Evaluating Seismic Capacity of a Newly Designed Wharf at the Port of Oakland

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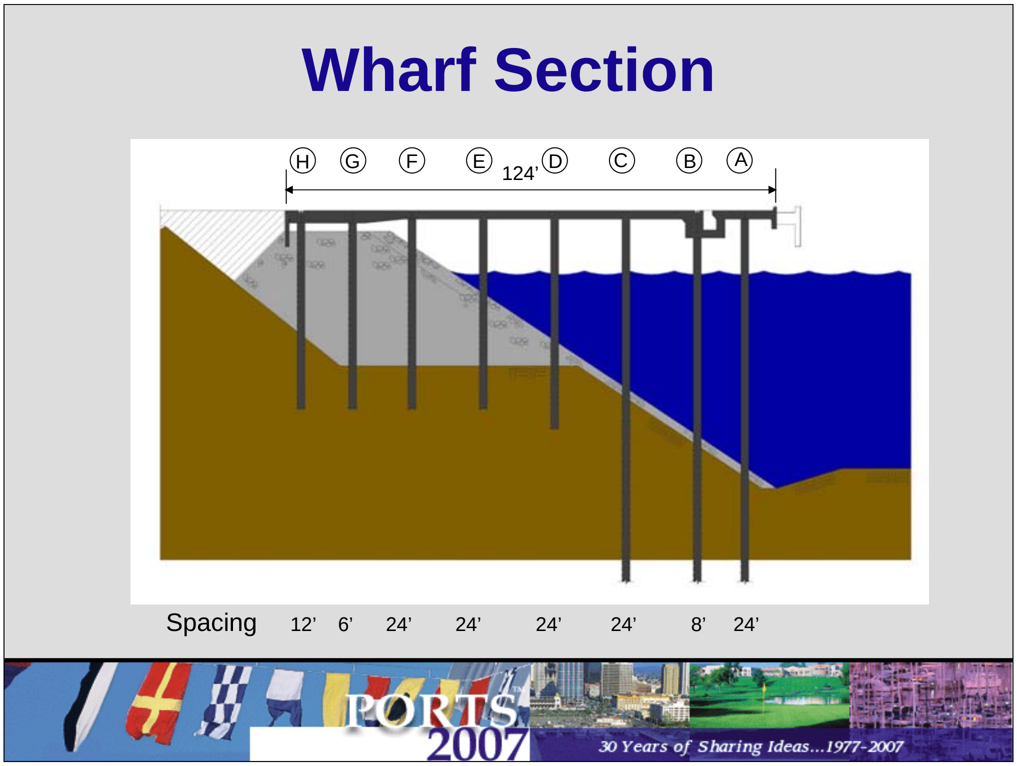


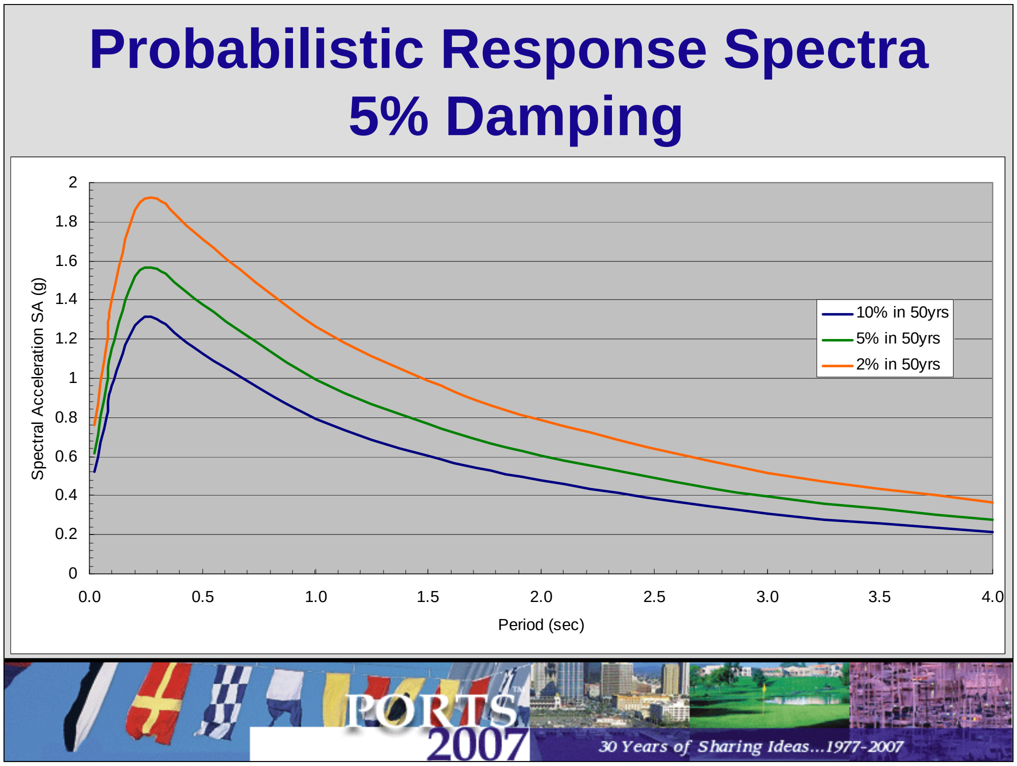
The wharf consists of a cast-in-place concrete deck typically 2'2" thick, thickening to 3'2" at the landside, supported on 24" octagonal prestressed piles at the spacing shown.
The cut-off wall is designed to rotate at the wharf connection and does not provide lateral resistance.

Subsurface Conditions

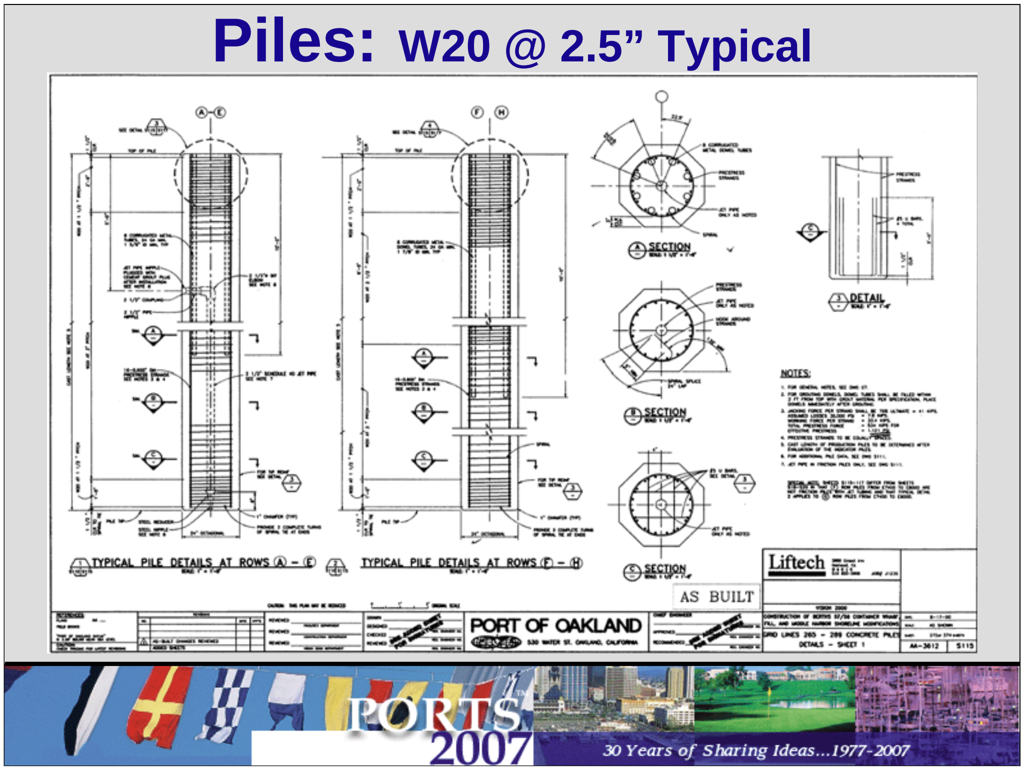
Layer	Material Type	Top Elevation (ft)	Total Unit Weight (pcf)	Friction Angle (degree)	Shear Strength (psf)	k (pci)	Vs (fps)	G/Gmax - Damping
1	New Fill	15	125	36	0	225	550/450	Fill
2	Mixed Fill	13	125	36	0	225	550/450	
3	Clayey Sand Fill	10	125	30	0	225	550/450	
4	Clayey Sand Fill (below gwt)	6	130	30	0	125	550/450	
5	Bay Mud	-2	100	0	see note	30	350 + 4d	YBM
6	Loose Clayey Sand	-15	130	0	250	30	1000 + 5d	SAF
7	Medium Dense Clayey Sand	-21	135	0	400	30	1000 + 5d	
8	Very Dense Sand	-25	130	45	0	125	1000 + 5d	
9	Dense Clayey Sand	-45	140	38	0	125	1000 + 5d	
10	Very Dense Sand	-60	135	45	0	125	1000 + 5d	
11	Dense Clayey Sand	-65	140	38	0	125	1000 + 5d	
12	OBM	-73	115	0	2500	1000	800 + d	OBM
13	Rock Dike (above gwt)	10	115	42	0	225	600 + 10d	Rock Fill
14	Rock Dike (below gwt)	6	120	42	0	125	600 + 10d	

