

Flexible Approach Walls Navigation Systems

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Technology Exchange Meeting

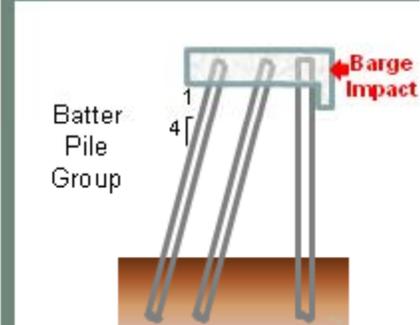
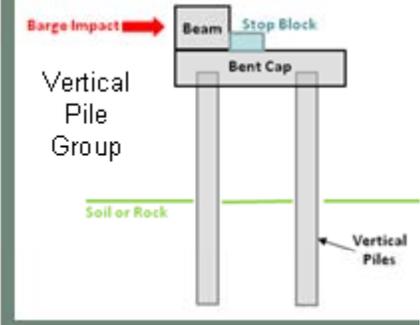
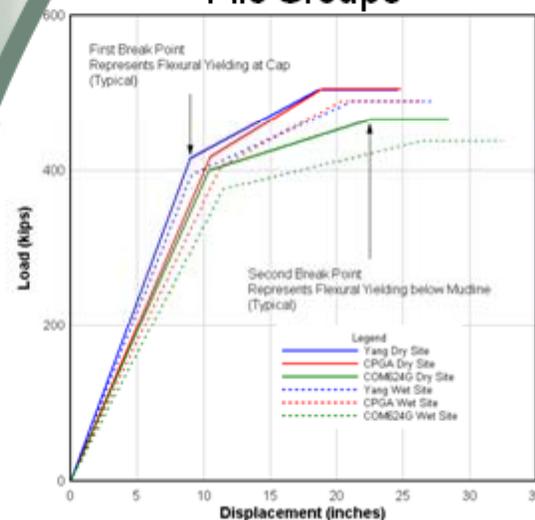
28 October 2014



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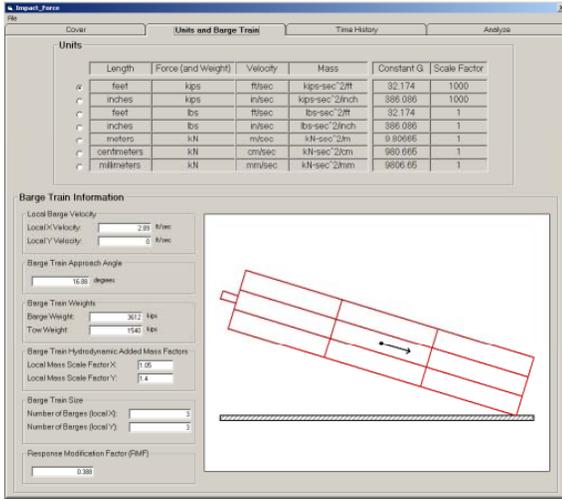
Pushover Analysis of Pile Groups





Full-scale Barge Train impact experiments were performed with a fully-ballasted 3x3 barge train with the flexible approach wall system at Winfield L&D

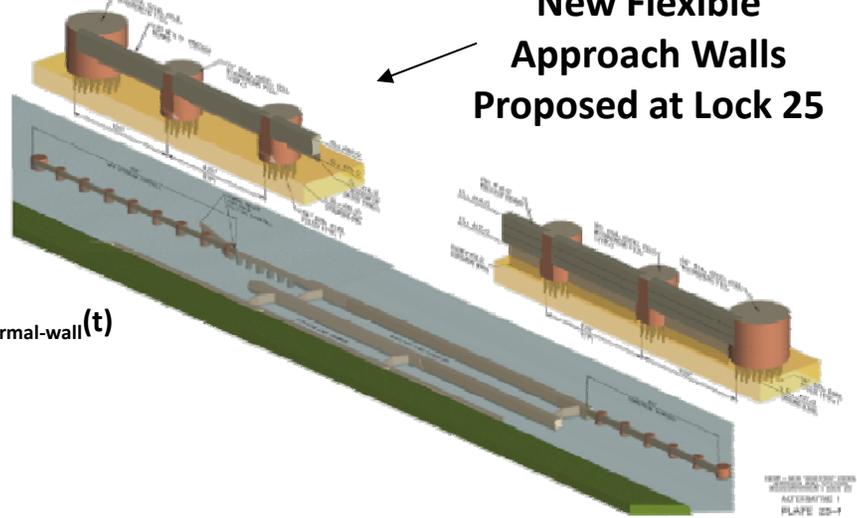
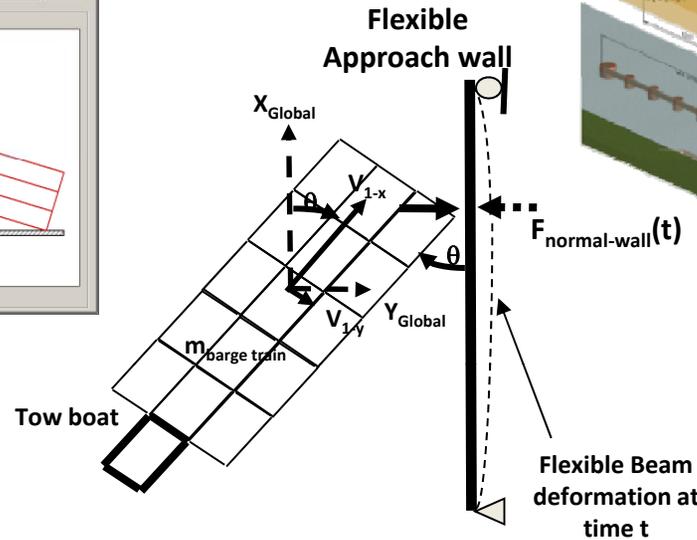
PC-software Impact_Force



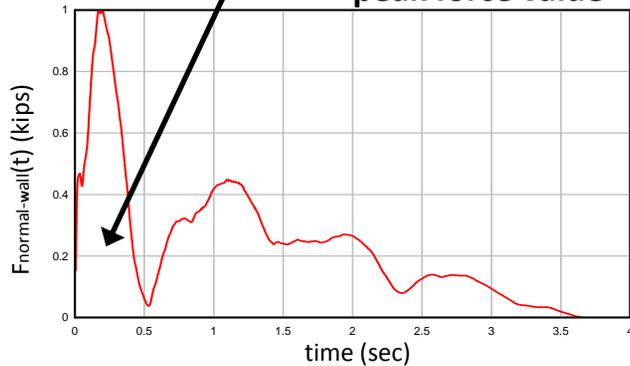
Impact_Force Software Scaling Time-History Formulation

Formulation

New Flexible Approach Walls Proposed at Lock 25



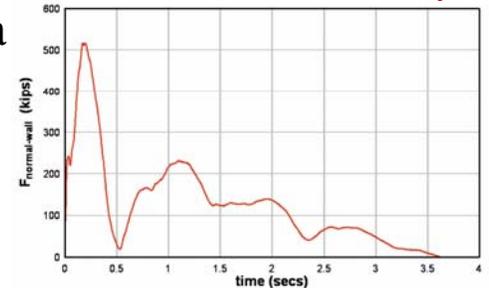
Winfield Barge Impact Test #10
Normal force measurement
- Normalized to a unit peak force value



$$\int_{t_1}^{t_2} F(t) dt = F_{\text{max}} \cdot \text{Unit pulse area}$$

$$F_{\text{max}} = \frac{m_{\text{barge train-normal}} \cdot (v_{1\text{-normal}}) \cdot \text{RMF}}{\text{Unit pulse area}}$$

