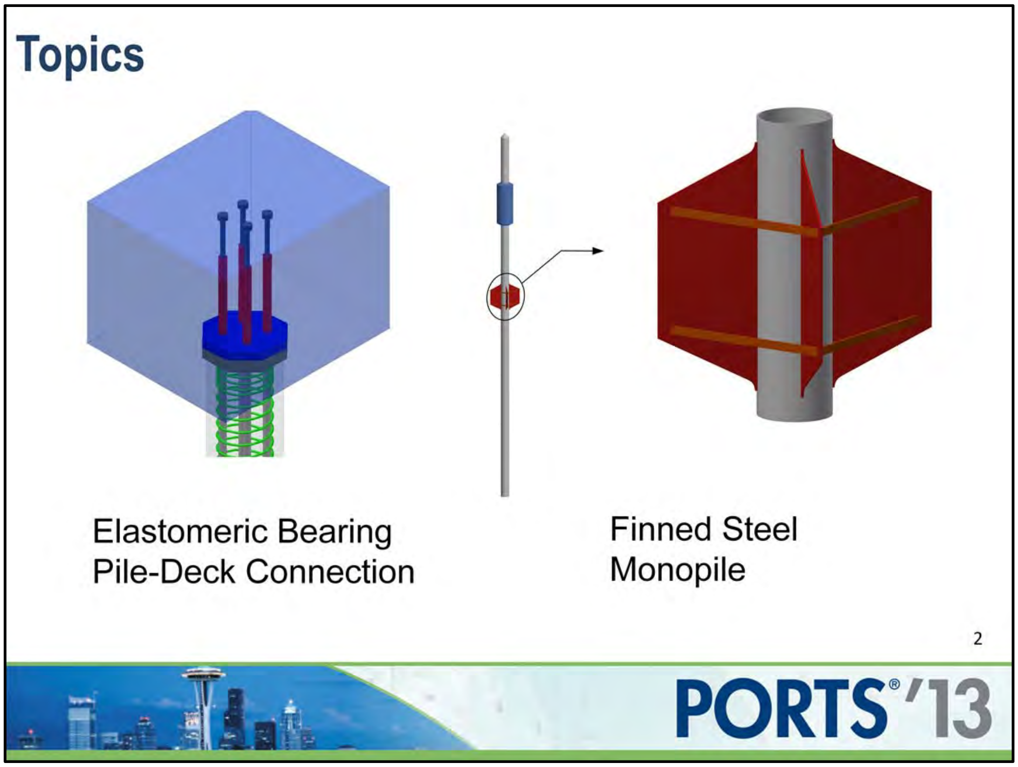
Liftech Consultants Inc. is a consulting engineering firm, founded in 1964, with special expertise in the design and procurement of dockside container handling cranes and other complex structures. Our experience includes structural design for wharves and wharf structures, heavy lift structures, buildings, container yard structures, and container handling equipment. Our national and international clients include owners, engineers, operators, manufacturers, and riggers.

Erik Soderberg is a Liftech structural engineer. He has worked in the industry for nearly 20 years on the design, review, modification, and repair of a variety of structures, including over two dozen wharves, over 100 container cranes, and over a dozen bulk loader structures. Other structures include crane lift and transfer systems, and concrete and steel floats. He has participated in the design of over 1 ½ miles of wharf and pier structures.

He recently completed the design of the Port of Redwood City, California, replacement wharf on a design-build team with Manson Construction Company, and is finishing the design of a MOTEMS-compliant wharf with significant prefabrication off site, resulting in limited operational downtime during construction.

He regularly presents at ASCE Ports, AAPA, TOC, PTI, and STEER conferences, has authored nearly a dozen articles and papers for industry publications and events, and has served on ASCE and NEES committees.



This presentation will cover two topics: a pile connection that uses an elastomeric bearing and unbonded dowel lengths to increase flexibility, and adding fins to steel piles to reduce bending.

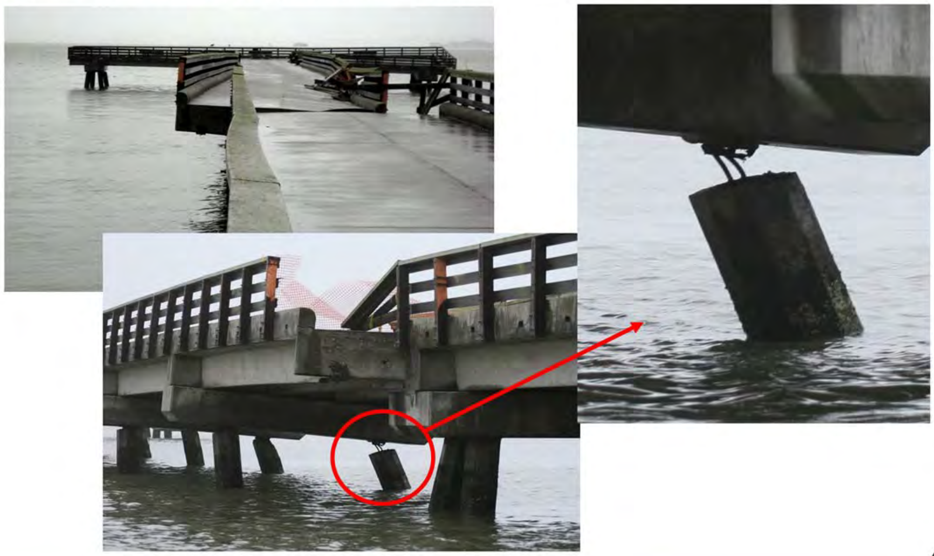
McNear’s Beach Park Pier – Barge Collision

3

PORTS® ’13

In 2008, a barge broke its mooring during a storm and collided with the McNear’s Beach Park Pier, resulting in significant damage to approximately half of the structure.