Note: 354 psf at Elevation -2, then increases at 9.4 psf/ft

The soil properties used in our calculations are shown here.



The calculated probabilistic response spectra is shown here for 5% damping



Typical 24” octagonal prestressed piling was used.

For confinement, W20 spirals at 2.5” on center was used.

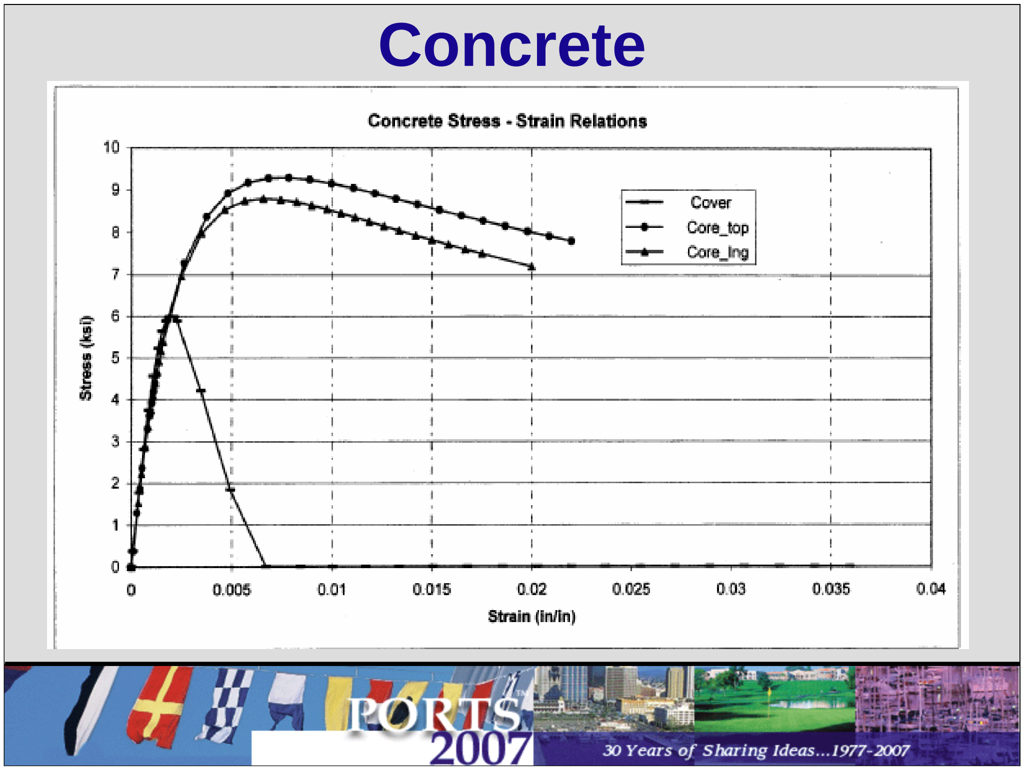
Pile Strain Limits

	Design 475yr MRI	Collapse 2500 yr MRI	Collapse / Design
Concrete			
Unconfined	0.004	0.006	1.5
Confined - Top	0.020	0.022	1.1
Confined - In-Ground	0.008	0.020	2.5
Steel			
Mild	0.05	0.15	3
Prestressing	0.01	0.05	5

The strain limits used to calculate the response of the piling is shown here.

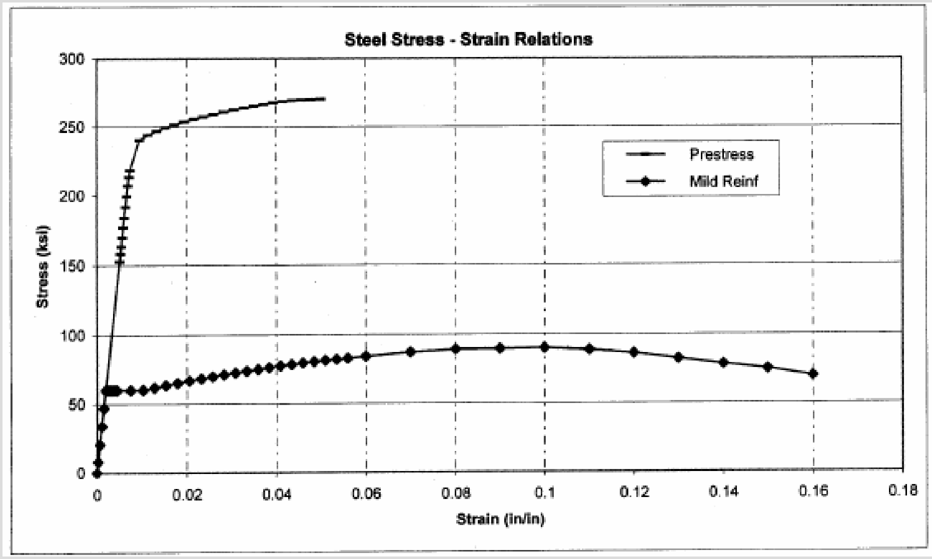
For the design earthquake with 475 MRI, standard Port of Oakland strain limits are used. These strain limits are set to limit damage.

For the collapse earthquake with 2500 MRI, strain limits where chosen to represent the expected strains at material failure.



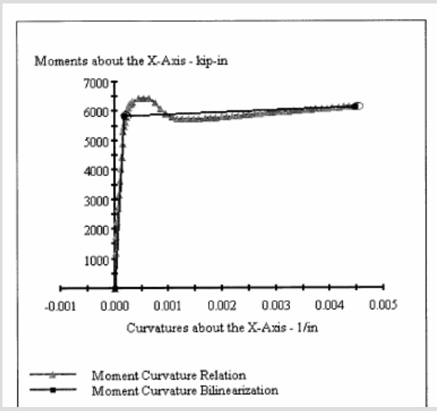
This is a graph of the concrete strains used for the collapse evaluation.

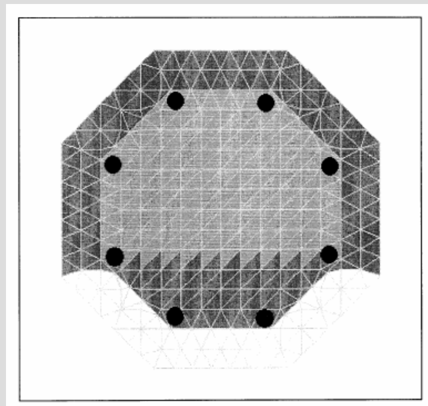
Steel



This is a graph of the steel strains used for the collapse evaluation.

