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HIGH PERFORMANCE PILE CONNECTION
MCNEAR'S BEACH PARK PIER REPAIR

Prepared by Liftech Consultants Inc.
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Project No. S1788

The ideas and designs presented in this paper were developed using recognized engineering principles. The purpose of this paper is to share information on a new design with the engineering community. Anyone making use of this information assumes all liability arising from such use.

Quality Assurance Review
for Liftech Consultants Inc.

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BACKGROUND

During a storm in the early morning of January 4, 2008, a 100 ft by 400 ft barge broke its mooring and collided with the pier at McNear's Beach Park in Marin, California, damaging about half of the pier structure. The damaged portions of the pier were replaced with new structure.

REPAIR DESIGN ISSUES

To meet current design standards, the repair design criteria required more strength, more ductility, and better seismic detailing than the original design. Additionally, environmental concerns required that the new piling be no larger in section than the original piles.

PIER STRUCTURE

The pier structure consists of a precast concrete superstructure supported by slightly battered 18 inch octagonal precast, prestressed piles (see Figures 1 and 2).

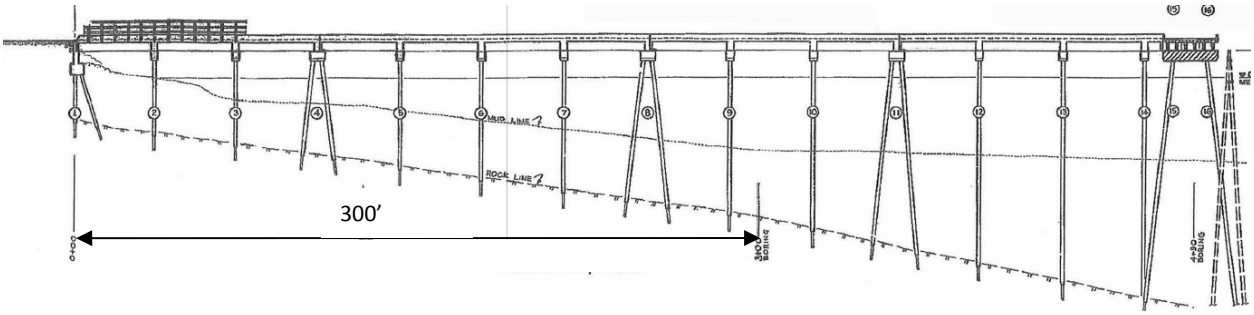

Figure 1: Pier Elevation

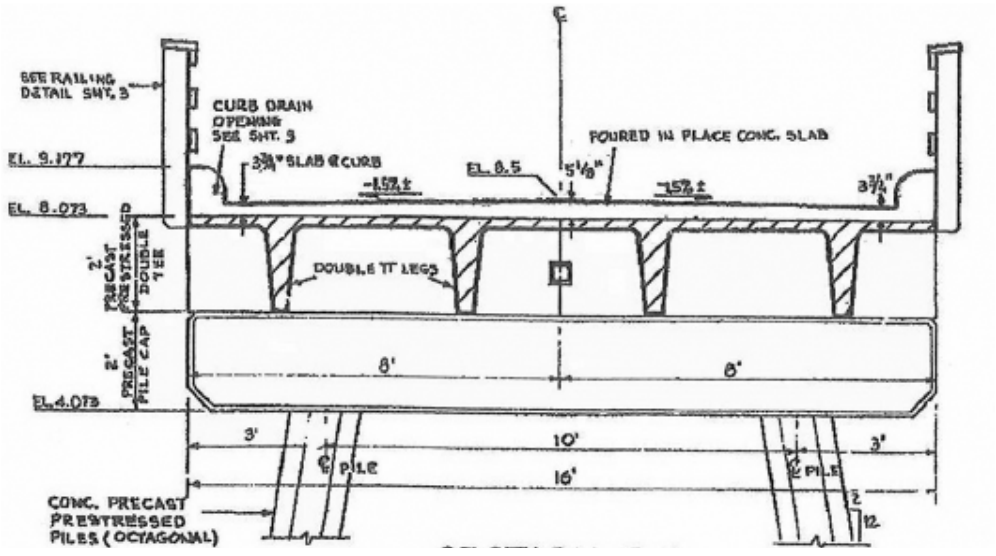

Figure 2: Typical Pier Section

HIGH PERFORMANCE PILE-TO-PILE CAP CONNECTION

It was impractical to design the lateral system of the new pier structure using a conventional pile connection design. A high performance ductile pile connection was developed to meet the design requirements.