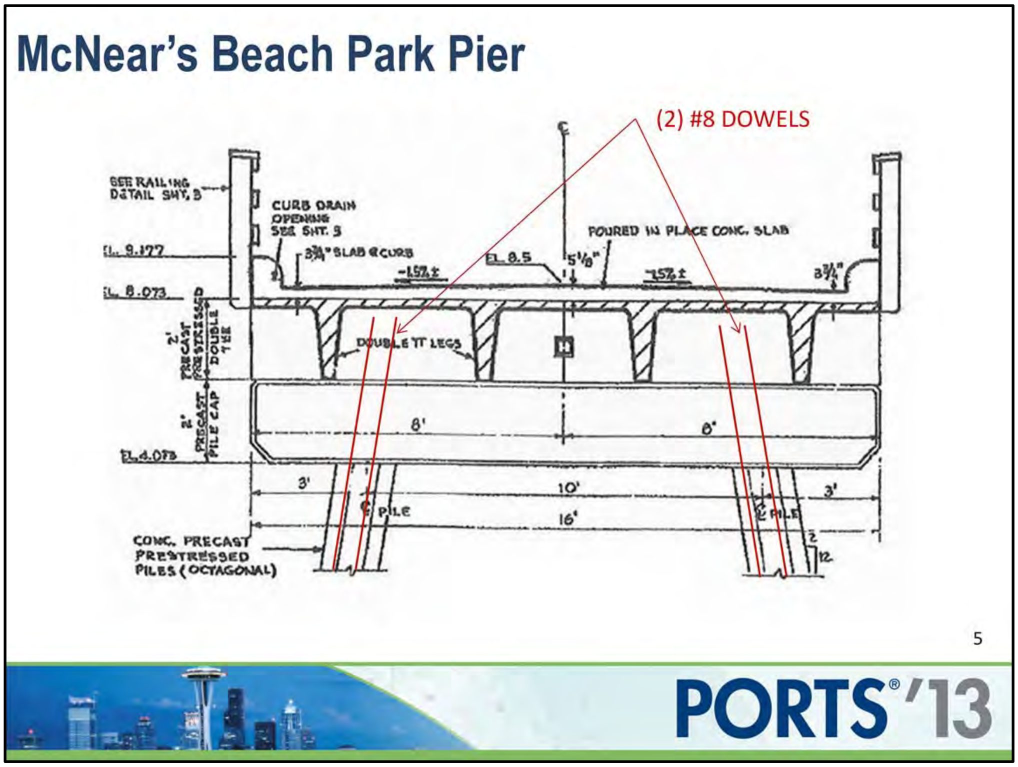
McNear's Beach Park Pier



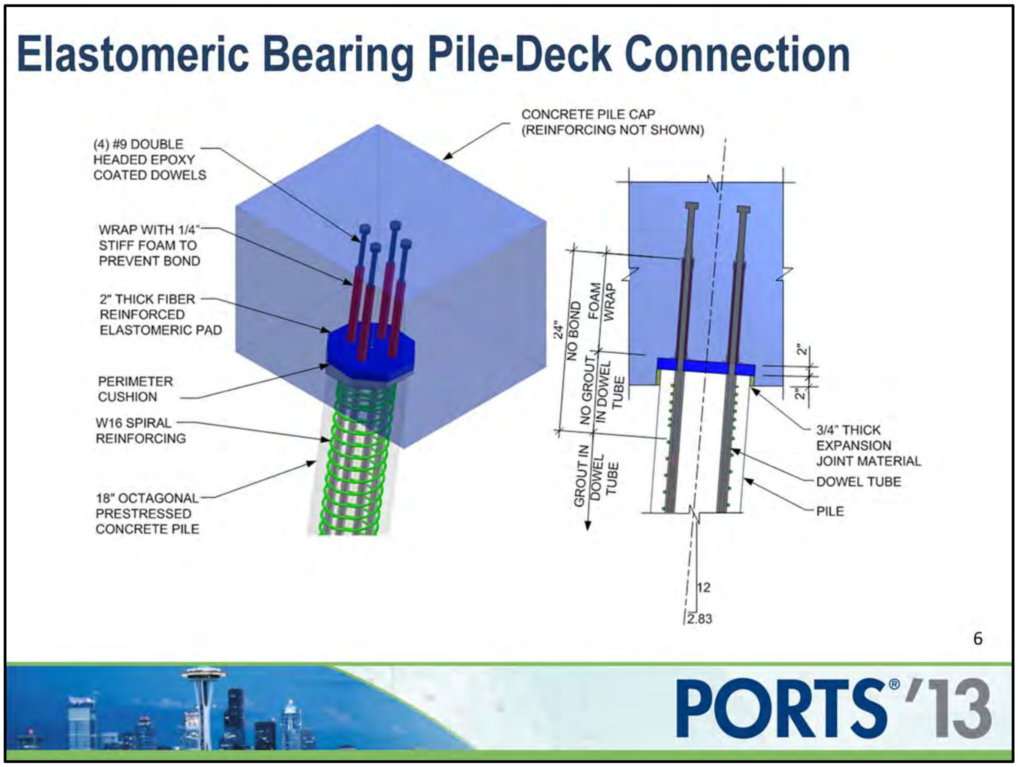
4

PORTS® '13

These photos show the end of one pier section displaced 5' laterally after the accident, the resulting pile damage, and the modest reinforcing in the pile connection.

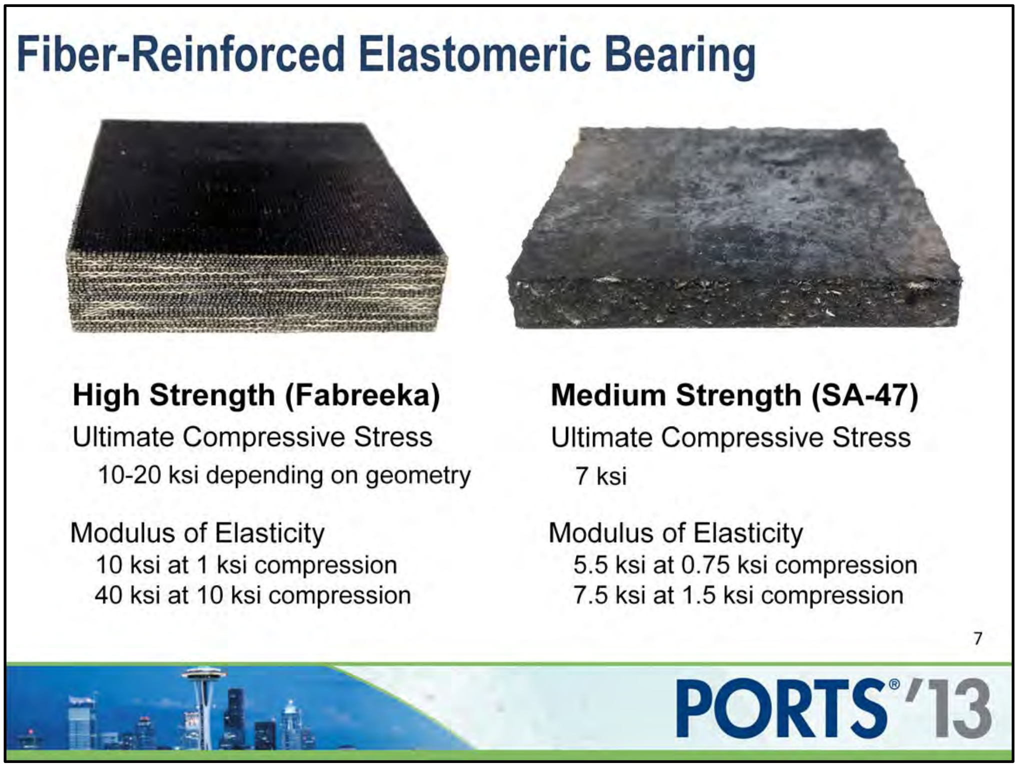


The repaired structure had to meet a more stringent design criteria than the original structure, and the number and size of the piling could not be increased due to permitting difficulties.