Moment Curvature – At Dowels

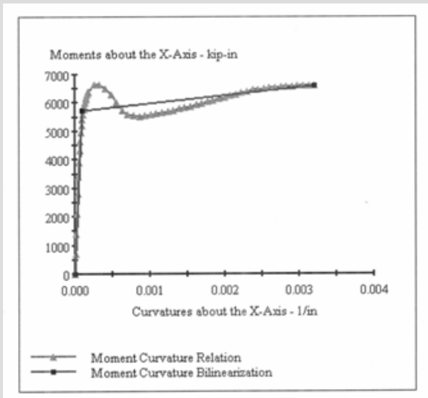


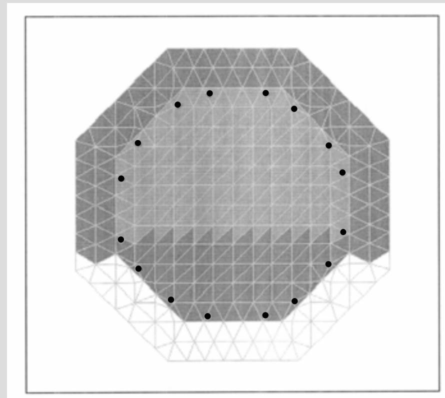


Using the chosen stress-strain relationships, moment curvatures were calculated for the piles.

The shown moment-curvature is for the upper end of the pile with dowels.

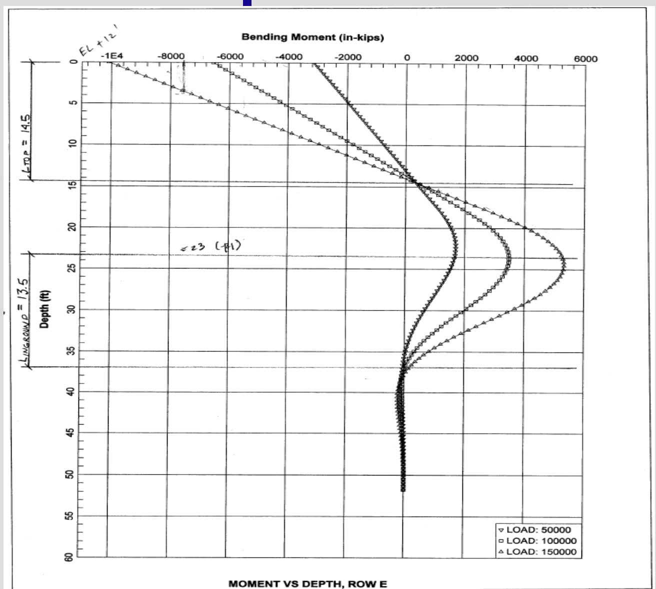
Moment Curvature – Typical





The moment curvature for the typical section of the pile with concrete and prestressing strands.

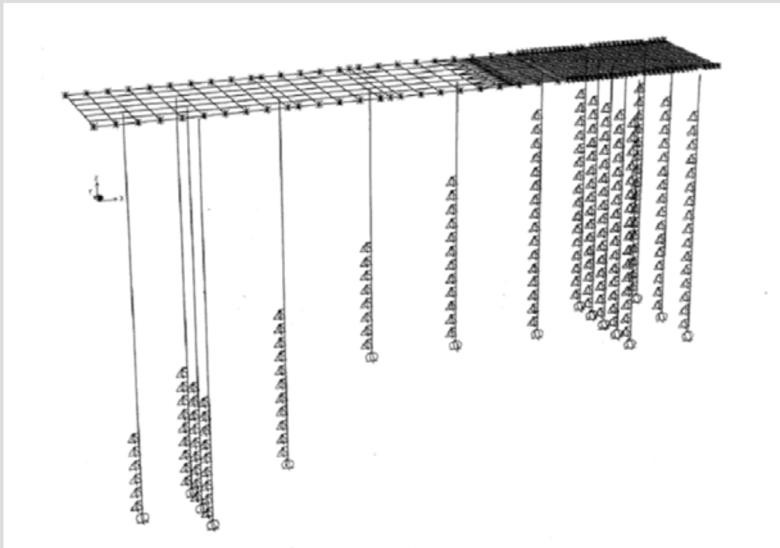
Pile Response - LPILE



The forces and moments in the piles were calculated using LPILE.

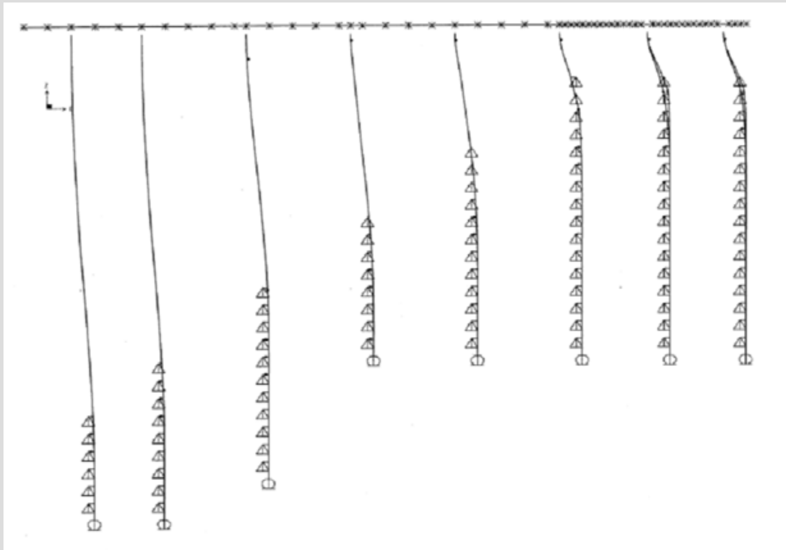
Plastic hinge locations and lengths were determined.

FEM Model



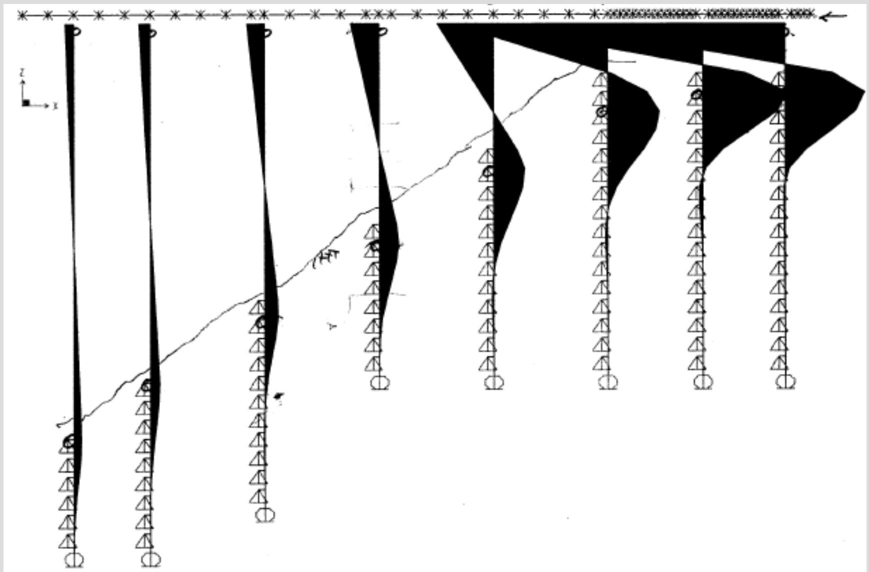
A finite element model of a length of wharf was analyzed.

Wharf Deformation with P-Delta



A pushover analysis including second order effects was performed.