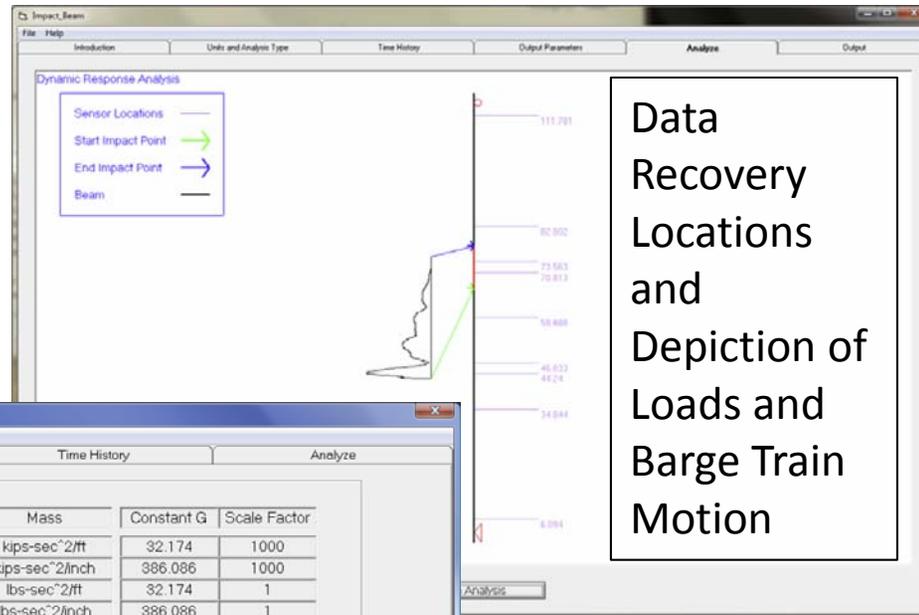
Resulting Scaled Force Time-History



Force time history $F(t)$, to be used in the dynamic impact beam analysis code Impact_Beam, is the unit time history force scaled by F_{max}

Impact_Beam

The flexibility of the impact beam provides energy absorption capability.



Impact_Beam software provides a means to compute the dynamic structural response of a simply-supported flexible beam during various barge train impact events.

Units

Length	Force (and Weight)	Velocity	Mass	Constant G	Scale Factor
feet	kips	ft/sec	kips-sec ² /ft	32.174	1000
inches	kips	in/sec	kips-sec ² /inch	386.086	1000
feet	lbs	ft/sec	lbs-sec ² /ft	32.174	1
inches	lbs	in/sec	lbs-sec ² /inch	386.086	1
meters	kN	m/sec	kN-sec ² /m	9.80665	1
centimeters	kN	cm/sec	kN-sec ² /cm	980.665	1
millimeters	kN	mm/sec	kN-sec ² /mm	9806.65	1

Barge Train Information

Local Barge Train Velocity:
 Local X Velocity: 2.699 ft/sec
 Local Y Velocity: 0 ft/sec

Barge Train Size:
 Number of Barges (local X): 3
 Number of Barges (local Y): 3

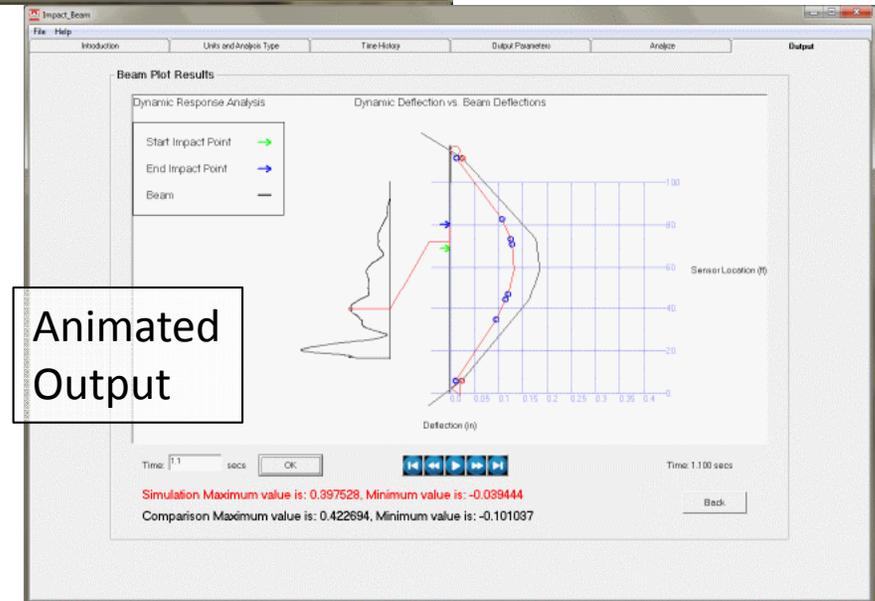
Barge Train Approach Angle: 16.88 degrees

Barge Train Weights:
 Barge Weight: 3729 kips
 Tow Weight: 1014 kips

Barge Train Hydrodynamic Added Mass Factors:
 Local Mass Scale Factor X: 1.05
 Local Mass Scale Factor Y: 1.4

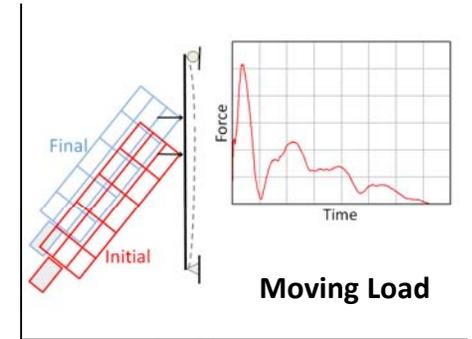
Response Modification Factor (RMF): 0.388

Barge Train Impact Description



Dynamic Response of Winfield Simply-Supported Flexible Approach Wall

PC-based Software Impact_Beam



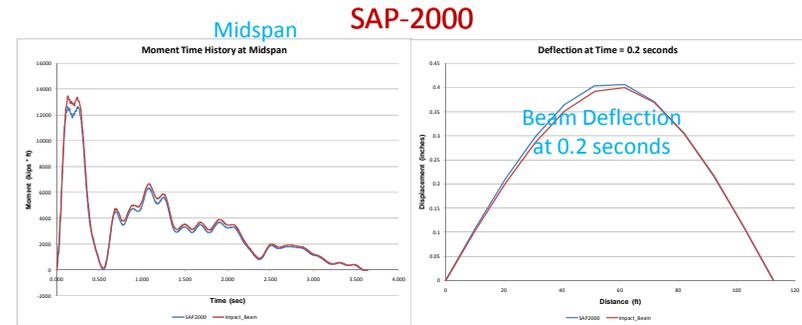
The screenshot displays the 'Impact_Beam' software interface. The 'Units' table is as follows:

	Length	Force (and Weight)	Velocity	Mass	Constant G	Scale Factor
#	feet	kips	ft/sec	kips-sec ² /ft	32.174	1000
r	inches	kips	in/sec	kips-sec ² /2000	386.088	1000
r	feet	lbs	ft/sec	lbs-sec ² /ft	32.174	1
r	inches	lbs	in/sec	lbs-sec ² /2000	386.088	1
r	inches	kN	m/sec	kN-sec ² /2000	9.80665	1
r	Centimeters	kN	cm/sec	kN-sec ² /2000	980.665	1
r	Millimeters	kN	mm/sec	kN-sec ² /2000	9806.65	1

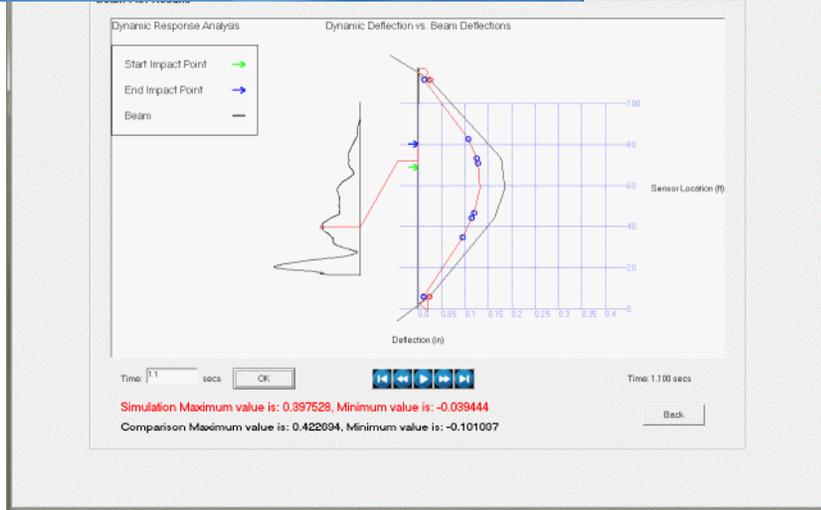
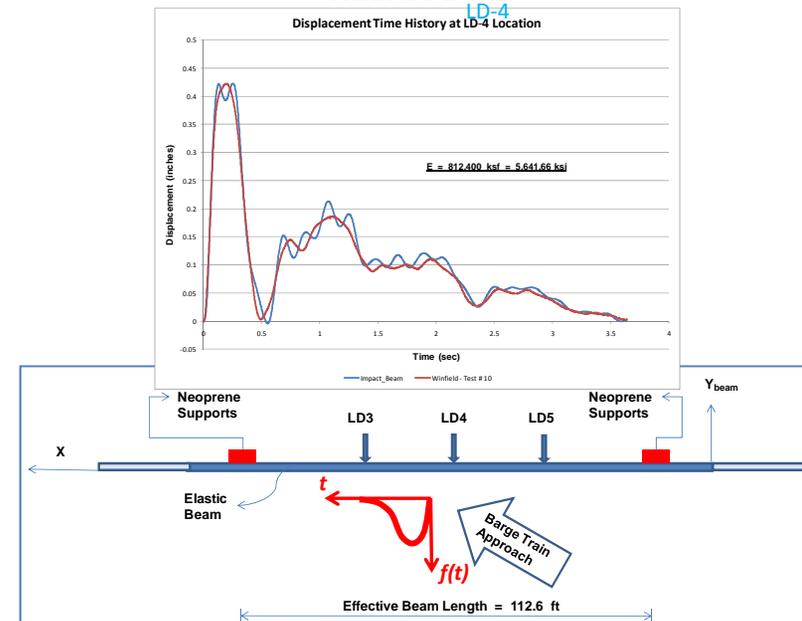
The 'Analysis Type' is set to 'Dynamic Response Analysis of a simply supported beam' with 'Single Degree of Freedom (SDOF)'. The 'Simply Supported Beam Span and Properties' section includes fields for Length, Impact Point, and Impact Velocity.

