservative ?

- ASCE 7
  - 2,500 year return period / non-collapse
  - 2/3 of that motion / life-safety
  - Lots of design coefficients e.g. “R” factor
- ASCE Piers and Wharves
  - Lower return periods
  - Controlled and repairable damage
  - “Failure” is more functional and economical
  - No real difference between life-safety and collapse

Arcrow

Table 3.3 CLE strain limits for "Controlled and repairable damage" per 2.4.2

Section	Strain Limits		
	Top of pile	**In-ground**	**Deep in-ground (>10D_p)**
Solid Concrete Piles - Doweled	$\varepsilon_c = 0.005 + 1.1\rho_s \le 0.025$	$\varepsilon_c = 0.005 + 1.1\rho_s \le 0.008$	$\varepsilon_c \le 0.012$
	$\varepsilon_s \le 0.4\varepsilon_{smd} \le 0.04$	$\varepsilon_p \le 0.025$	$\varepsilon_p \le 0.025$
Hollow Concrete Piles[a] - Doweled	$\varepsilon_c \le 0.006$	$\varepsilon_c \le 0.006$	$\varepsilon_c \le 0.006$
	$\varepsilon_s \le 0.6\varepsilon_{smd} \le 0.06$	$\varepsilon_p \le 0.025$	$\varepsilon_p \le 0.025$
Solid Concrete Piles - Fully Embedded	$\varepsilon_c = 0.005 + 1.1\rho_s \le 0.025$	$0.005 \le \varepsilon_c \le 0.008$	$\varepsilon_c \le 0.012$
	$\varepsilon_p \le 0.025$, $\varepsilon_s \le 0.025$	$\varepsilon_p \le 0.025$	$\varepsilon_p \le 0.025$
Steel Pipe Piles (concrete plug doweled connection)	$\varepsilon_c \le 0.025$	$\varepsilon_s \le 0.025$	
	$\varepsilon_s \le 0.6\varepsilon_{smd} \le 0.06$	~	$\varepsilon_s \le 0.035$
Steel Pipe Piles (hollow steel section) - Fully Embedded	$\varepsilon_s \le 0.025$	$\varepsilon_s \le 0.025$	$\varepsilon_s \le 0.035$
Steel Pipe Piles (concrete filled) - Fully Embedded	$\varepsilon_s \le 0.035$	$\varepsilon_s \le 0.035$	


POLA Experimental Program at UCSD
Current Experimental Work – Phase I
Final Semi-cycle from 7 to 8 in. Displacement
non-seismic Pile Test Unit

Tests at Oregon State University

Tests at University of Washington

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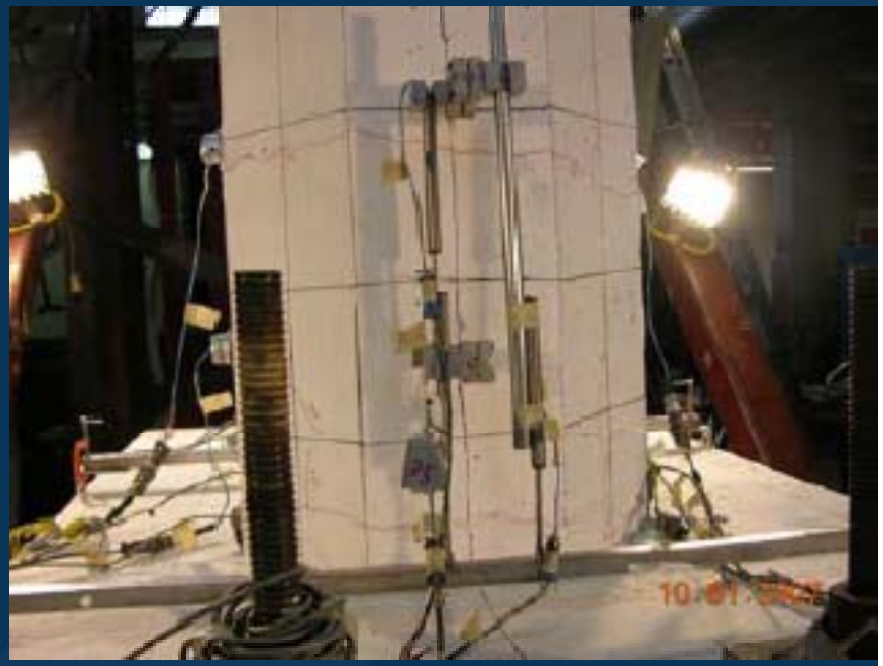
Tests at University of Washington

1.75 % Drift



- 9% Drift

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Advantages to industry specific standards

- Address common structural configurations
  - “Irregularities”
  - Sloping foundations
  - Battered piles
  - Strong beam / weak column
- Actual loading conditions
  - Kinematic
  - Mooring and berthing
- Code developers who work in the industry
  - Building designers think they know best
- Standing as “ASCE Mandatory Standard”
- Address issues like structural detailing