Pile Moments



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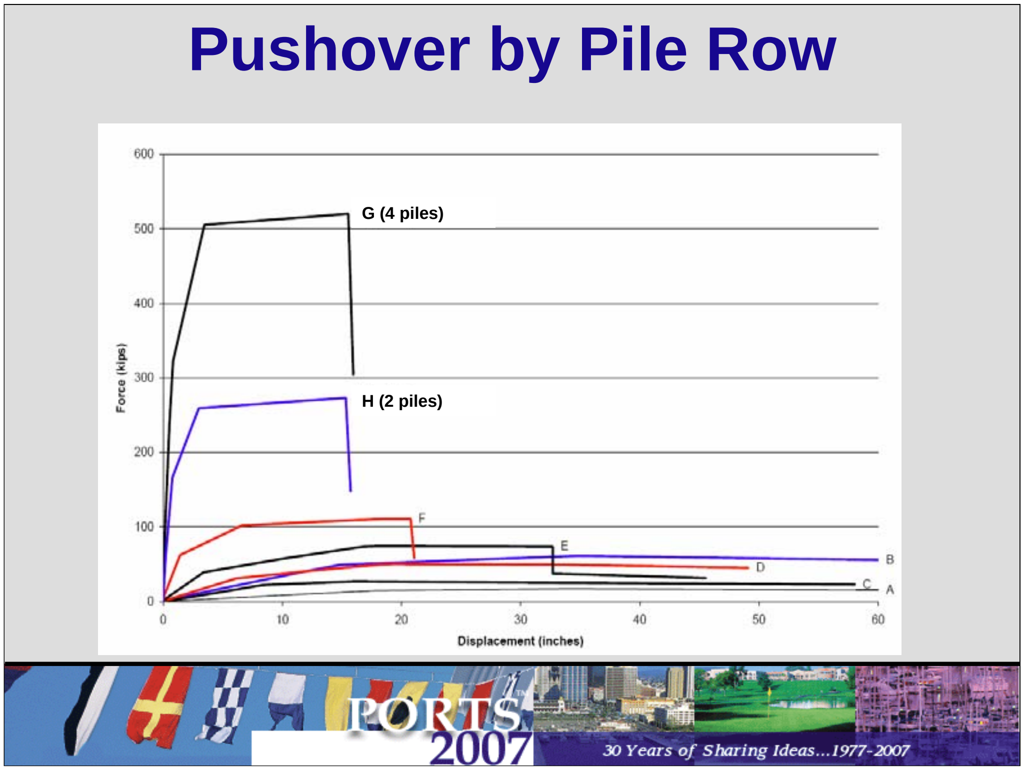
The stiffer landside piles provide the most lateral resistance and experience the largest moments.

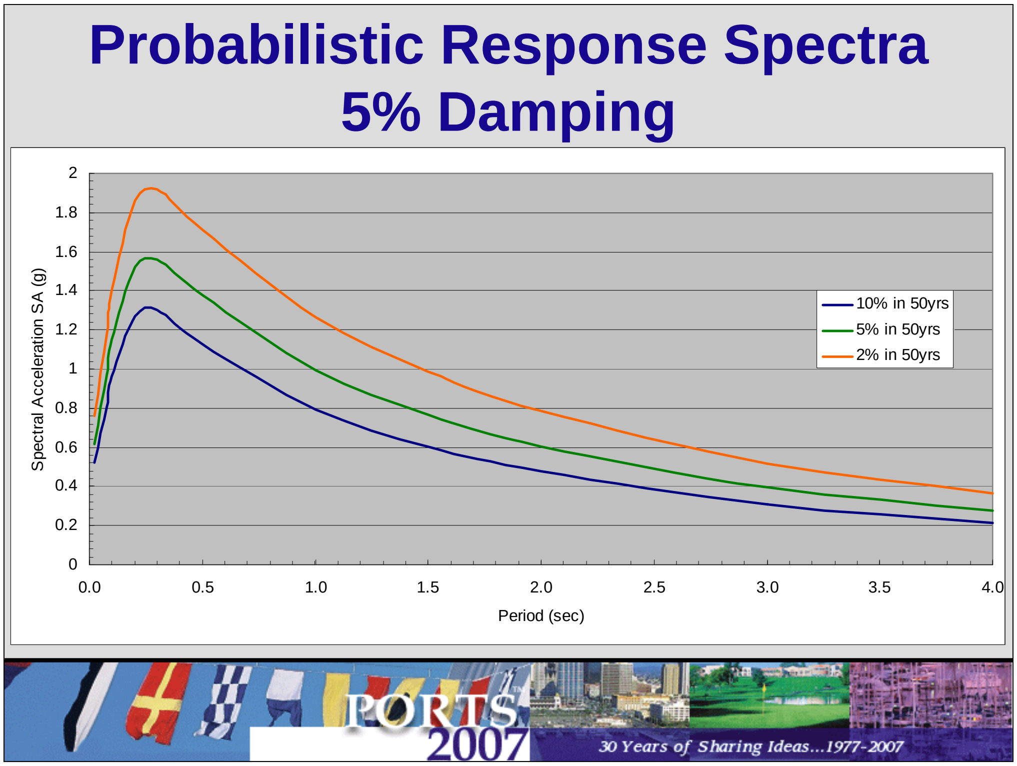


This graph shows the calculated lateral force and the displacement at the wharf deck for the various pile rows.

The stiffer landside piles initially resist the most load and have the greatest lateral capacity.

For each pile row, the reduction in stiffneses occur as follows:

1. Spalling of unconfined shell
2. Plastic hinging near the wharf connection
3. Plastic hinging slightly below the soil boundary
4. Failure due to the pile breaking at the wharf connection and at the in-ground plastic hinge

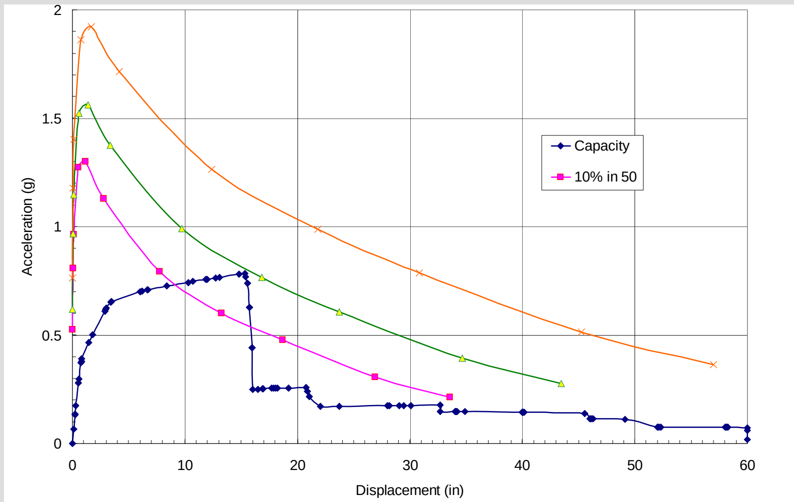


The calculated response spectra for the design earthquakes and collapse earthquakes.

5% damping

Collapse = 2% in 50, MRI = 2500 years

Demand versus Capacity
5% Damping



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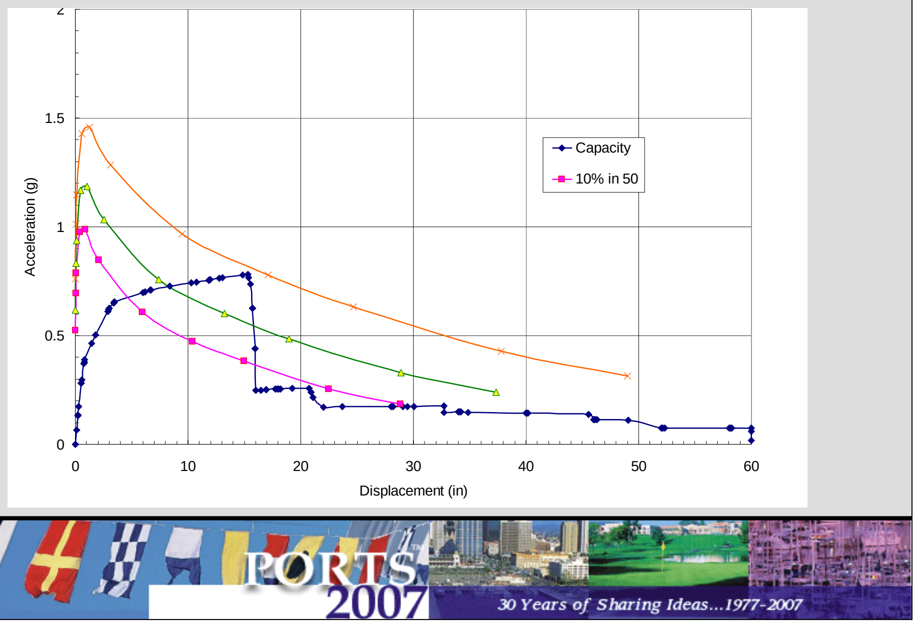
Pushover curve for 5% damping.