Impact_Beam performs a dynamic modal response time-history analysis of the equation of motion.

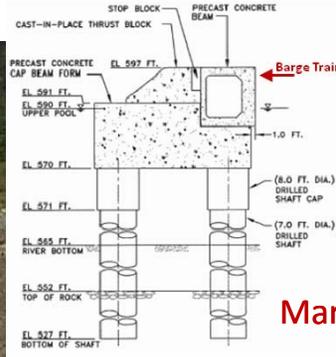
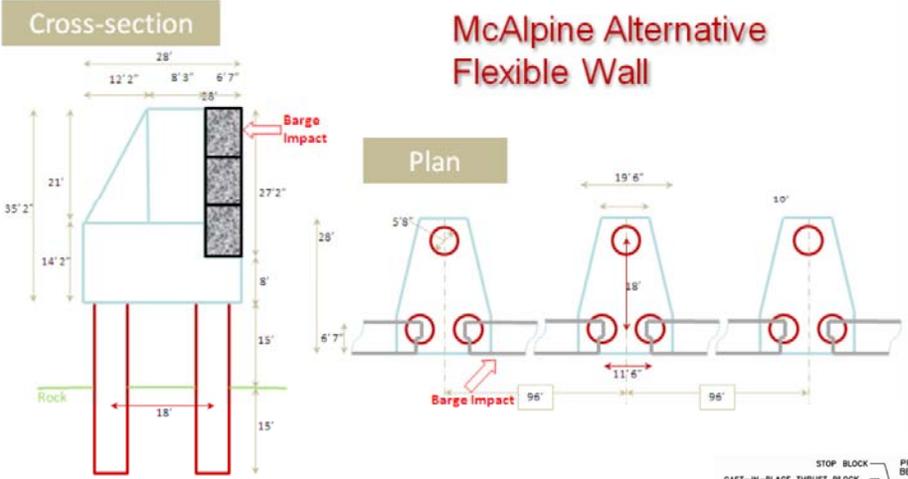
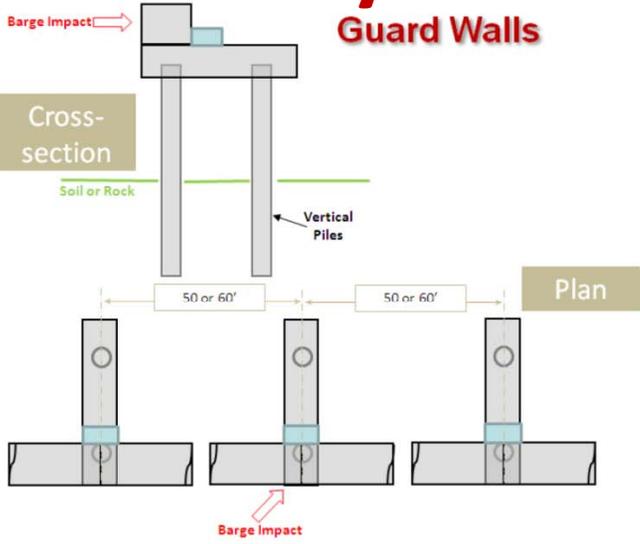
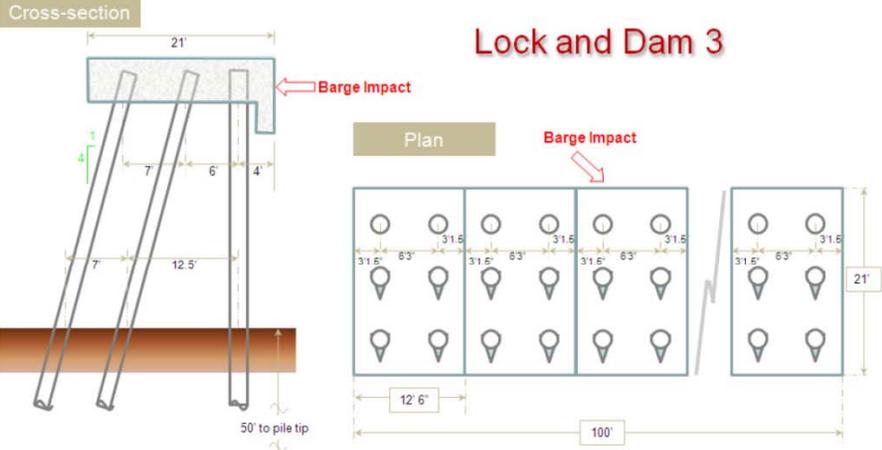
Validation



Winfield Data



Pile-Founded Flexible Approach Wall Systems



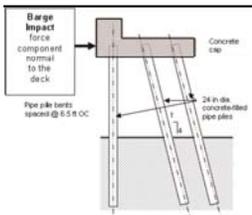
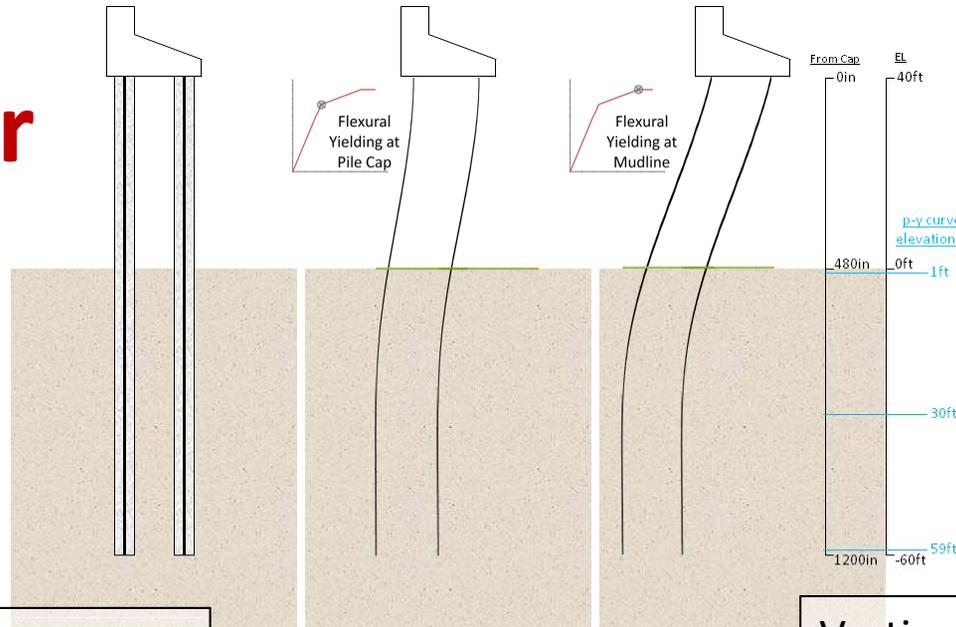
Marmet Pile Founded Wall