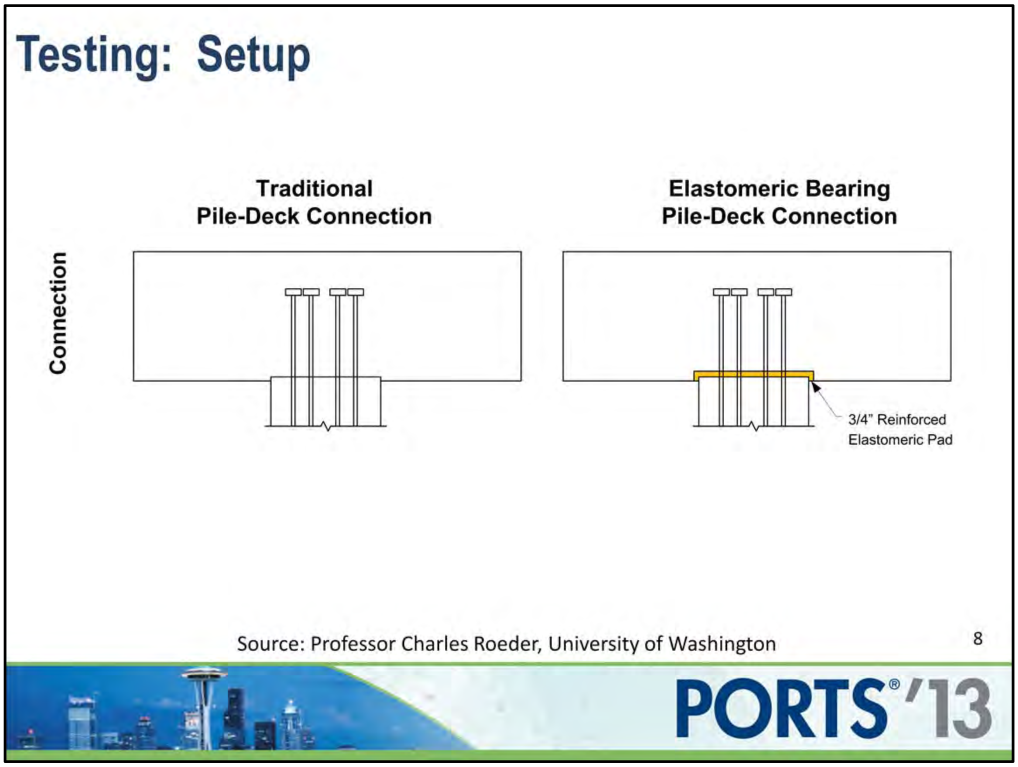


To meet the more stringent seismic criteria using the same pile design, a more flexible pile connection was developed. The flexible connection uses unbonded dowel lengths to allow the bars to stretch farther elastically, and a fiber reinforced elastomeric bearing to allow the end of the pile to displace in compression farther into the pile cap.

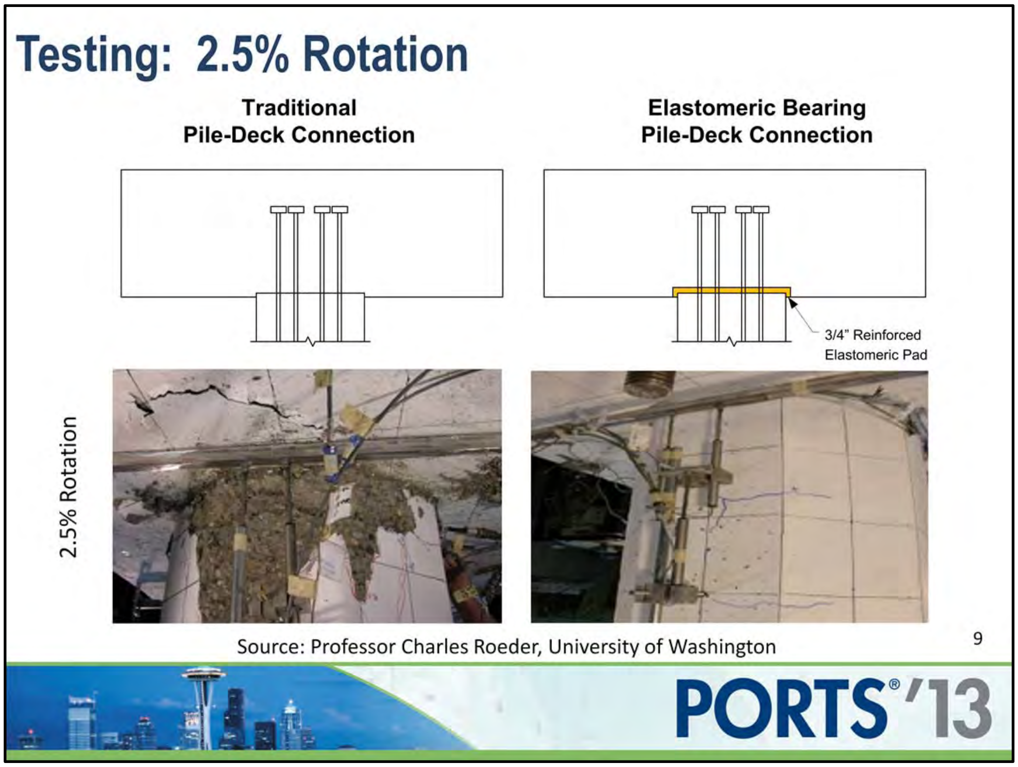
These methods have been studied and implemented in a similar manner by other engineers.



For the McNear’s Beach Park Pier project, a high strength elastomeric pad was required. Less costly, lower strength, more flexible pads are also available.