Notice that at this damping, the seismic demand exceeds the capacity of the structure and the structure will collapse.

Fortunately, as the structure is damaged, the damping increases well above 5%.

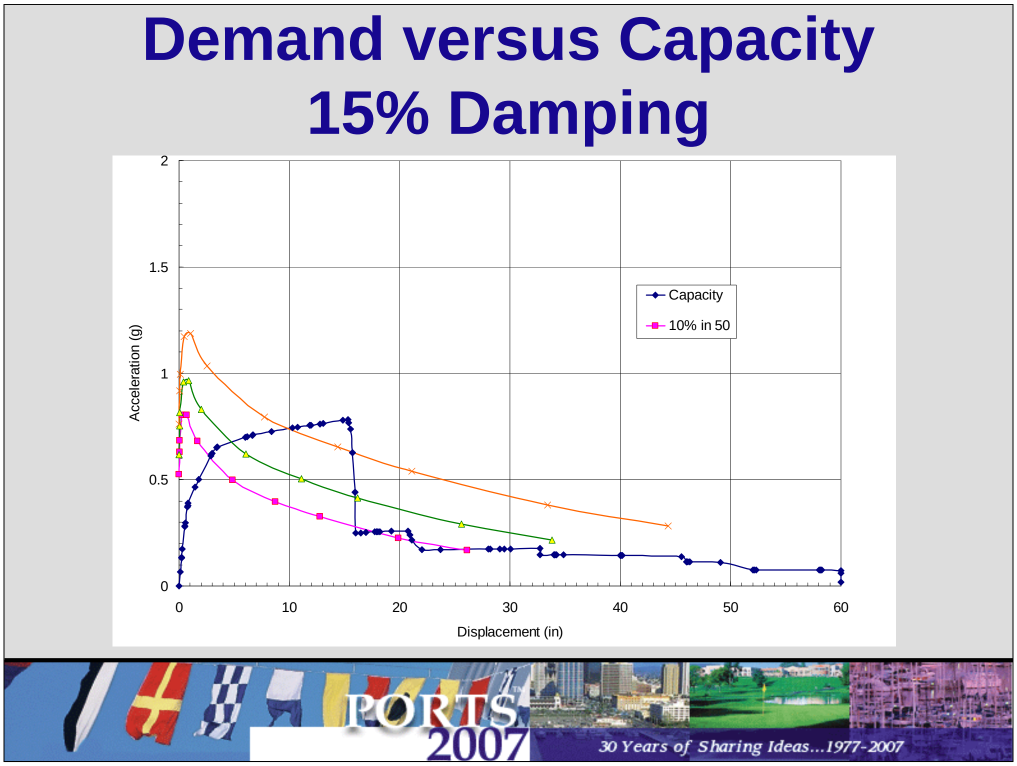
Demand versus Capacity 10% Damping



The same pushover graph but for 10% damping.

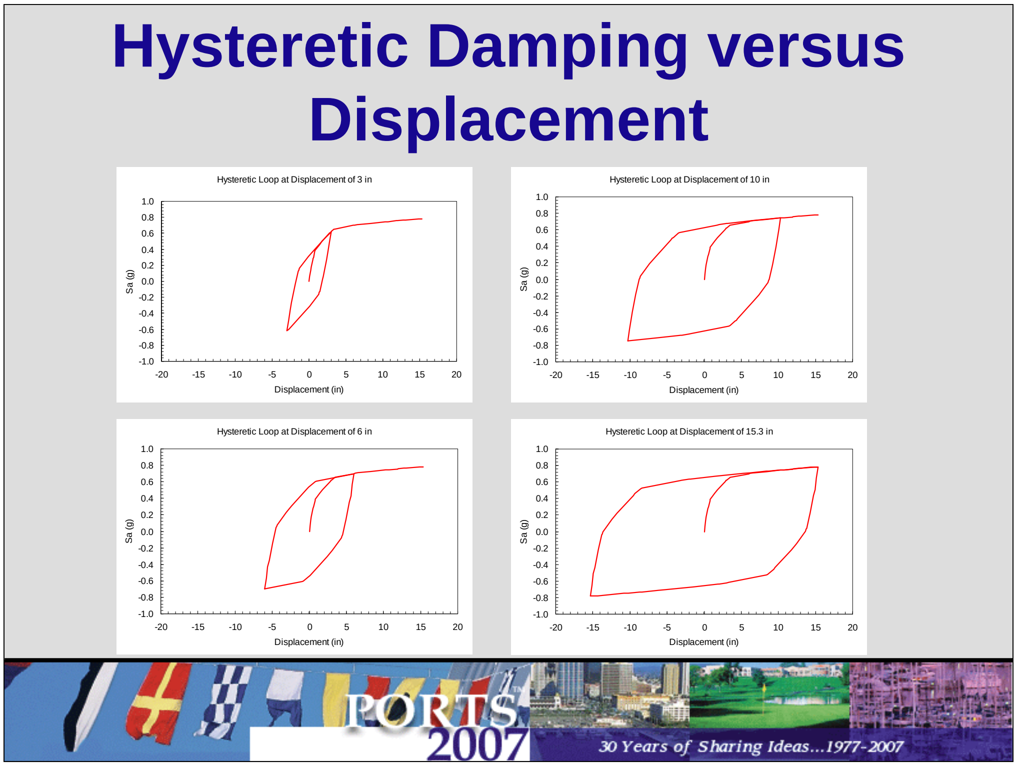
Again, the damage to the structure will result in damping greater than 10%.

This graph is shown to present the significance of damping on the seismic demand on the structure.



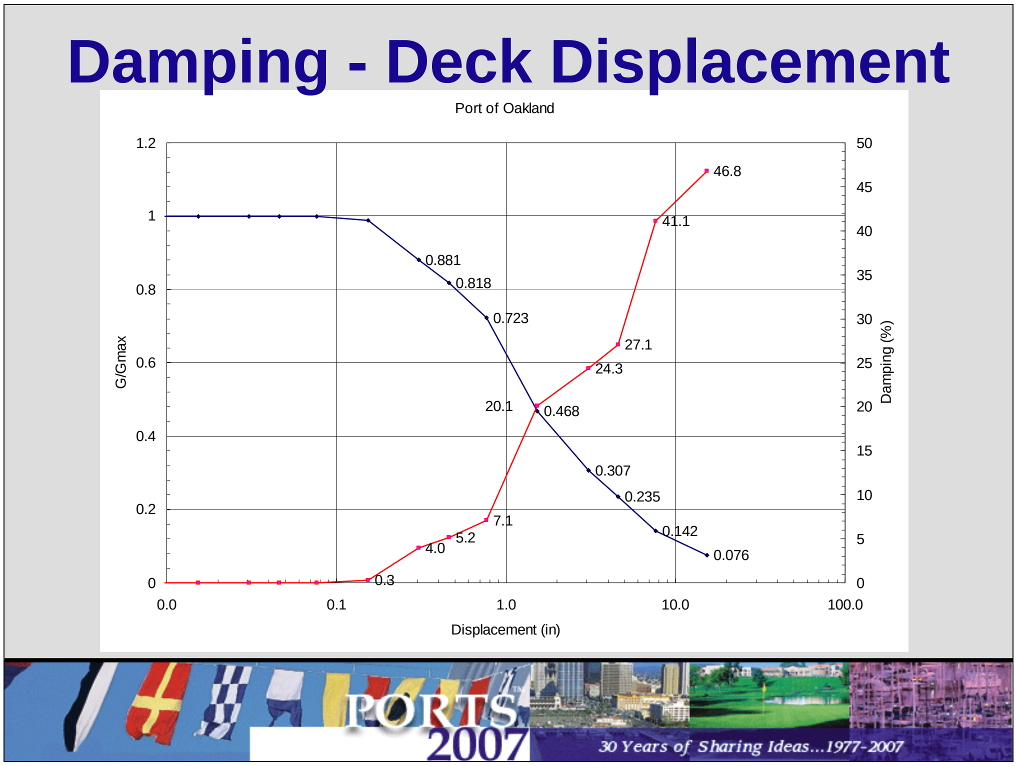
The same graph shown with 15% damping.