Halcrow

Table 7.1 Pile-to-deck connections

Connection	Referenced Section	Permitted Moment Curvature Analysis Method(s)
Pipe Pile Connections	**7.4.2**	
Embedded Pile	7.4.2.1	Method B
Concrete Plug	7.4.2.2	Method B
Isolated Shell	7.4.2.3	Method B
Welded Dowels	7.4.2.4	NA
Welded Embed	7.4.2.5	Method B
Prestressed Concrete Pile Connections	**7.4.3**	
Pile Build-Up	7.4.3.1	Method A
Extended Strand	7.4.3.2	Method A
Embedded Pile	7.4.3.3	Method A
Dowelled	7.4.3.4	Method A or B
External Confinement	7.4.3.5	Method B
Hollow Dowelled	7.4.3.6	Method A or B
Other Connections [1]	**7.4.4**	
Pinned Connection	7.4.4.1	Method B
Batter Pile	7.4.4.2	Method A or B

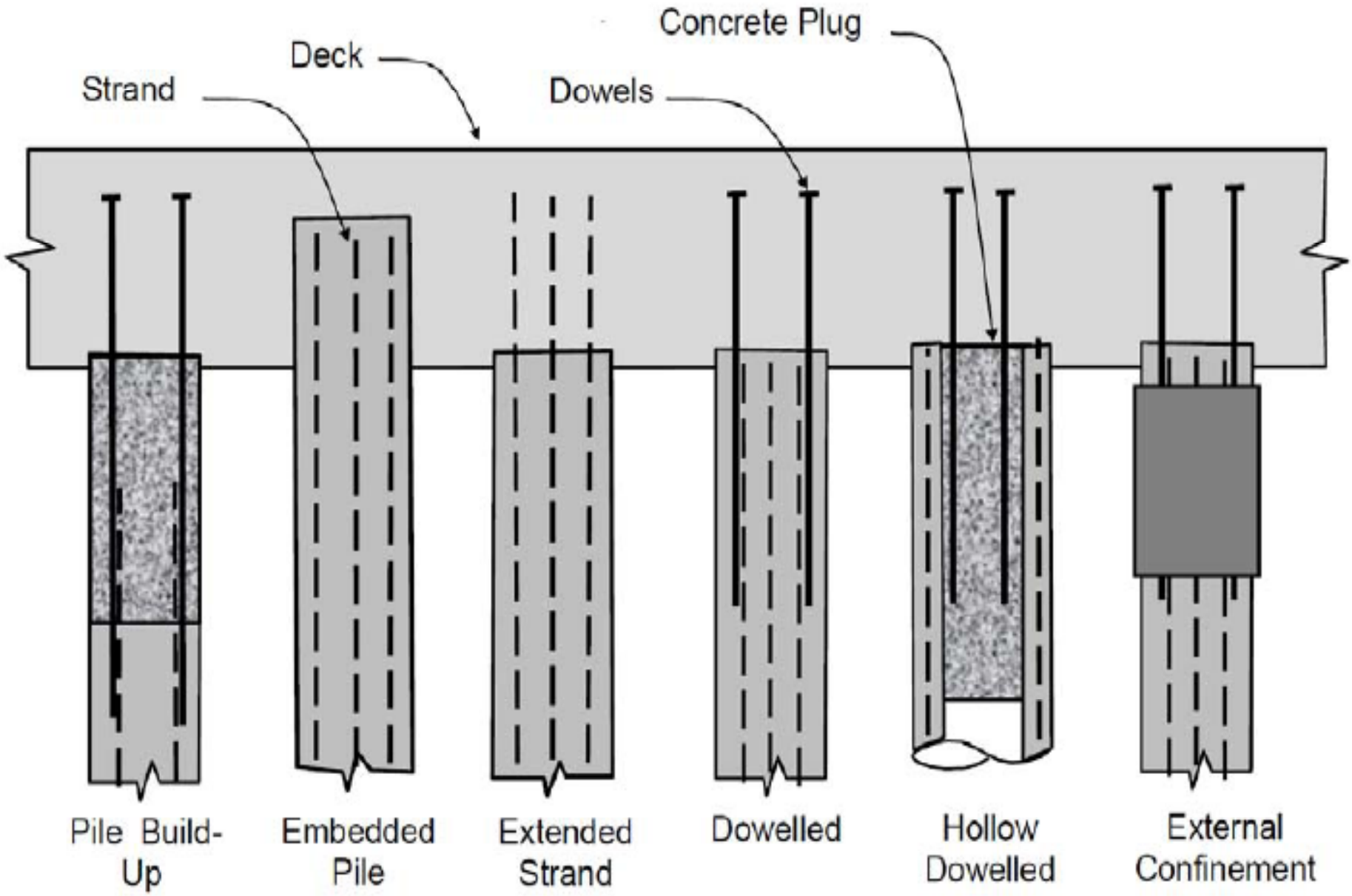

Figure C7.5 Examples of prestressed concrete pile connections

What's next ?

- Standard to be balloted this year
- Lengthy public review process
- Best case – published late 2011
- Over time – gain national standing and acceptance by building officials
- Continued application by marine industry

Icrow

Acknowledgements

- Bob Harn – Berger ABAM
- Arul Arulmoli – Earth Mechanics
- Omar Jaradat – Moffatt & Nichol
- Nate Lemme – U.S. Navy

Icrow

Questions ?

Icrow