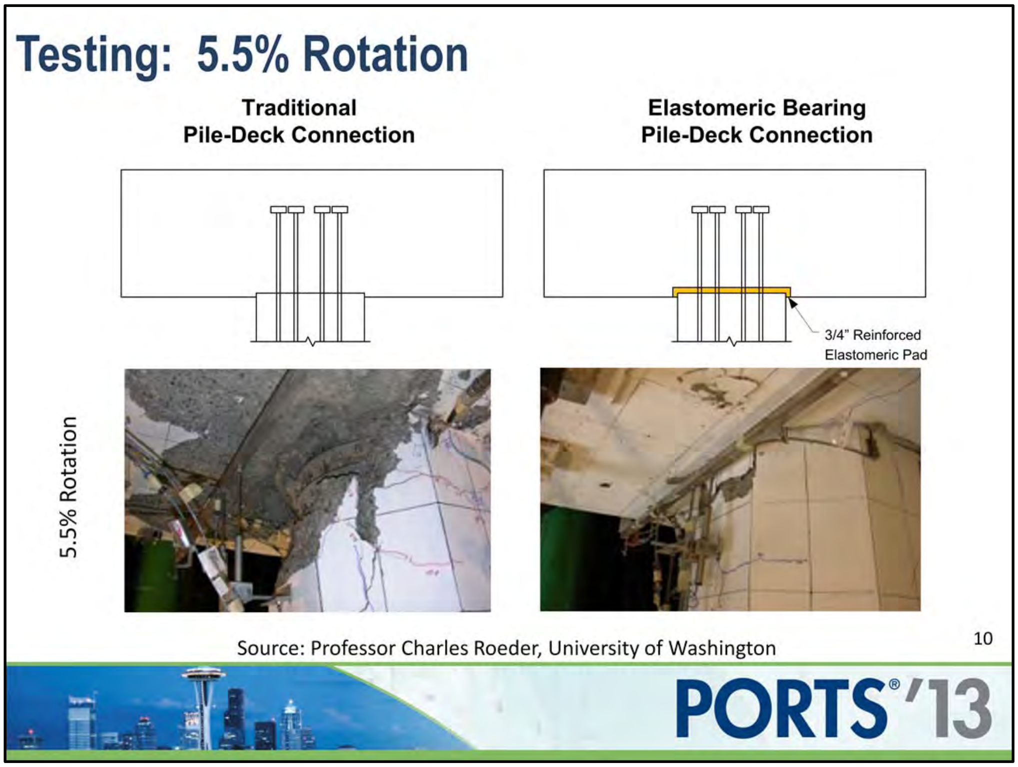
A variety of pile connections, including connections with elastomeric bearing pads, have been tested by Professor Charles Roeder of the University of Washington. The next slides present test results of two piles selected from many tests, one with and one without a bearing pad. These tests used 24" prestressed octagonal piles, a large 450 kip axial loading, and a ¾" thick reinforced elastomeric pad.



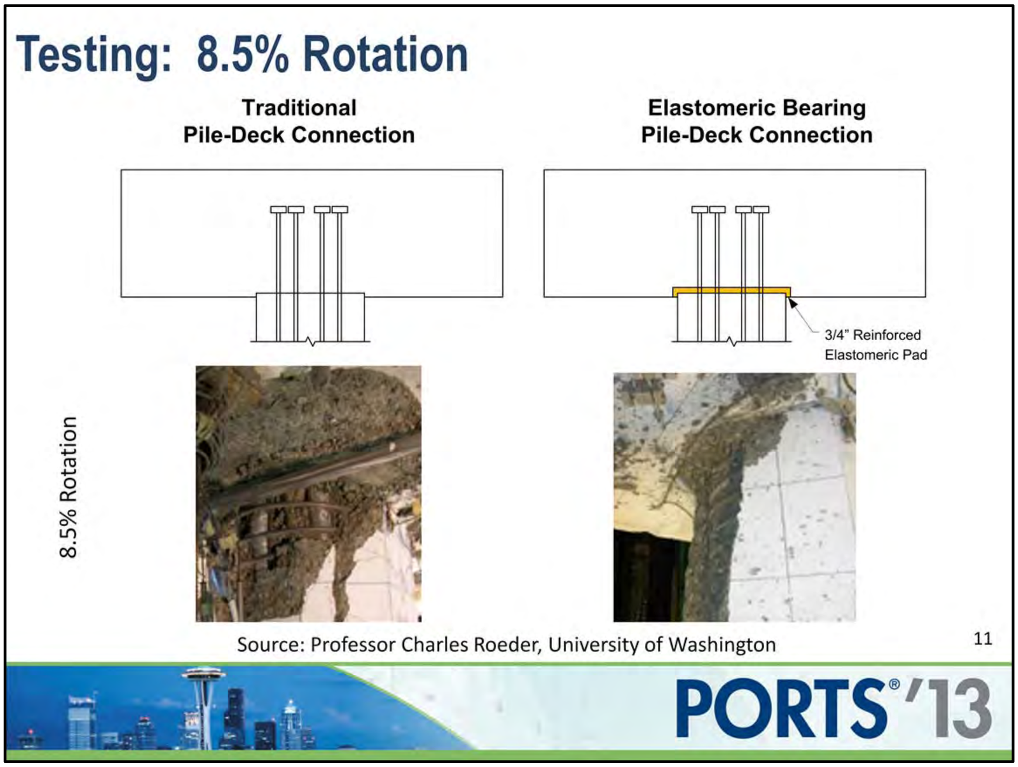
These photos are of test piles pushed laterally to obtain 2.5% rotation at the pile connection.

Testing was performed with the piles and cap upside down from that of a wharf structure, with the wharf deck or bent connected to the floor, and a pile stem rising from the deck. Hydraulic cylinders loaded the top end of the pile stem axially and laterally over many cycles of loading.