Pushover Analysis

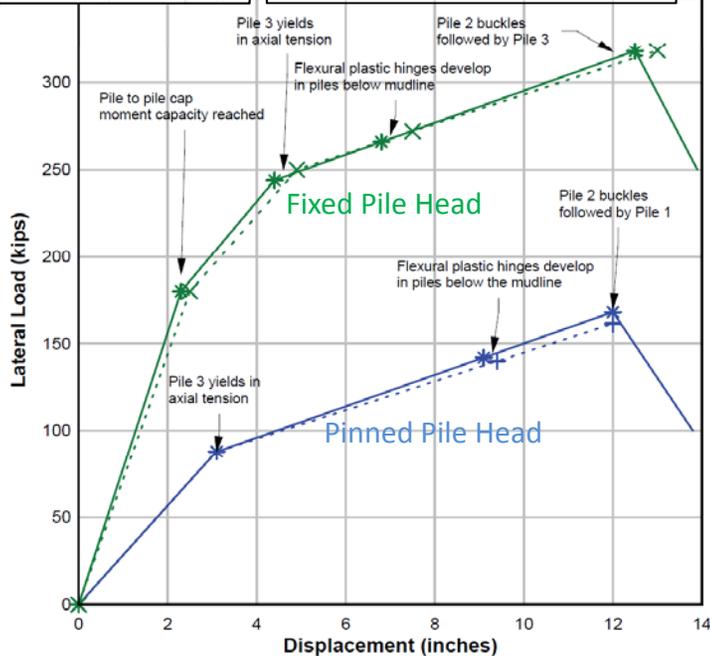
Pre-Pushover

Pushover Stage One
Pile cap just before moment capacity lost at pile cap

Pushover Stage Two
Pile cap pinned before moment capacity lost at mudline



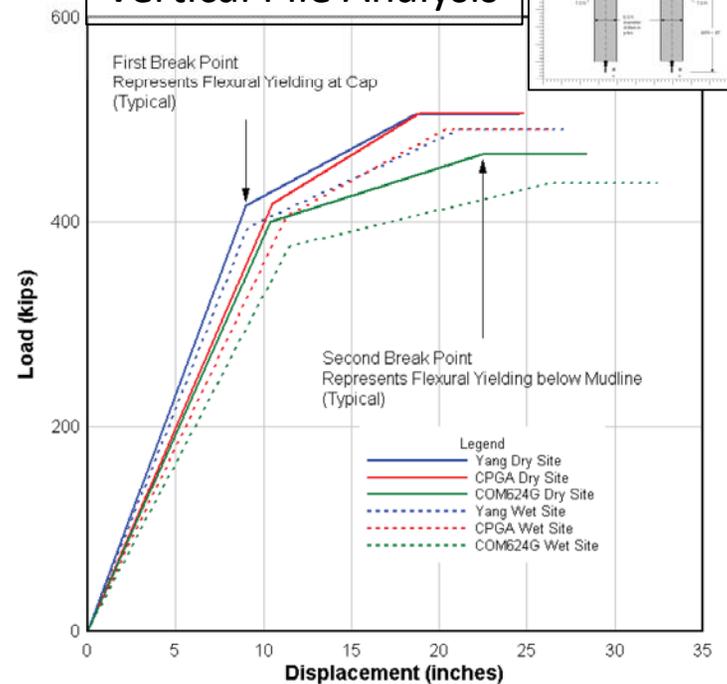
Batter Pile Analysis



A pushover analysis is performed on a clustered pile group to:

- Establish the potential energy absorption capacity and the displacement of the pile group.
- Provides the non-linear force-deflection (spring) model of an individual clustered pile group for use in static or dynamic analysis of approach wall models (Impact_Deck, etc.)

Vertical Pile Analysis



ERDC/ITL TR-12-3

Information Technology Laboratory

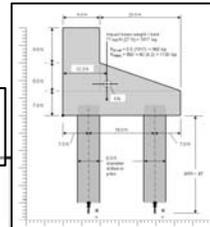
Navigation Systems Research Program

Simplified Analysis Procedures for Flexible Approach Wall Systems Founded on Groups of Piles and Subjected to Barge Train Impact

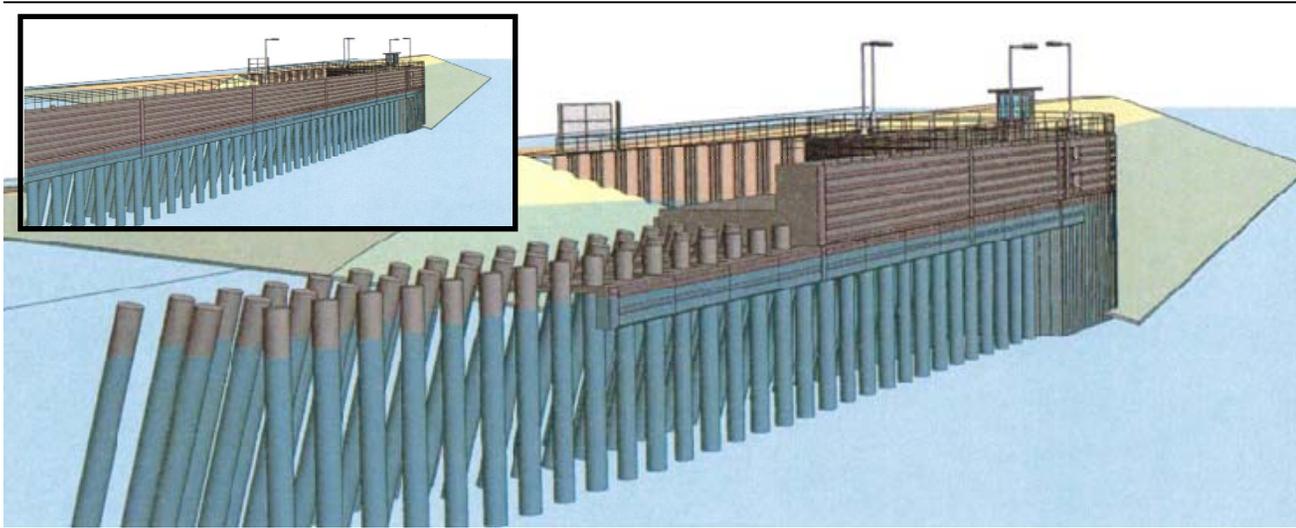
Robert M. Ebeling, Ralph W. Strom, Barry C. White, and Kevin Abraham

September 2012

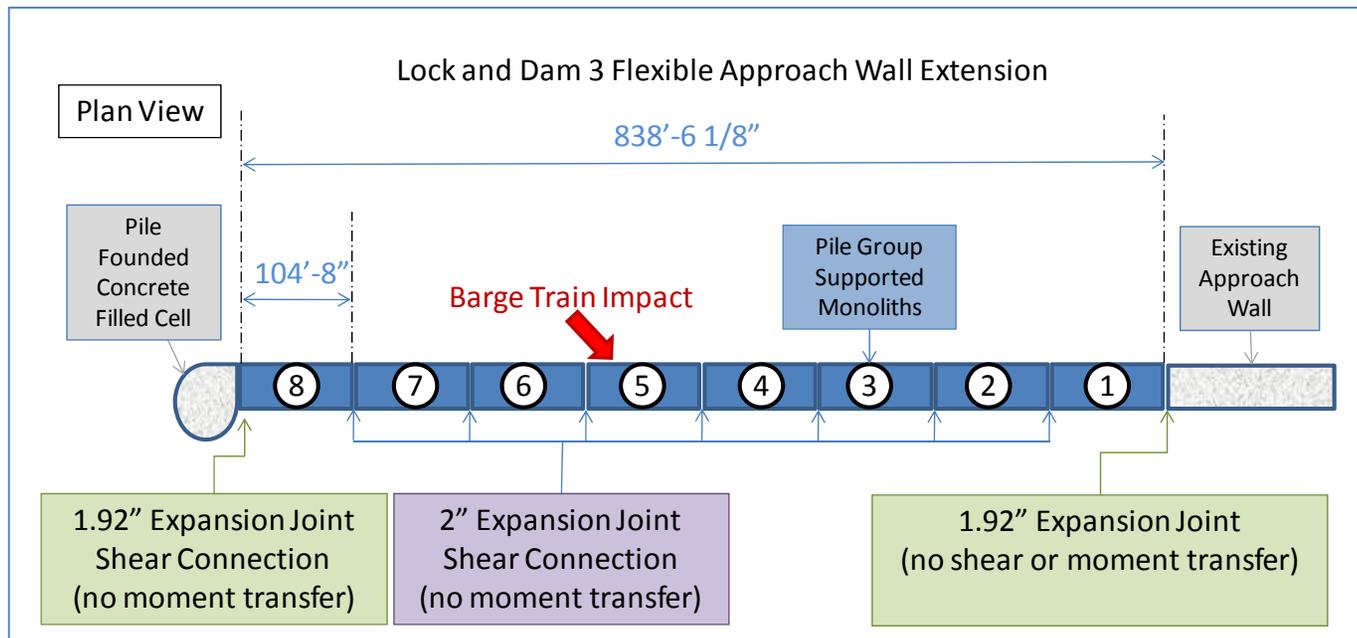
Approved for public release; distribution is unlimited.