For this seismic demand, the landside pile rows have formed plastic hinges and are severely damaged; however, the structure does not collapse.



So what damping develops in the structure?

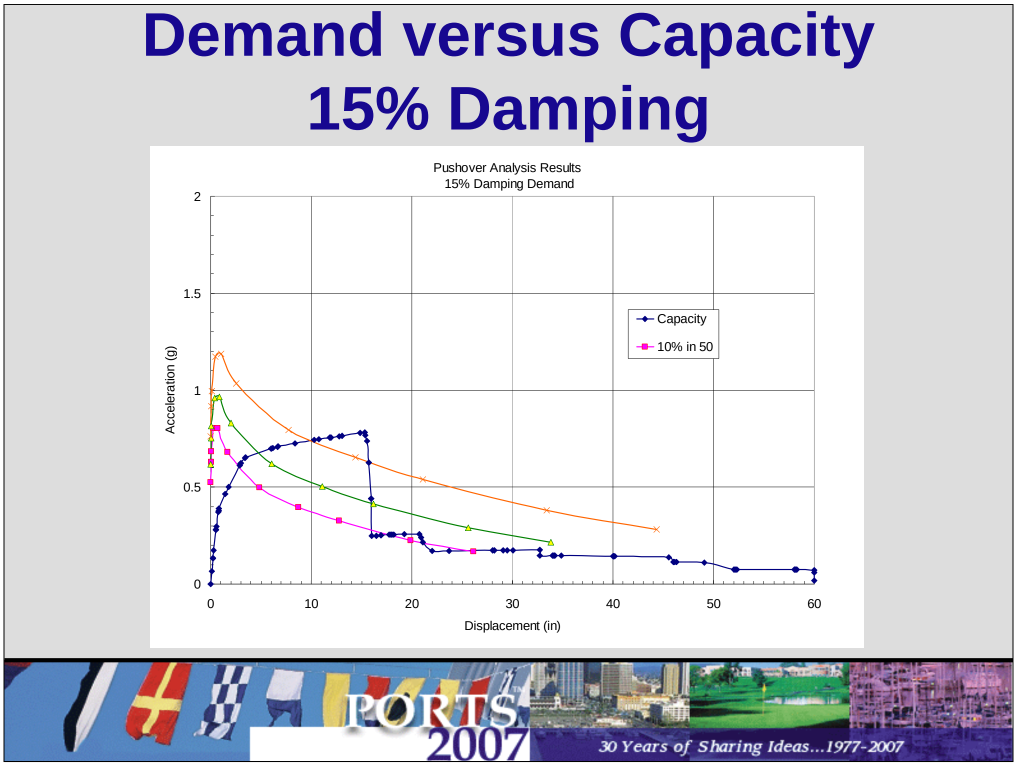
The following graphs present the hysteretic loops at various wharf deck lateral displacements.



Even at small displacements, the damping in the structure is significant.

At slightly less than 1" of displacement, approximately 10% damping is expected.

15% damping is attained at deck movements slightly above 1".

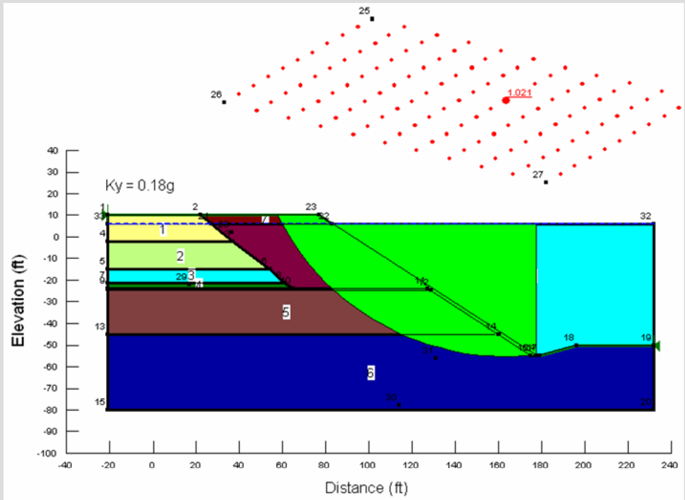


The point of the previous graph is to illustrate that there will be significant damping in the structure at small displacements.

As shown again, at damping greater than 15%, collapse does not occur.

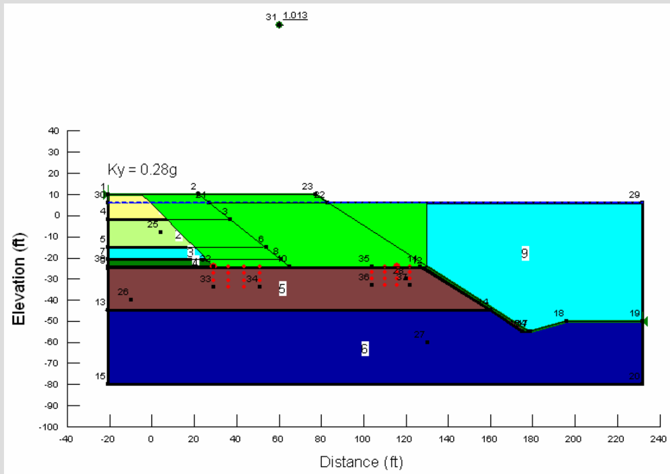
Based on our calculations, we do not expect collapse due to structural deformations in an earthquake with a 2500 year MRI.

Static & Pseudo-Static Slope Stability



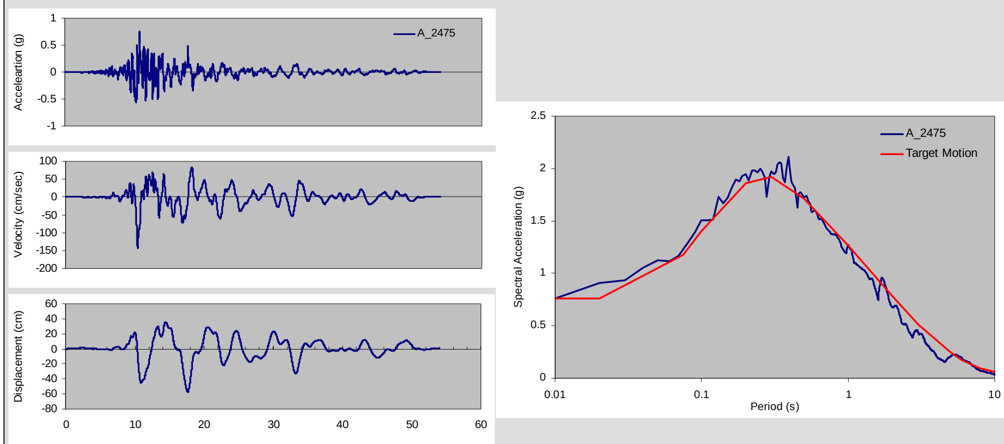
Circular Type of Failure Surface with a Yield Acceleration of 0.18G