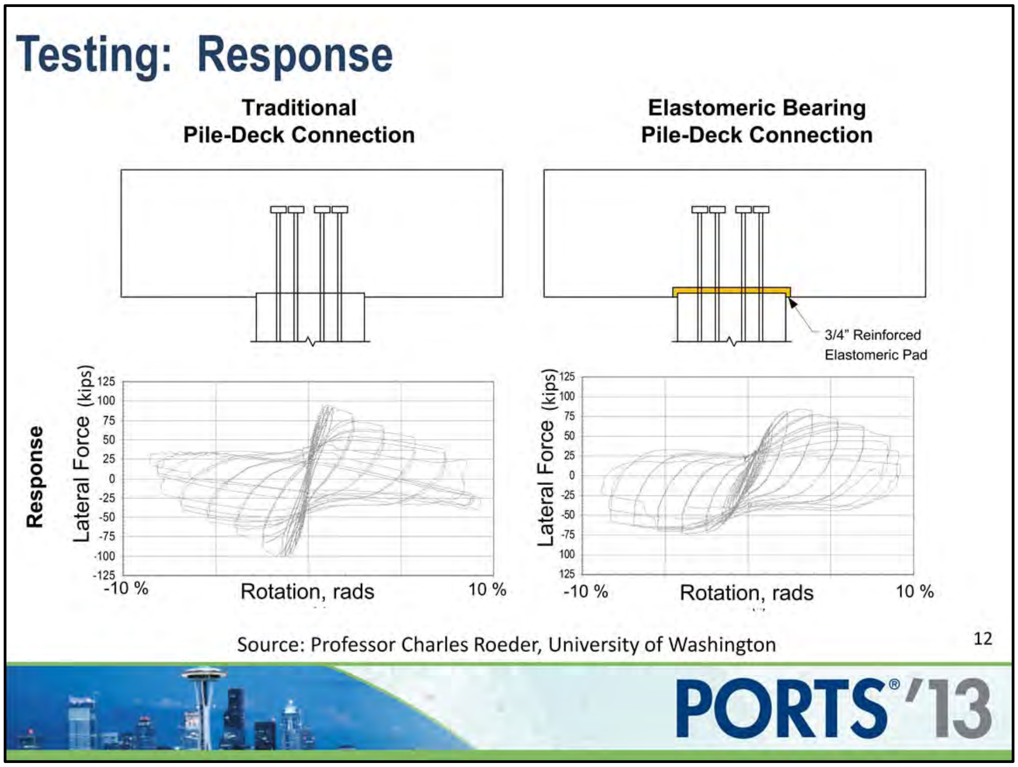
The Traditional Pile Connection experienced spalling of the outer layer of concrete. The Flexible Connection with elastomeric pad bearing had minor cracking and no spalling.



At 5.5% of rotation, the Traditional Pile Connection experienced severe spalling of the outer concrete shell, exposing multiple turns of the inner core spiral reinforcing. The Flexible Connection had more significant cracking, but no spalling.



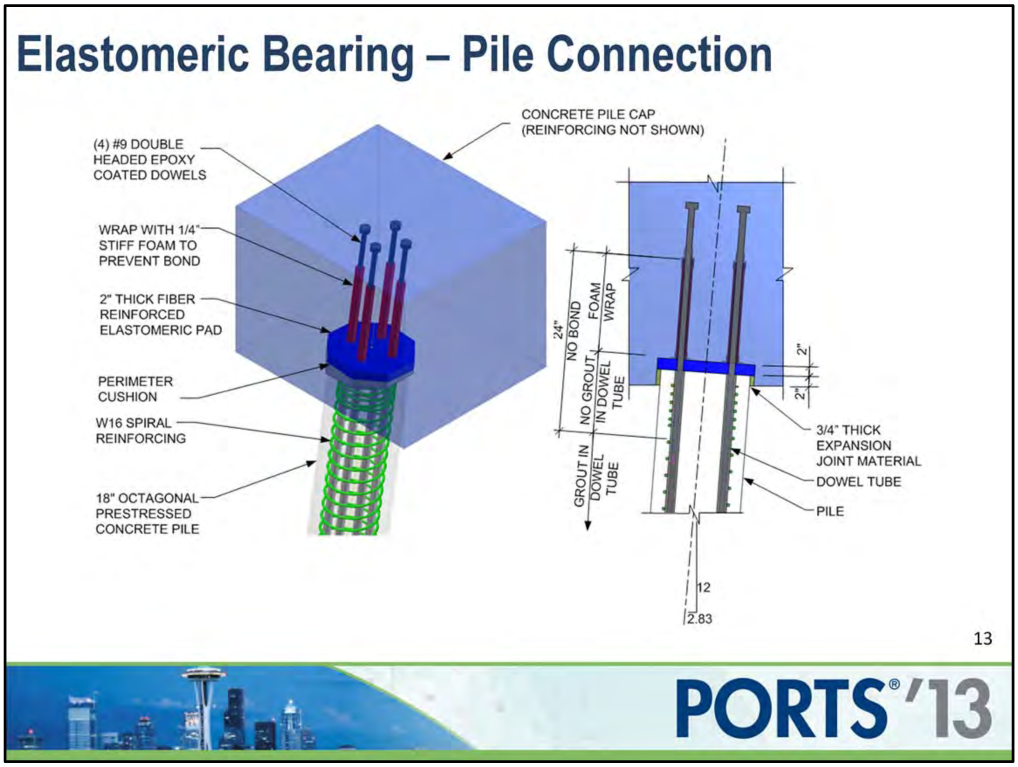
At 8.5% rotation, the concrete in the core of the Traditional Connection crushed and failed. The outer concrete shell of the Flexible Connection spalled but the core was intact. Local "buckling" deformation of the reinforcing dowels occurred near the pile-to-cap boundary as the bars elongated in tension when the piles were rotated in one direction, and then compressed when rotated in the opposite direction.



Load-displacement graphs of the testing indicate that:

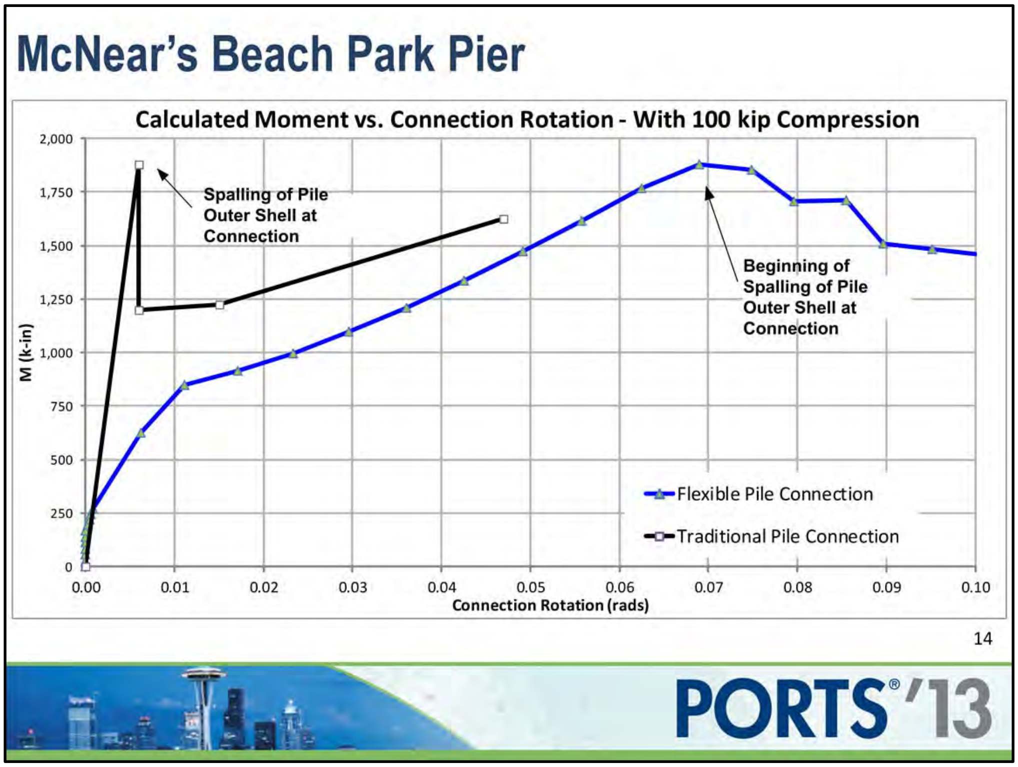
1. The strength of the Traditional Pile Connection deteriorates with rotation more than the Flexible Connection.
2. The maximum strength of the Traditional Pile Connection is more than the Flexible Connection.
3. The Flexible Connection is about 35% stronger than the Traditional Pile Connection at 5% rotation. They are equal strength at about 8% rotation.
4. Both connections fail at around 9% of rotation due to “bar buckling fracture.”

Most significantly, the Flexible Connection does not spall until large rotations develop.



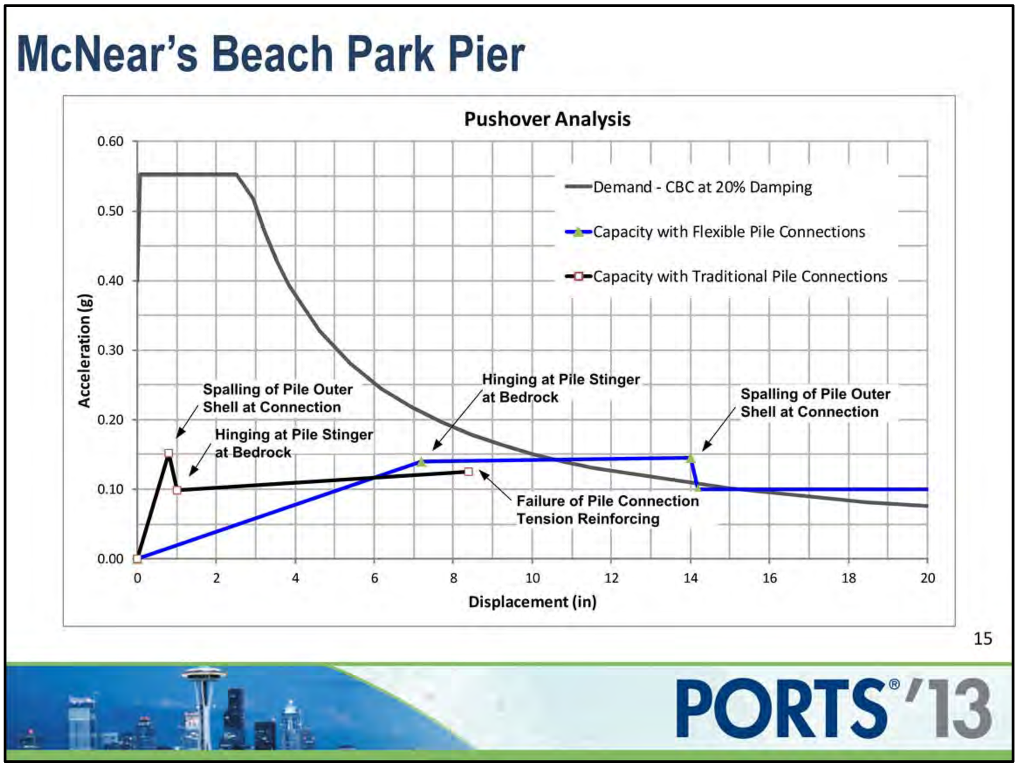
For the McNear’s Beach Park Pier design, compared to the specimens tested at the University of Washington, the dowels are unbonded for two feet and a 2” thick pad is used instead of a ¾” thick pad.

Design of the unbonded length and pad thickness were chosen to provide additional flexibility while limiting P-Delta effects.



For the McNear’s Beach Park Pier design, calculations based on specified yield and failure strains indicate that the outer shell of a Traditional Pile Connection design would spall at about 0.6% rotation and the McNear’s Beach Park Pier Flexible Connection at 7% rotation. Failure of the Traditional Connection is estimated at about 5% rotation. Failure of the Flexible Connection is estimated at over 10% rotation.

These calculations do not account for the multiple cycles of strain and assume no remaining strength after spalling or crushing occurs.