Basis

The basis for the high performance pile-to-pile cap connection used on this project was the testing of its components in a variety of prototype connections studied as part of a research study for the National Earthquake Engineering Simulation Research Seismic Risk Management of Port Systems (NEESR SRMPS).

Liftech Consultants Inc. (Liftech), as a member of the advisory committee for the NEESR SRMPS study, was involved with the development of flexible pile connections specifically designed to mitigate seismic damage between piles and wharf structures. As part of this study, researchers, under the direction of Professor Charles Roeder at the University of Washington, designed, fabricated, and tested a variety of pile connection designs.

This study determined that providing a layer of strong but relatively flexible material in the pile connection, and a perimeter cushion, significantly reduced the damage from pile rotation while achieving connection strengths similar to a traditional pile connection.

Details and test results for traditional and flexible pile connections are provided in Figures 3 and 4. The test results are for 24 inch octagonal piles with 450 kip compressive axial loads.

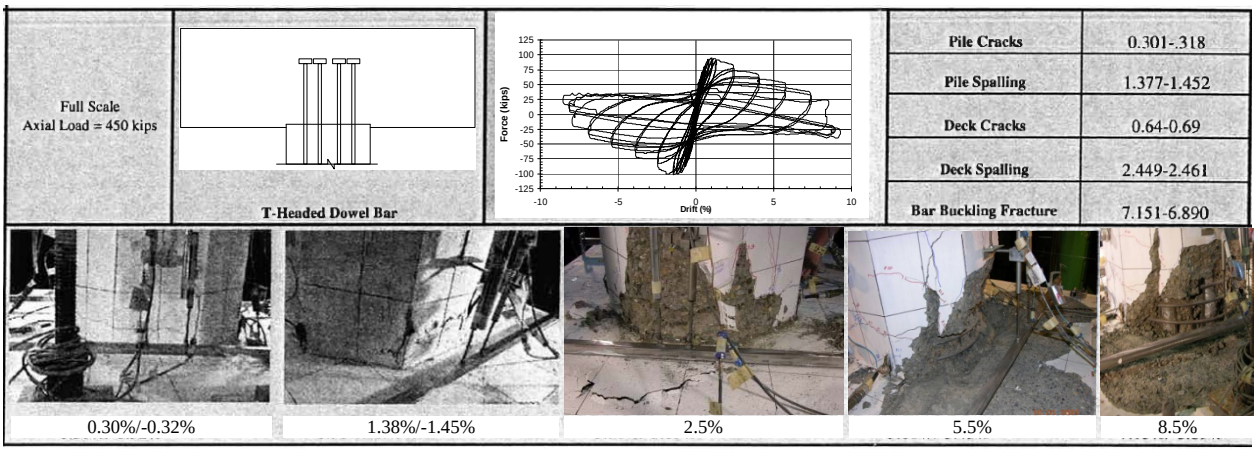

Figure 3: Traditional Pile Connection Test Results (Photo by Charles Roeder, Univ. of Washington)

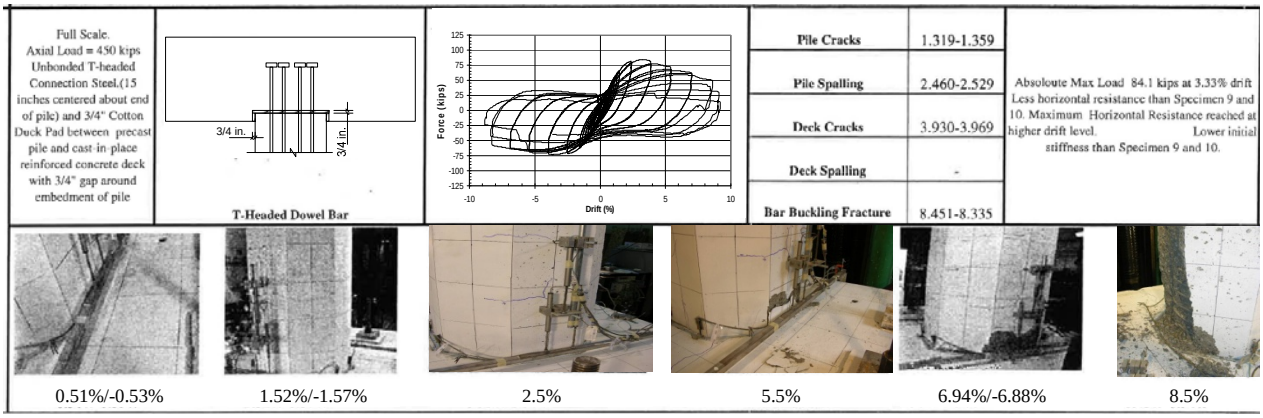

Figure 4: Flexible Pile Connection Test Results (Photo by Charles Roeder, Univ. of Washington)