Static & Pseudo-Static Stability Analysis

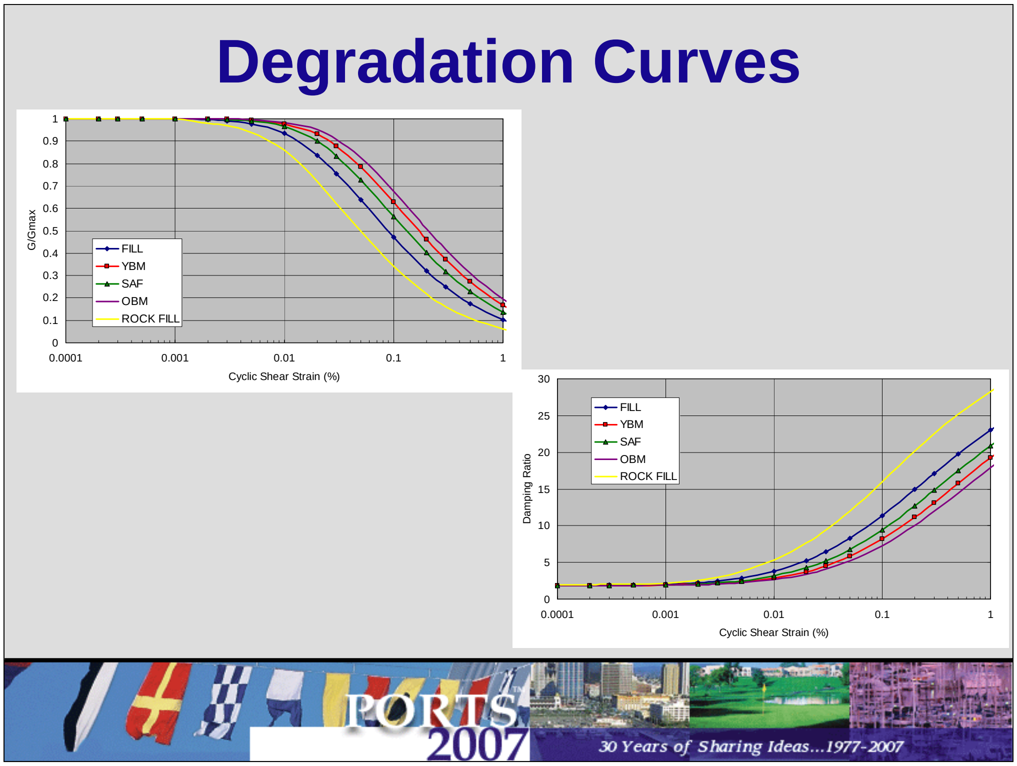


Wedge Type of Failure Surface with a Yield Acceleration of 0.28G

Spectrum Compatible Ground Motion

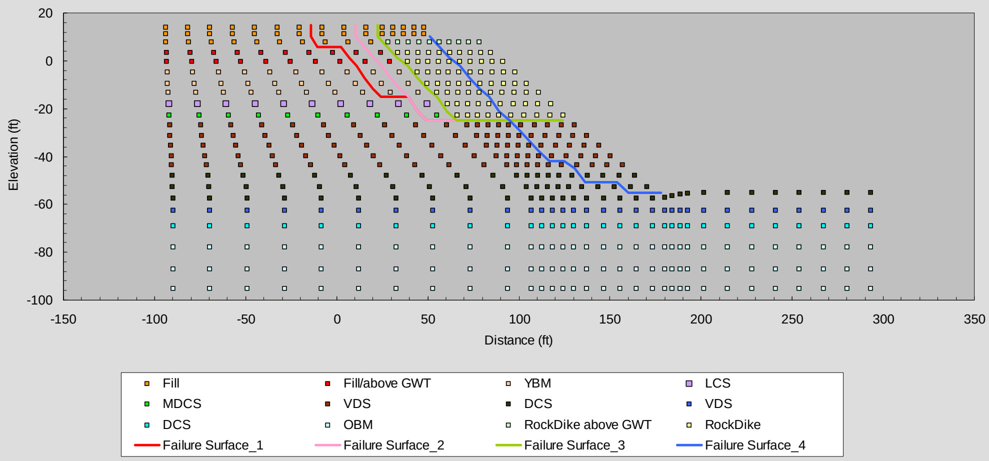


Acceleration, Velocity, and Displacement time history of one design ground motion compatible with response spectrum of 2475-yr return period



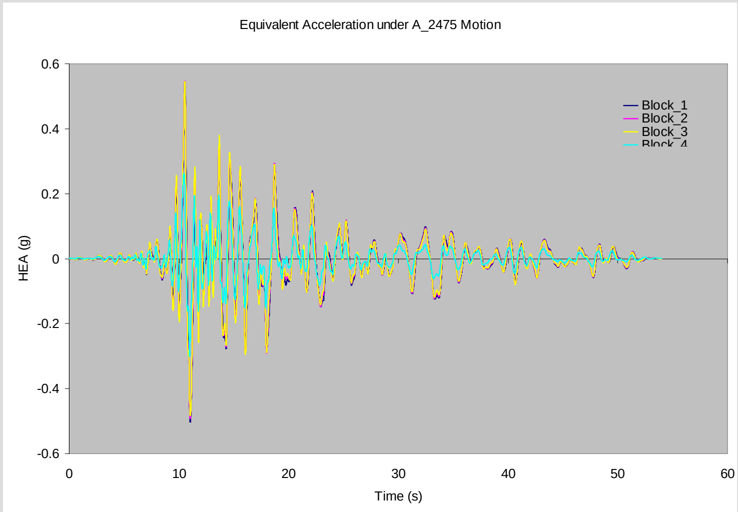
Modulus degradation and damping curves used in quad4m analysis