Load Sharing for an Impact Deck Founded on Clustered Pile Groups with Batter Piles



Each of the 8 deck monoliths is supported by 16 clustered pile groups



Definition of Clustered Pile Groups Founded Wall

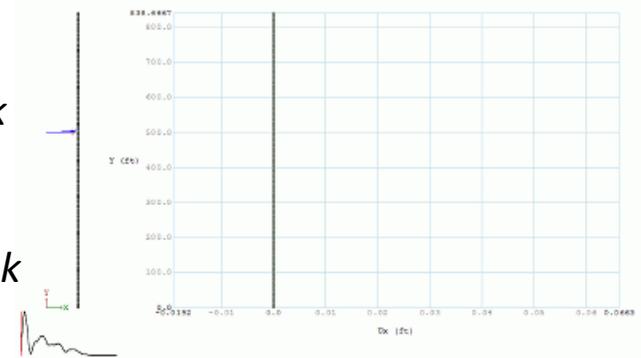
Property Definition

Nonlinear Spring (Pushover Curve)

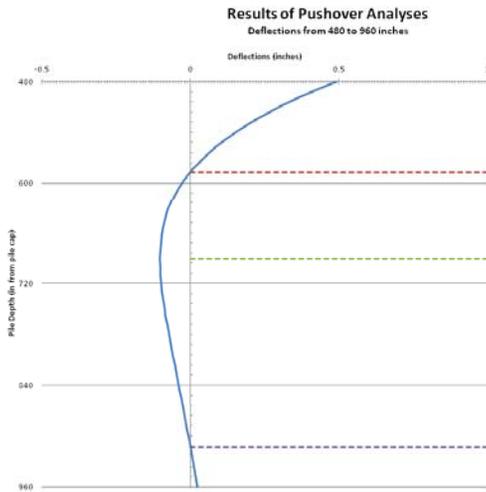
Static and Dynamic Output of Response Force, Moments, and Shear

Impact_Deck

- Load sharing between clustered pile groups
 - Individual pile group clusters carry only a fraction of the total impact load (e.g., Lock and Dam 3)
- Dynamic Structural Response is important
 - The total response peak force is greater than the input peak force
 - A phase lag exists between time-based response of pile groups and the applied impact load; The total response peak force occurs at a different time than the input peak force.

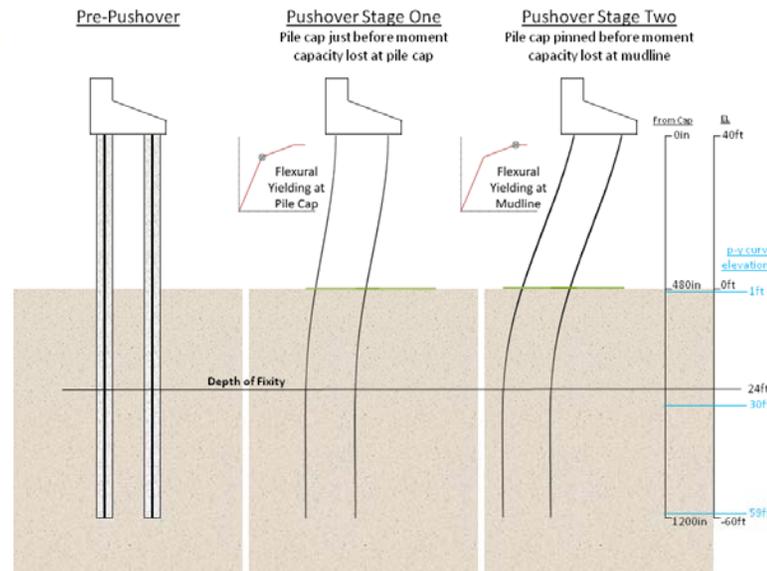
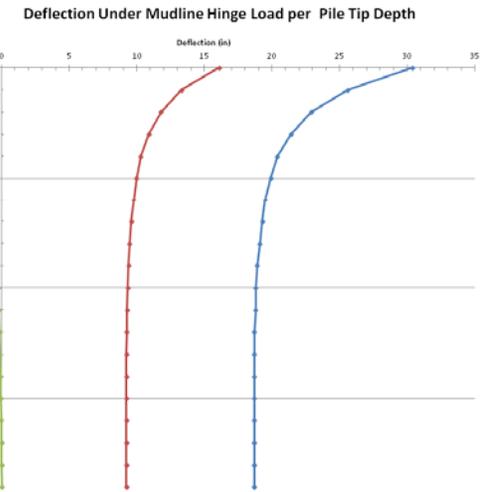
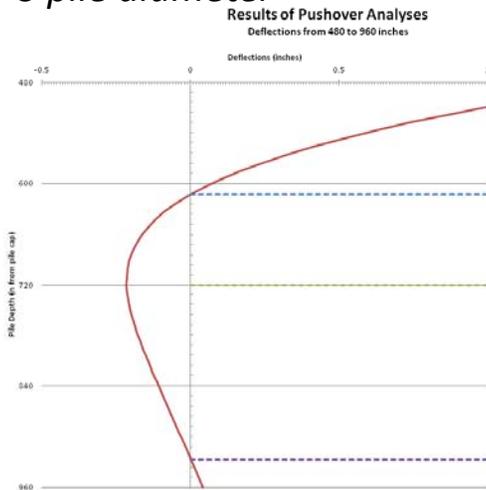


Using a Pushover Analysis To Determine Depth of Embedment



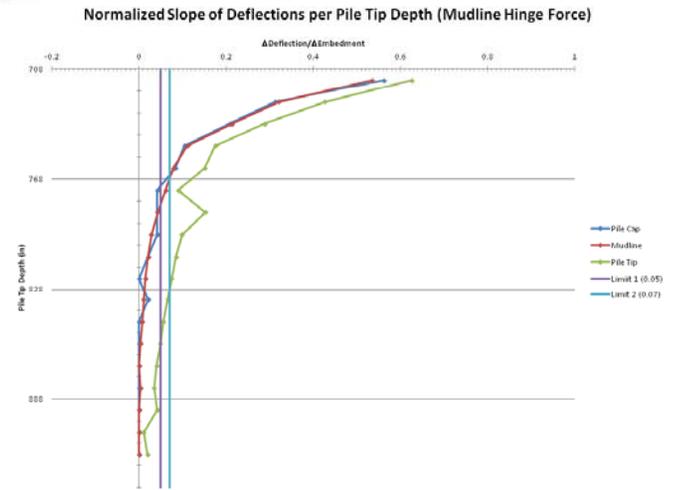
Research revealed a handful of methods to provide a “rule of thumb” estimate for the depth of embedment (fixity) of piles based on:

- deflection points
- peak value points
- pile diameter



Our analysis reveals that an asymptotic relationship exists for pile cap deflection versus pile tip depth. Constraints can be placed to provide a **quantitative** (as compared to qualitative) determination of fixity for a pile.

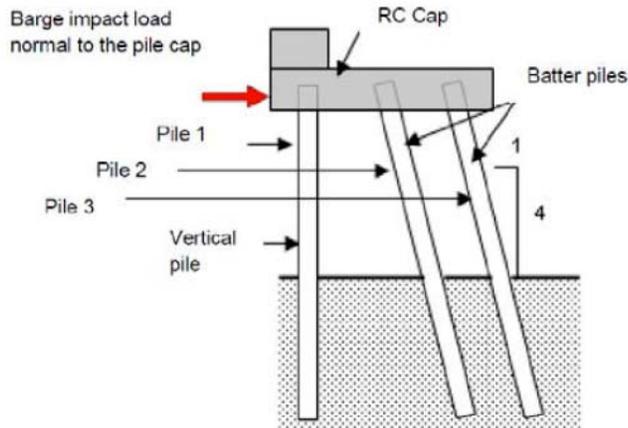
We are developing limits for the slope of the asymptotic deflection curve to quantitatively minimize depth of embedment and guarantee a level of fixity in order to reduce cost.