Notice:

1. The flexible pile connection is nearly as strong as the traditional connection at small rotations. The flexible pile connection is stronger than the traditional connection at large rotations.
2. The rate of lateral capacity decrease is greater for the traditional pile connection due to structural deterioration.
3. The flexible pile connection prevents spalling damage to the "deck" structure.
4. For both pile connections, the lateral load decreases with rotation due to P-Delta effects.
5. Under cyclic loading, both traditional and flexible connections degrade due to spalling. Both connections ultimately fail when the dowels buckle in compression. The dowels fail after spalling occurs.

Pier Lateral System Design

Initial analysis indicated that a traditional pile connection would result in severe damage at a small lateral displacement, much less than required by the seismic design requirements.

To meet the design requirements, a high performance connection was designed that is flexible and ductile. Significant P-Delta moments limit the pile connection flexibility that could be provided. An acceptable pile connection stiffness was obtained using a 2 inch thick reinforced elastomeric pad between the pile and pile cap, a 24 inch unbonded dowel length, and a perimeter cushion (see Figure 5). Notice that the pad required in this design is significantly thicker than that tested in the NEESR SRMPS study and the unbonded pile length is longer.

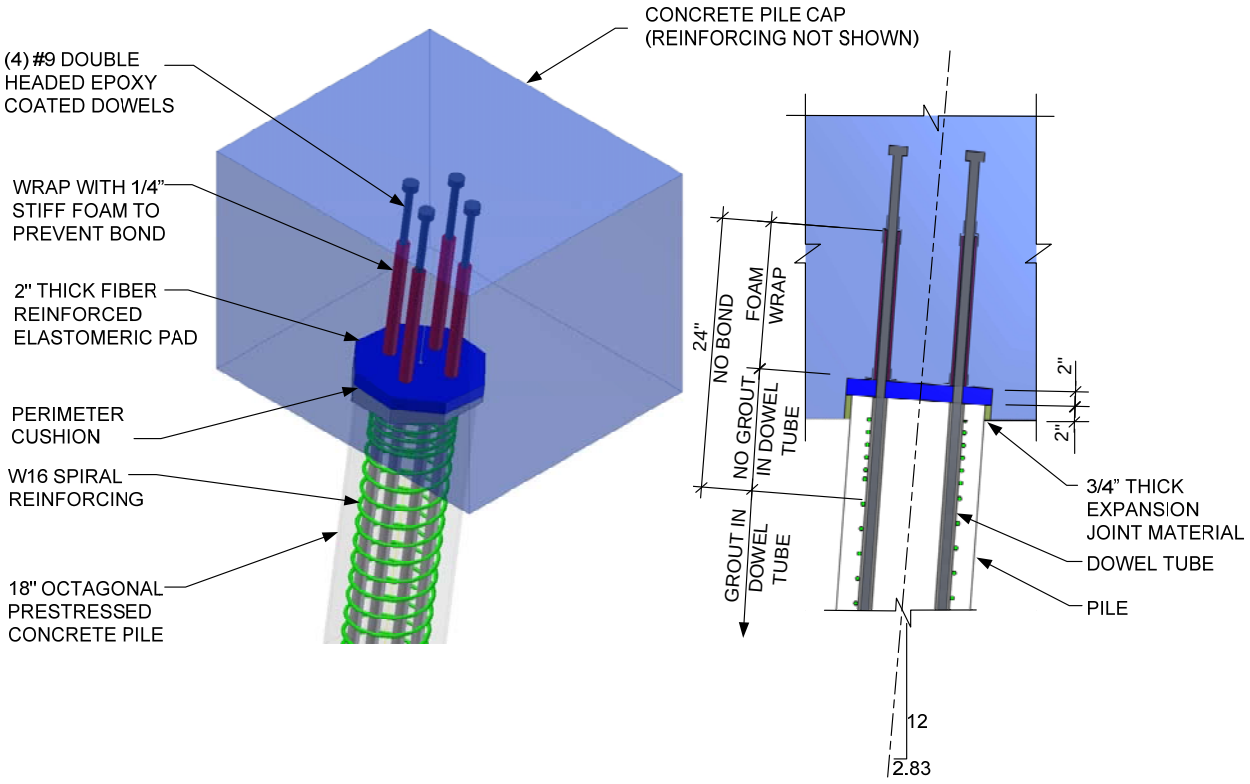

Figure 5: High Performance Pile Connection

The elastomeric pad is flexible enough that it will compress about ½ inch in the design earthquake. The unbonded length of dowel provides flexibility by permitting axial dowel deformation over a much longer distance than if no unbonded length were provided. Unbonding the reinforcing at the pile and pile cap faces prevents tension spalling.