Two-Dimensional Site Response Analysis

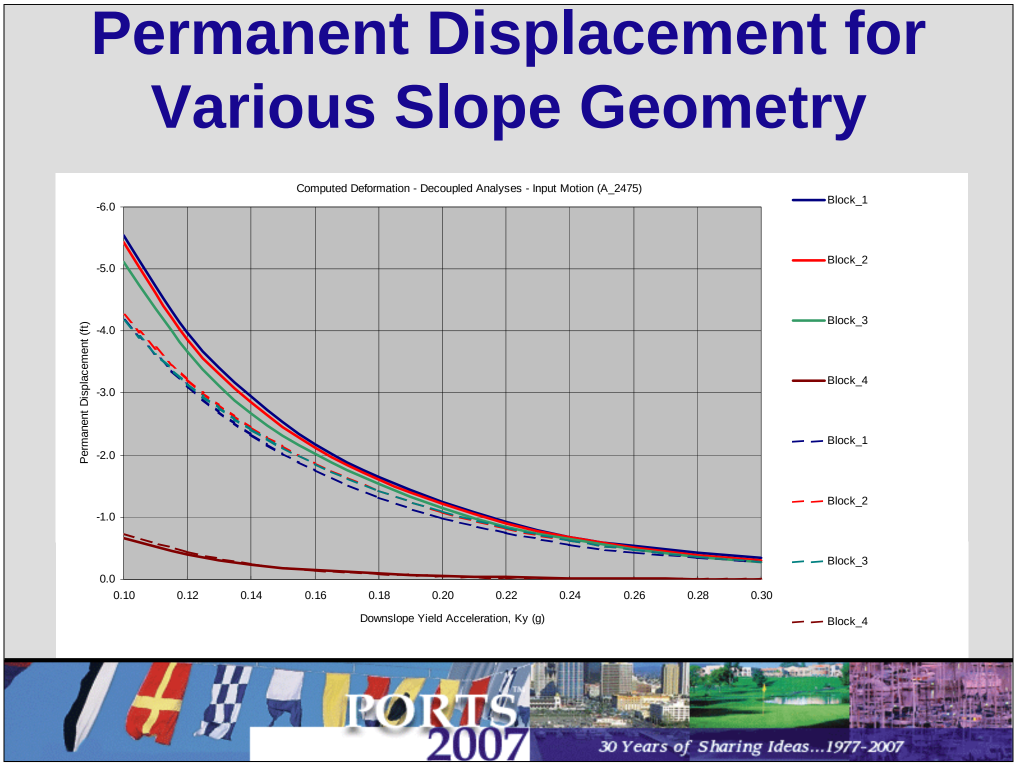


2D quad4m site response analysis with 4 different failure surfaces

Average Induced Ground Acceleration



Horizontal equivalent accelerations calculated by QUAD4M for each block



Calculated permanent deformation vs. Ky

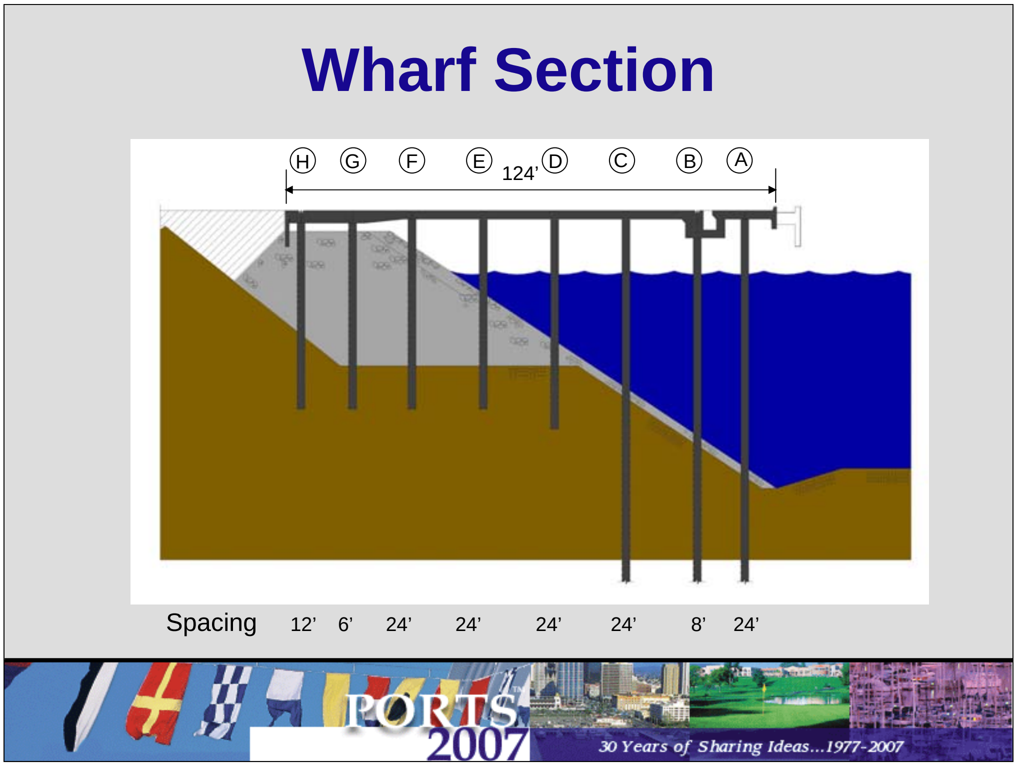
Static Slope Stability & Newmark Deformation

Slope Stability		
	Circular Failure	Wedge Failure
Static FOS	1.8 ~ 1.9	2.9 ~ 3
Yield Acceleration (g)	0.18	0.28

Decoupled Displacements using QUAD4M/Newmark (ft)		
Ground Motions	Circular Failure	Wedge Failure
10% in 50 yrs (~475 yrs)	0.1	0.2
5% in 50 yrs (~950 yrs)	0.2	0.6
2% in 50 yrs (~2475 yrs)	0.5	1

Decoupled Displacements using QUAD4M/Newmark (in)		
Ground Motions	Circular Failure	Wedge Failure
10% in 50 yrs (~475 yrs)	1.5	2.5
5% in 50 yrs (~950 yrs)	2.5	7.5
2% in 50 yrs (~2475 yrs)	6	12

Summary of static and dynamic slope stability analyses



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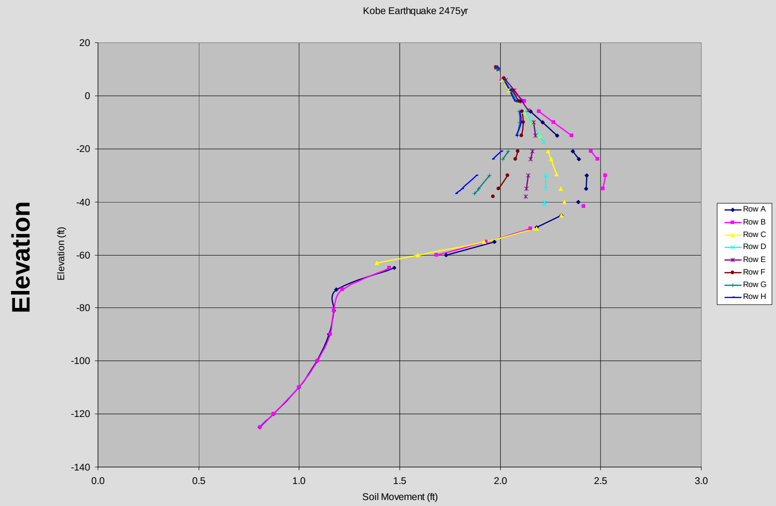
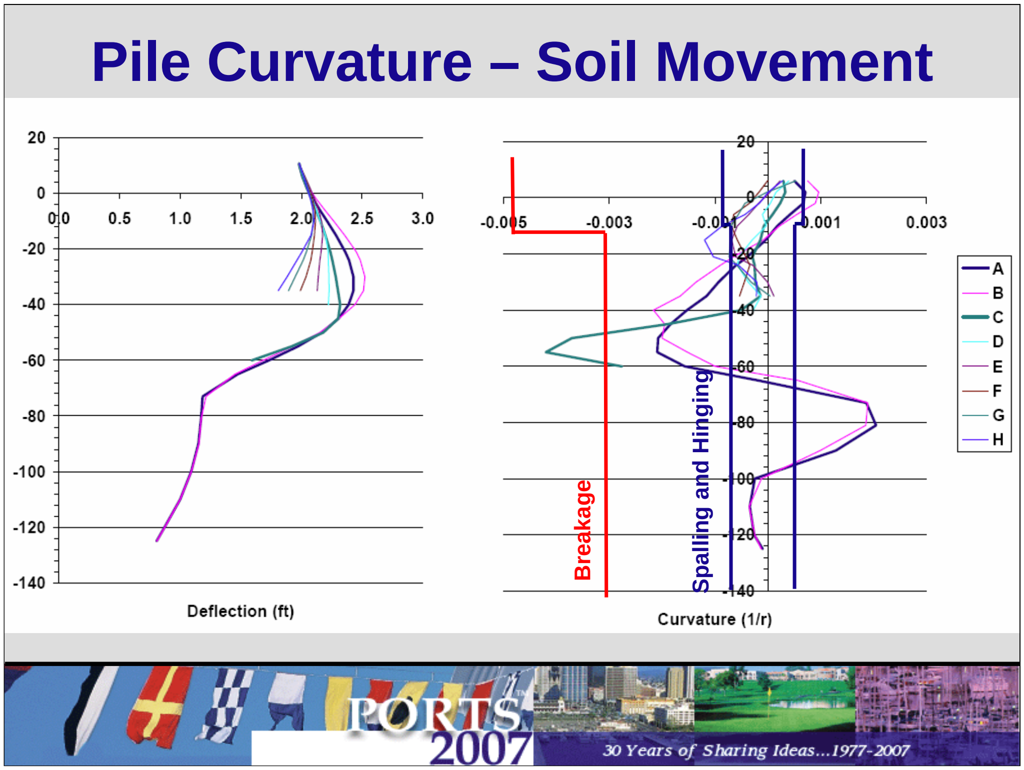
Two-Dimensional Nonlinear FLAC SSI Analysis



Pile deformation pattern by FLAC-2D analyses



Pile deflections were calculated using the FLAC analysis for multiple design earthquakes with 2500 year MRIs.

Calculated pile deflections for the scaled Kobe earthquake are shown in the graph on the left.

The calculated curvatures shown in the right graph were calculated using the finite difference method.

As shown, at several locations, plastic hinges are expected to form in the piles. At only one location is the pile expected to break.

The locations of high strain due to soil movement shown here differ enough from the locations of high strain from the dynamic response of the wharf that the two deformations are not considered simultaneously.

Thank you

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