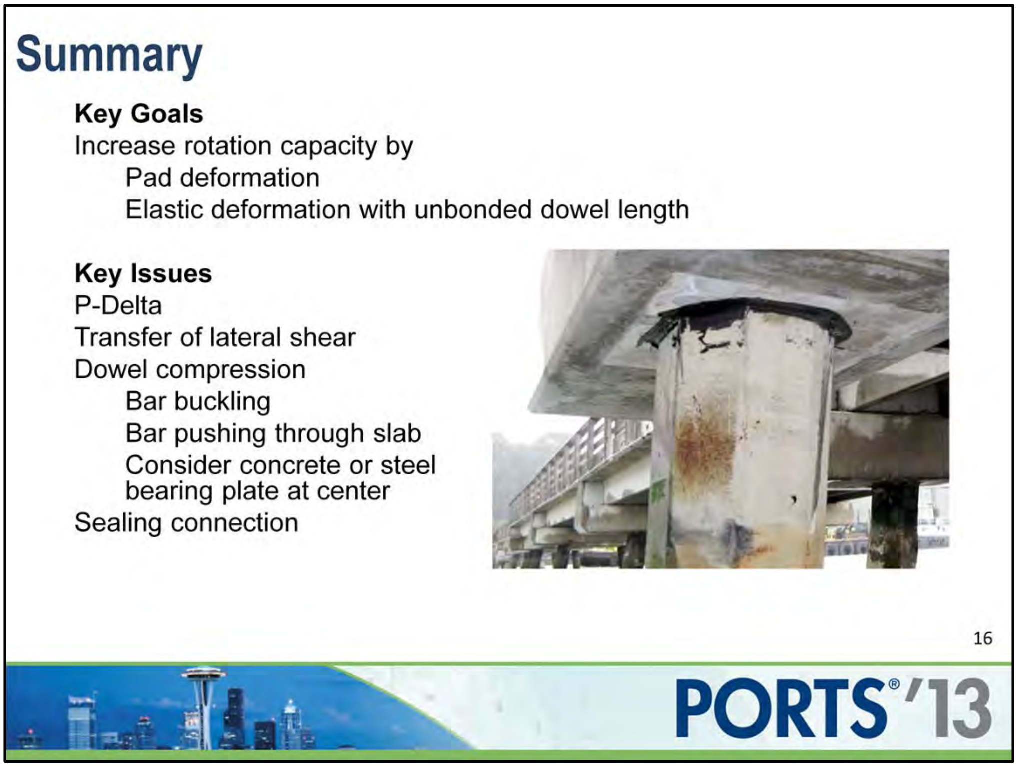


This graph presents the design displacement demand at an estimated 20% damping and the calculated lateral displacement of the structure for a design that uses a Traditional Pile Connection and a Flexible Pile Connection.

This level of damping is estimated based on the large pile movements through the soil and yielding of the structure. The elastomeric bearing pad will also contribute a little damping.

As shown in the graph, the increased pile flexibility is expected to allow for large relative displacements between the ground and structure without spalling or failure.

P-Delta effects are considered.



In summary, the key goal of the Flexible Pile Connection is to increase rotation capacity while maintaining connection strength. This goal is obtained using the elastomeric pad, perimeter cushion, and unbonding the dowels for some length.

The rotational flexibility of the connection and lateral stiffness of the system that can be used is limited by P-Delta effects.

Some comments:

Consider how the lateral shear is transferred between the pile and superstructure.

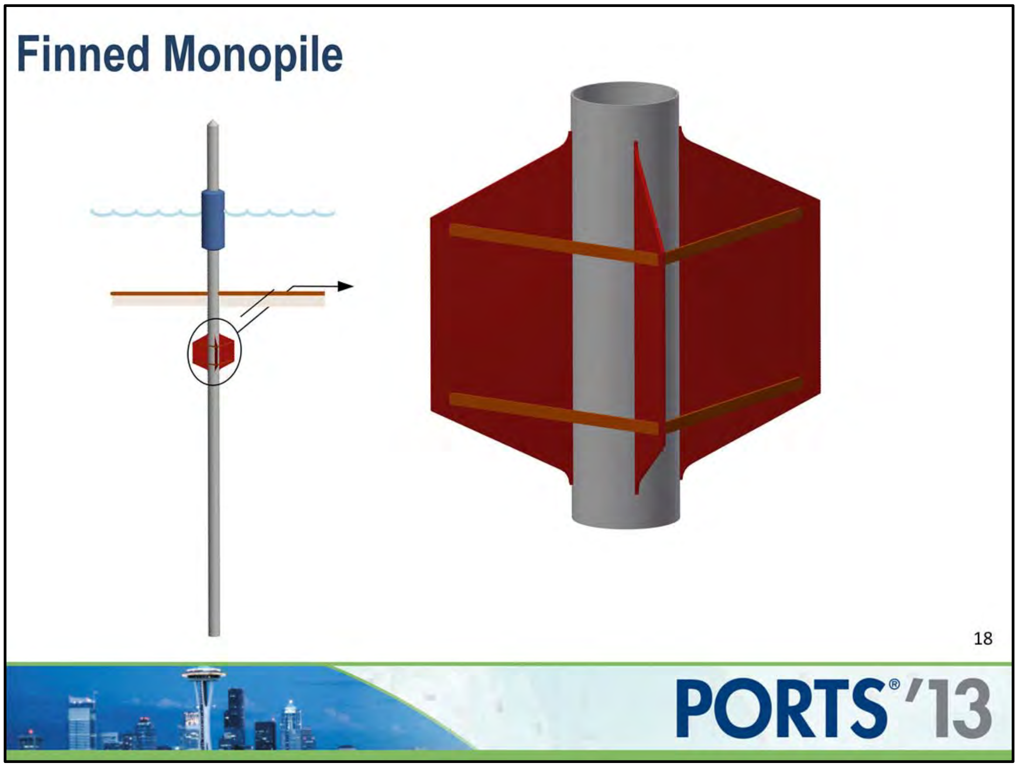
For McNear's Pier, a Sika Flex Sealant was used at the perimeter cushion.

Compression in the bar is a significant issue for both buckling and for the bar pushing up through the superstructure. Most testing has been performed with a deep "deck" member tensioned against the floor not allowing the phenomenon of the bars pushing through the deck. We will consider a narrow steel center bearing plate on the next project where an elastomeric bearing connection is used.

Since this project, researchers have studied this type of connection more. See PTI Summer 2013 article titled "Seismic performance of improved pile-to-wharf deck connections" by Lehman, Roeder, Stringer, and Jellin at: http://www.pci.org/pdf/publications/Journal/2013/Summer/JL-13-SUMMER-8.pdf. Also refer to the upcoming ASCE seismic standard for new wharves and piers.