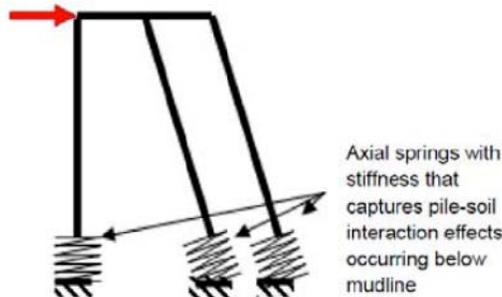
Pile-Founded Flexible Approach Walls

Finite Element Models are being used to determine deformations and terms for axial stiffness related to batter piles

Lock & Dam 3 Flexible Approach Wall Extension



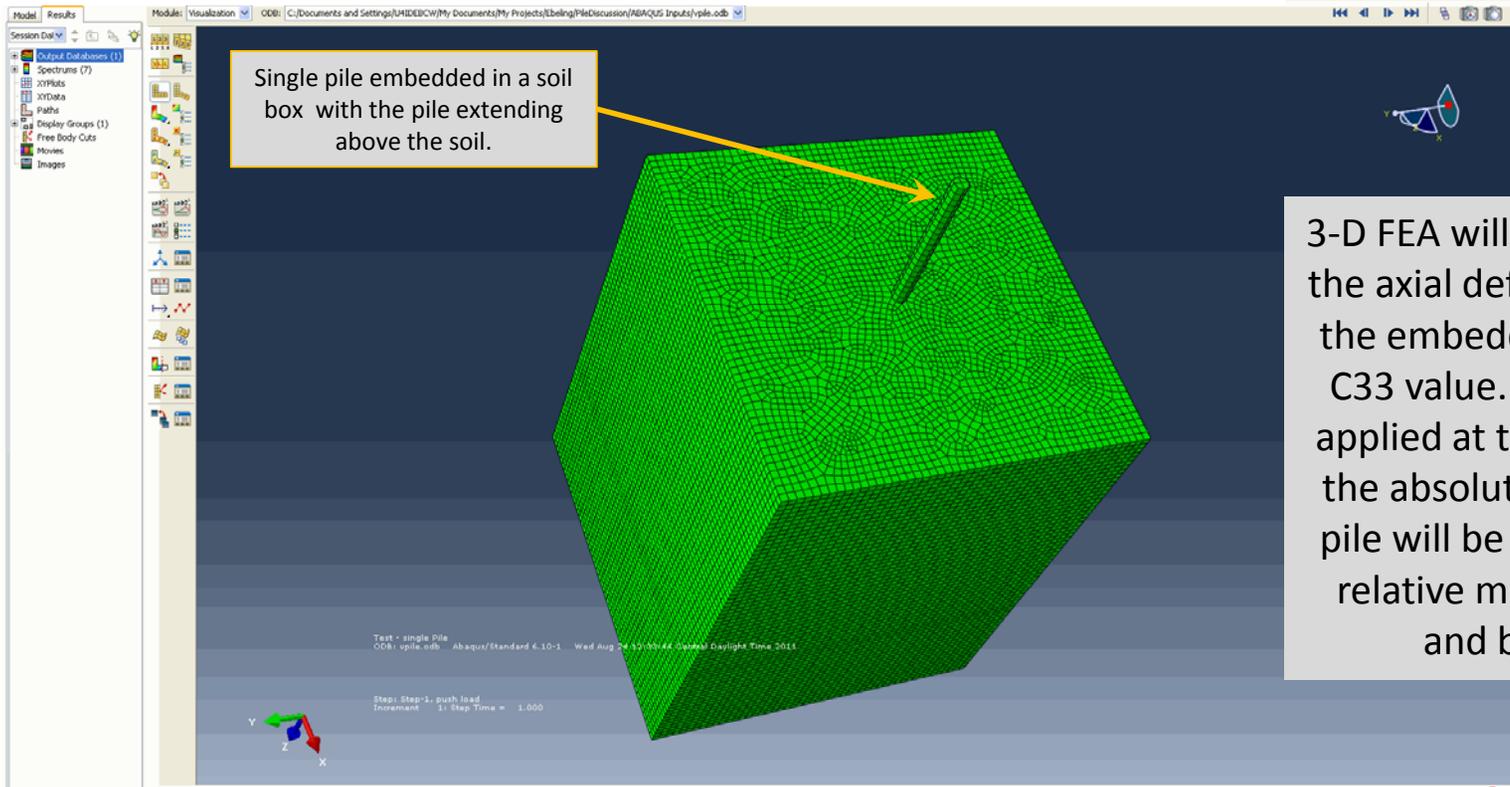
Simplified CPGA Pile-to-Soil Interaction idealization



C_{33} is the scale factor for the relative axial stiffness in soil (with a large impact on batter piles):

$$C_{33} * AE / L_e = b_{33}$$

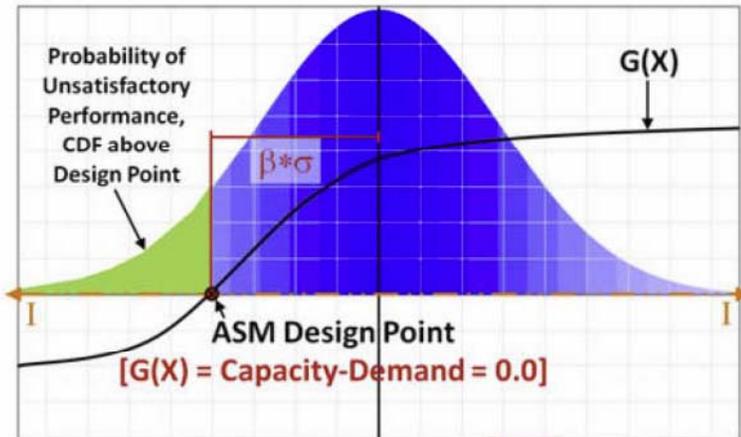
An axial load is applied to the pile and the deflection of the pile can be computed for the soil regime.



3-D FEA will be used to determine the axial deformation response of the embedded pile to define the C_{33} value. An axial load will be applied at the top of the pile and the absolute deformation of the pile will be determined from the relative movements at the cap and base of the pile.