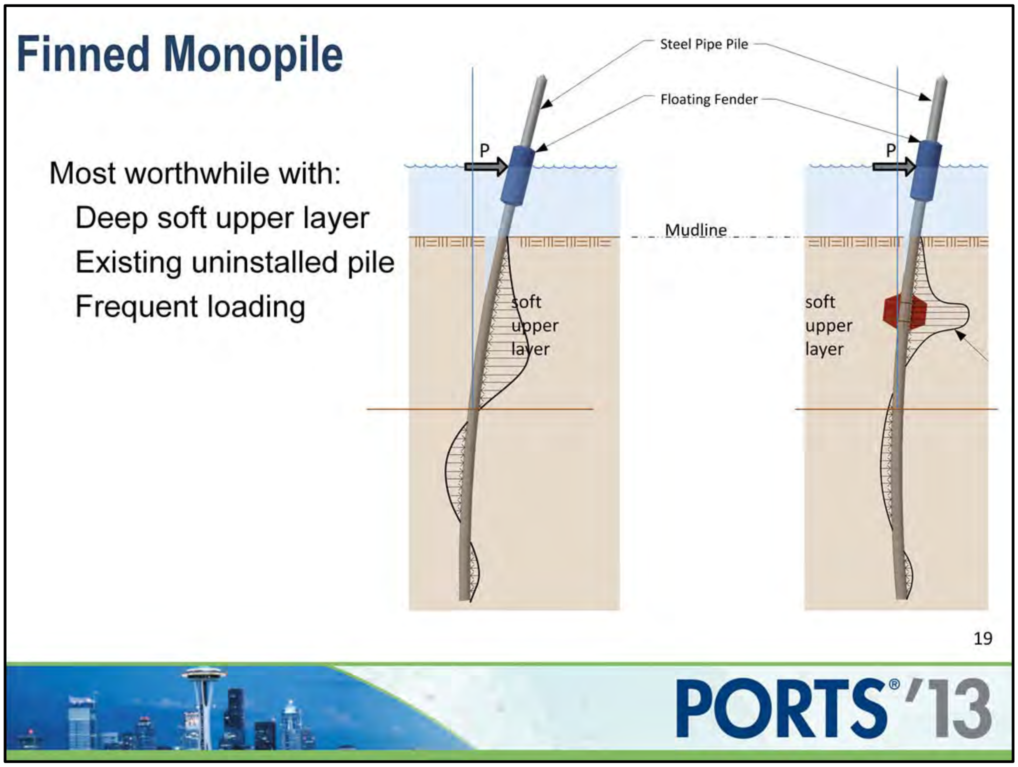
The next topic is using fins on a monopile.

The inspiration for adding fins to a pile was the fin common to fence posts, and a project where already-purchased piles had excessive bending. Adding small fins to the piles just below the soil surface significantly reduced the bending moment, permitting the use of the available piles.



The idea is to add steel plate fins to a steel pipe pile to develop more soil reaction higher on the pile and reduce the bending moment and deflection.

The fins shown are for a weak, flexible bay mud. Much smaller fins are appropriate for stiffer soil.



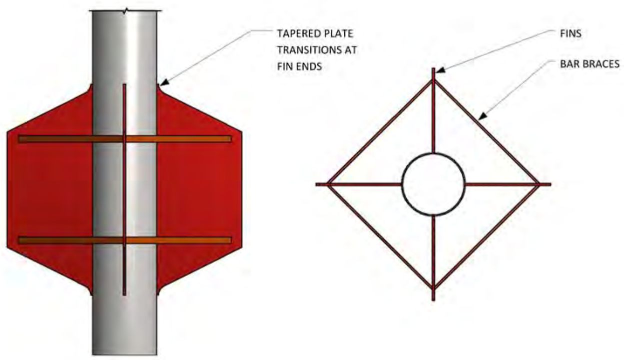
For a steel dolphin pile on a recent Liftech project, four large steel fins were added to significantly increase the soil resistance on the pile.

The concern on this project was that a pile without fins could become out-of-plumb over time due to large, frequent fender loadings.

As shown in the slide, the fins better anchor the upper portion of the pile in the soft bay mud, reducing the pile lateral displacement.

Some Design Suggestions

Design plate to yield before failing weld or pile wall
Transition ends to avoid stress concentration
Provide bar braces to permit laydown and rough handling

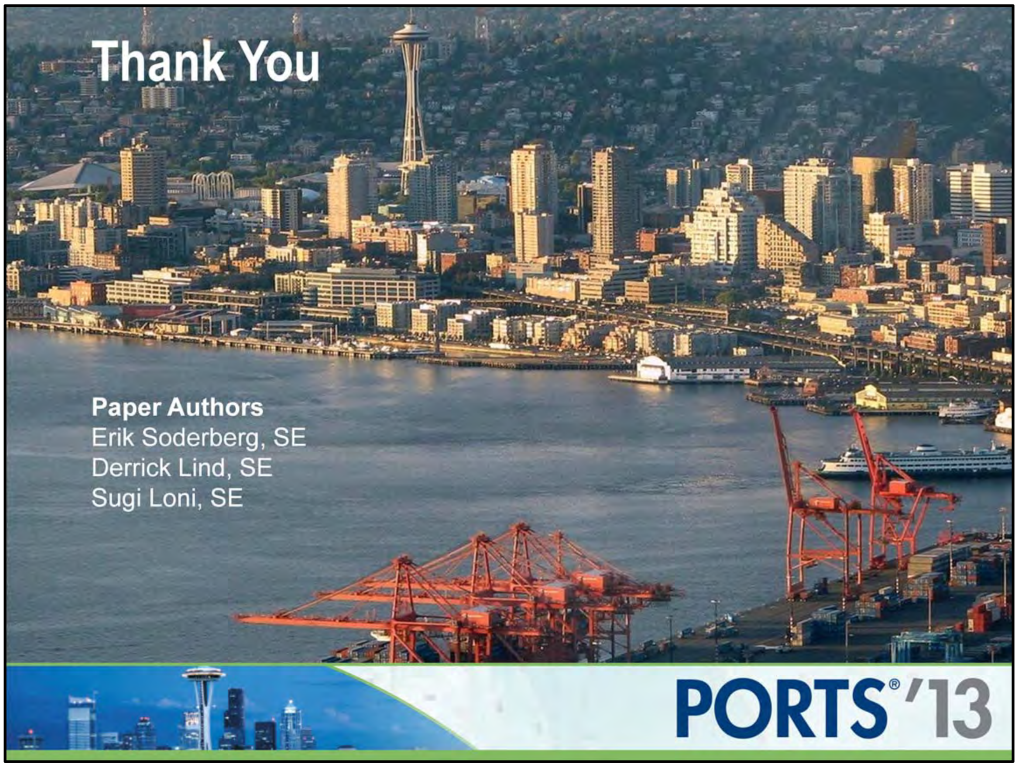


20

PORTS®'13

The geometry of the fin will depend on the soil properties.

Be sure to design the fin to yield before the pile wall, and transition the ends to limit the stress concentration from the fin. For large fins, consider struts between fins to avoid damage during handling.



The paper and presentation will be available on our website, www.Liftech.net.

I would like to thank my co-authors, Derrick Lind and Sugi Loni, who contributed to the paper and presentation.

Quality Assurance Review:

Author: Erik Soderberg
Editor: Derrick Lind, Linda Weber
Principal: Erik Soderberg

22

PORTS® '13

Presentation-259_Liftech-Soderberg_InnovativeWharfDetails_FORWEB.pptx