CPGA-R *Pile Group Reliability Analysis*

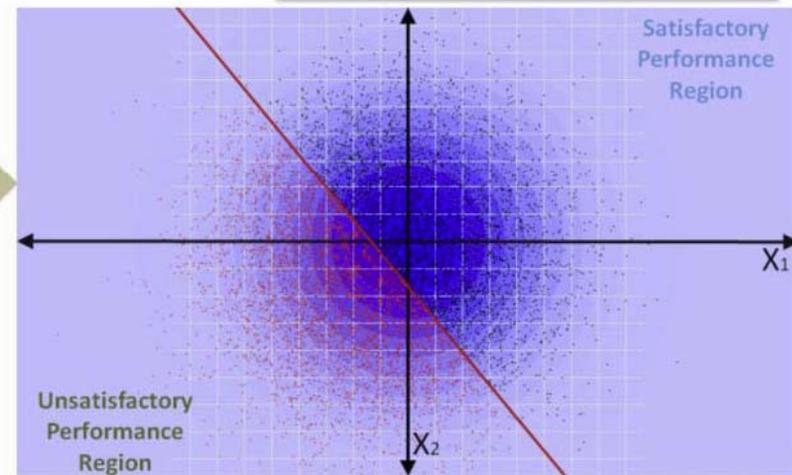
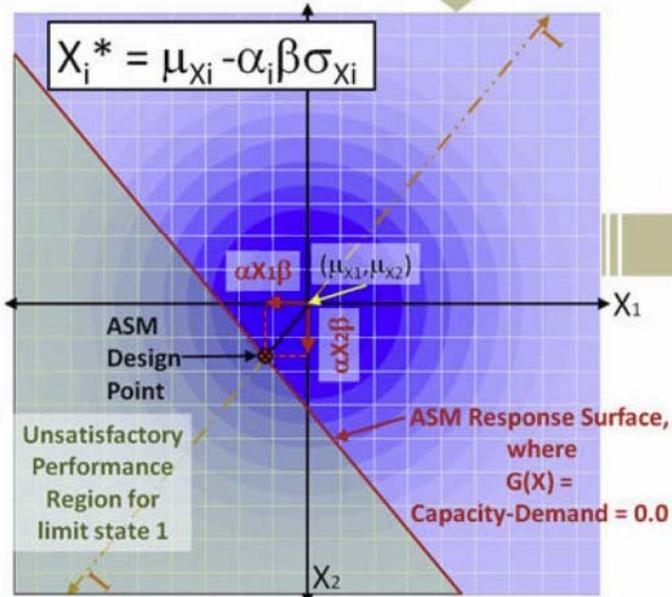
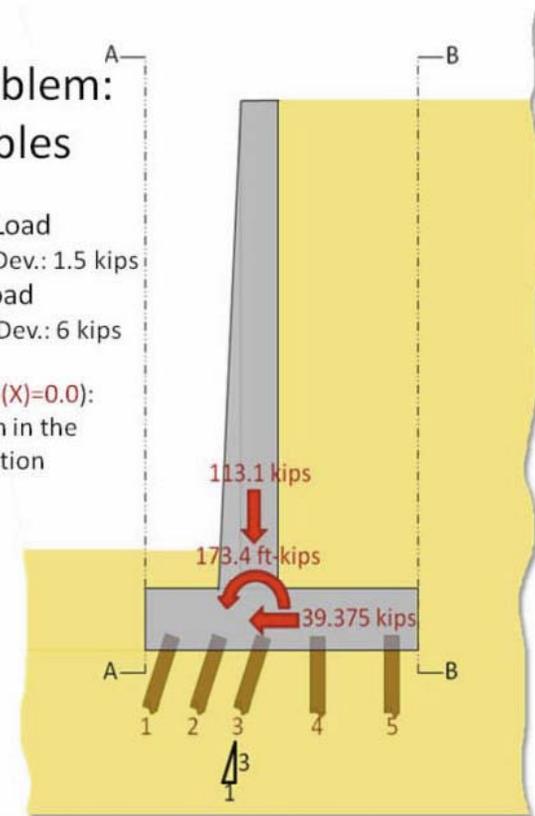
The Advanced Second Moment



Example Problem: Two Variables

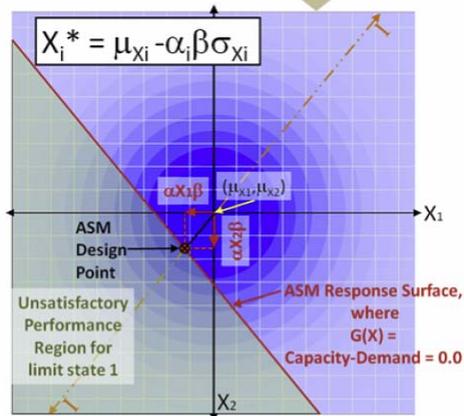
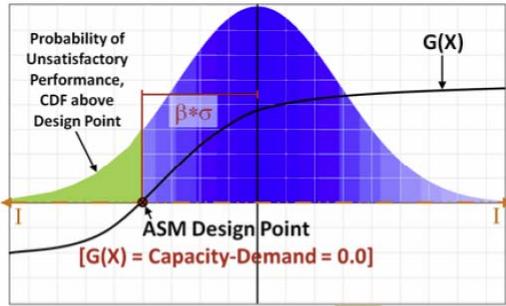
X1-Horizontal Load
Mean: 39.375 kips Std.Dev.: 1.5 kips
X2-Vertical Load
Mean: 113.1 kips Std.Dev.: 6 kips

Limit state (where G(X)=0.0):
0.25 inch deflection in the horizontal direction

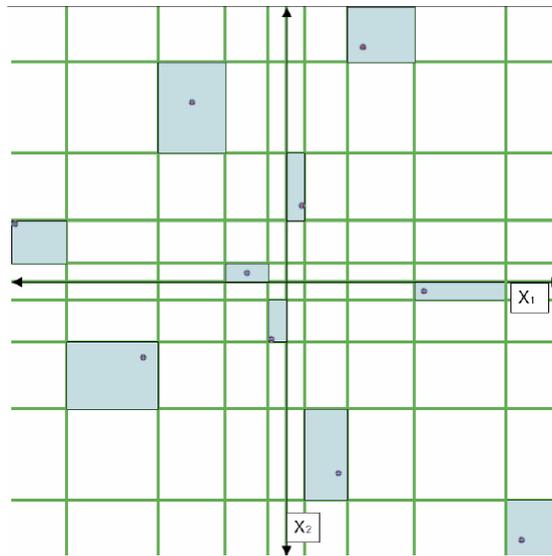


Importance Sampling using Latin Hypercube and Based Around The Advanced Second Moment Design Point

The Advanced Second Moment

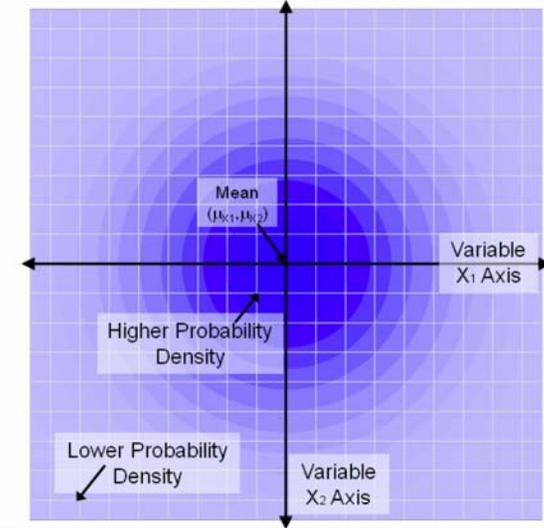


Latin Hypercube Sample Selection



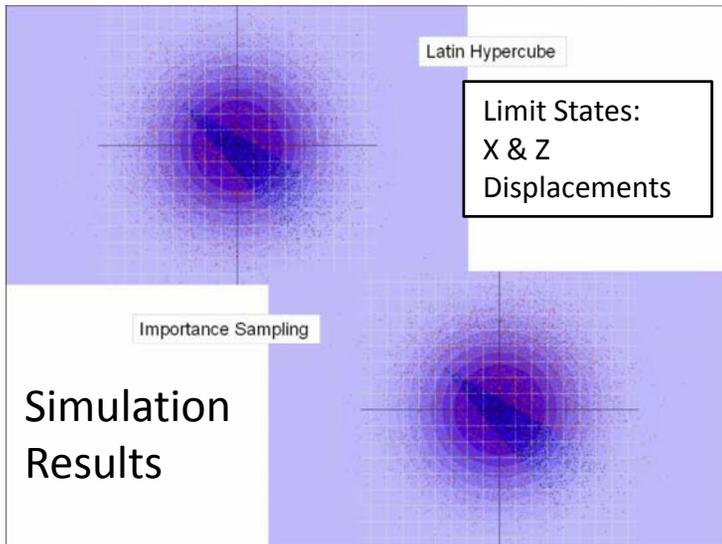
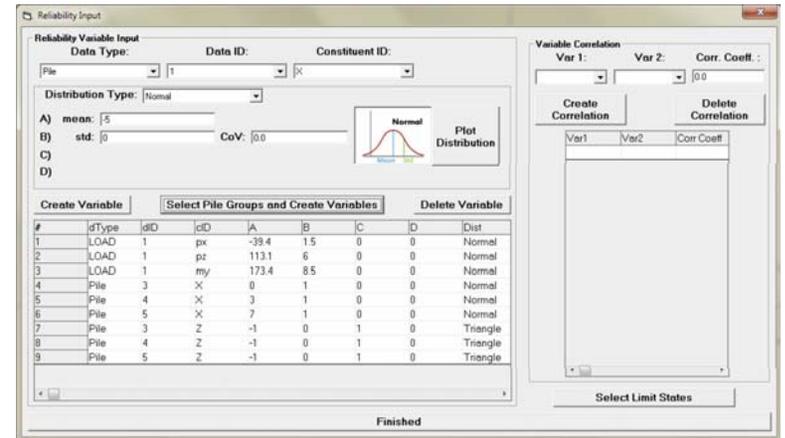
2 Variable Space (plan view)

In order to have a two variable space, the variables (X_1 and X_2) must be uncorrelated, and therefore orthogonal. The Standard Normal Distribution is axis-independent acting equally in all directions from the origin.



CPGA-R

Additional GUI Inputs



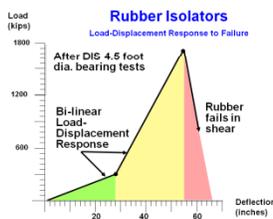
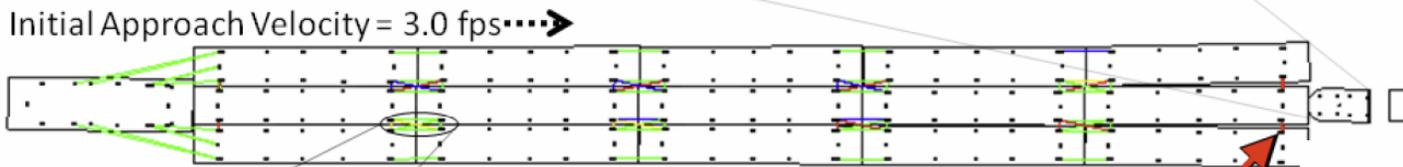
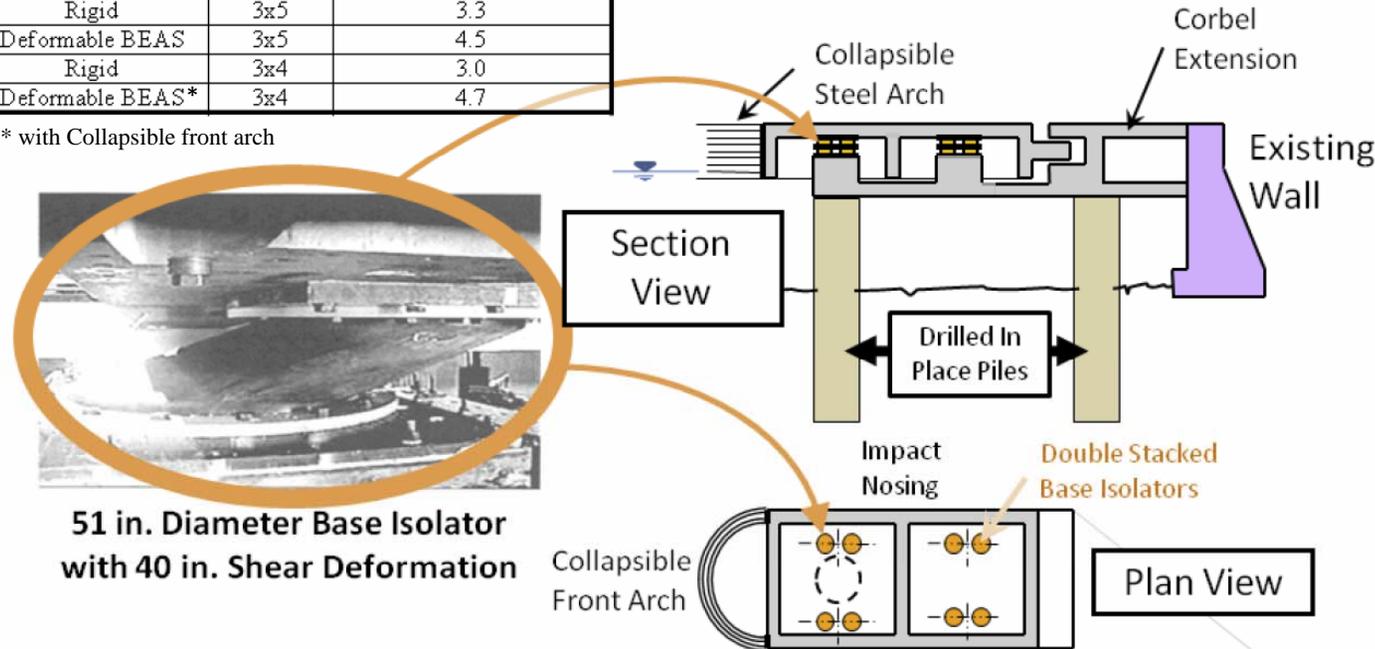
- Provides the capability of **Reliability Analysis** of pile founded hydraulic structures for use in **Major Rehabilitation studies**.
- Computes the **Probability of Unsatisfactory Performance (PUP)**.
- Computes a PUP value using **Importance Sampling** simulation method with efficient **Latin Hypercube** sampling guided by the **Advanced Second Moment** method to focus the center of simulation.
- Maintains all the **Deterministic** capabilities of CPGA

Deformable Bullnose Energy Absorbing System (BEAS)

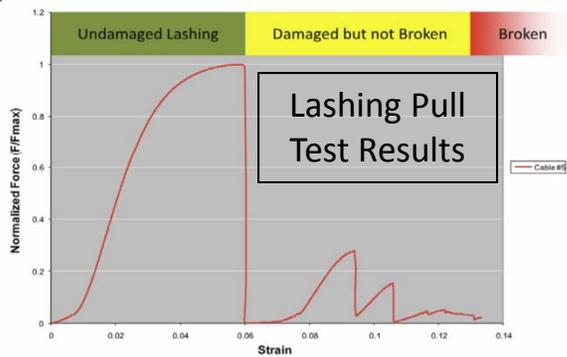
Bullnose Type	Barge Train Size	Barge Train Integrity Limit Velocity (fps)
Rigid	3x5	3.3
Deformable BEAS	3x5	4.5
Rigid	3x4	3.0
Deformable BEAS*	3x4	4.7

* with Collapsible front arch

System (BEAS)



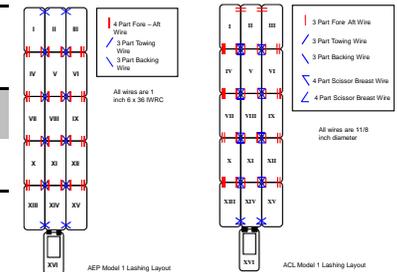
Legend: Lashing intact Lashing damaged Lashing broken



Deformable BEAS Limiting Velocities

Lashing Layout Comparison

Barge Train Size	Velocity (fps)	Lashing Layout	Barge Train Integrity
3x5	2.7	AEP	Complete Loss
		ACL	Maintained

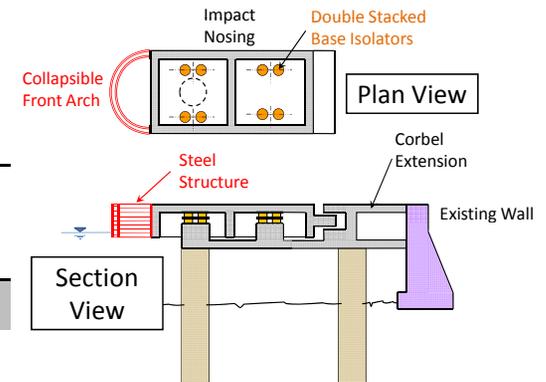


Rigid vs Deformable BEAS

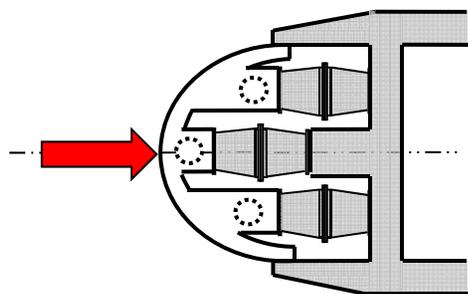
Barge Train Size	Deformable BEAS Configuration	Max Velocity to Maintain Barge Train Integrity (fps)
3x5	Rigid	3.3
	8 Double-Stacked Reduced Stiffness	4.5

Collapsible Front Arch

Barge Train Size	Deformable BEAS Configuration	Max Velocity to Maintain Barge Train Integrity (fps)
3x4	Rigid	3.0
	8 Double-Stacked Reduced Stiffness	4.7



Preliminary Double Super Cone Front Arch Results



Barge Train Size	Number of Double Super Cones	70" Deformation Force (kips)	Peak Calculated Force (kips)	Impact Nosing Deflection (ft)	Max Velocity to Maintain Barge Train Integrity (fps)
3x4	5	4,000	5,003	6.66	6.2
	6	4,800	4,148	6.42	6.1
	7	5,200	n/a	n/a	<5.5