The pile shear forces are small and are carried mainly by the expansion joint material when the pile is in compression, and jointly by the dowels and expansion joint material when the pile is in tension.

Fiber Reinforced Elastomeric Pad and Perimeter Cushion

The key components of the high performance pile-to-pile cap connection are the fiber reinforced elastomeric pad and perimeter cushion.

Fiber reinforced pads are commonly used to limit impact forces and to control vibrations in structural and mechanical systems. They are useful for structural bearing applications such as bridge bearings. They are also useful at the pile connection for this project because they have a breakdown stress of about 10 ksi and they are flexible, having a secant modulus of elasticity of about 25 ksi.

The perimeter cushion is made of expansion joint material that is sealed with silicone caulk. The material allows for movement while sealing the interior of the connection.

Expected Performance

The calculated moment-rotation relationship for the high performance and traditional pile connections are shown in Figure 6. The high performance connection is rotationally more flexible than the traditional connection and, more importantly, the pile outer shell fails at a much larger rotation. Accommodating large rotations without spalling greatly reduces the risk of earthquake damage.

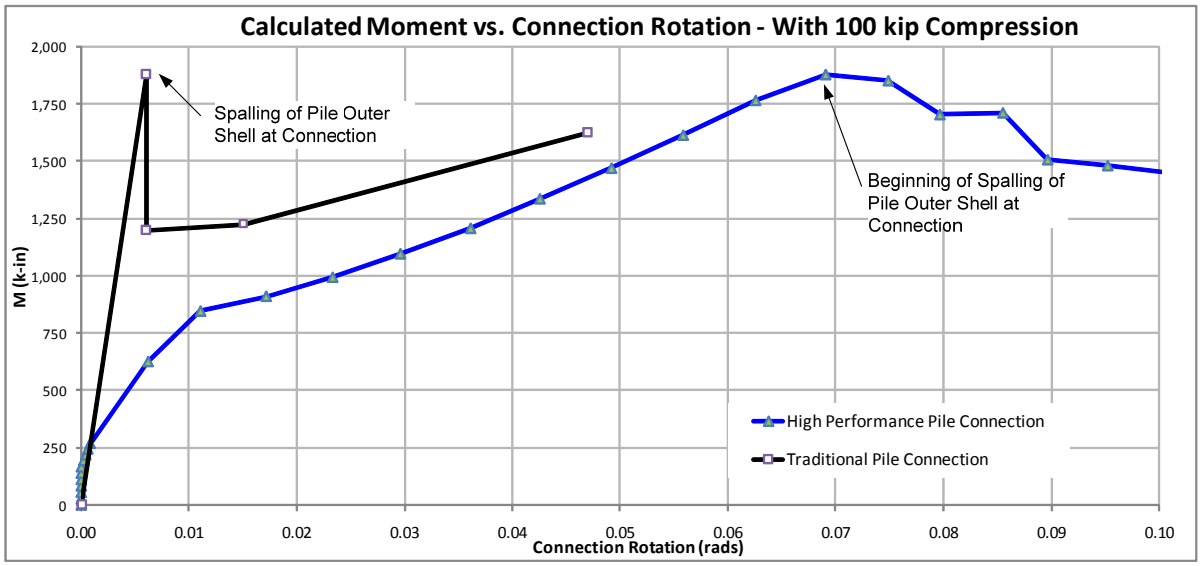

Figure 6: Pile Connection Moment vs. Rotation

The calculated pier pushover curve based on a non-linear analysis considering P-Delta effects is provided in Figure 7 for both the high performance pile connection used and a traditional pile connection.

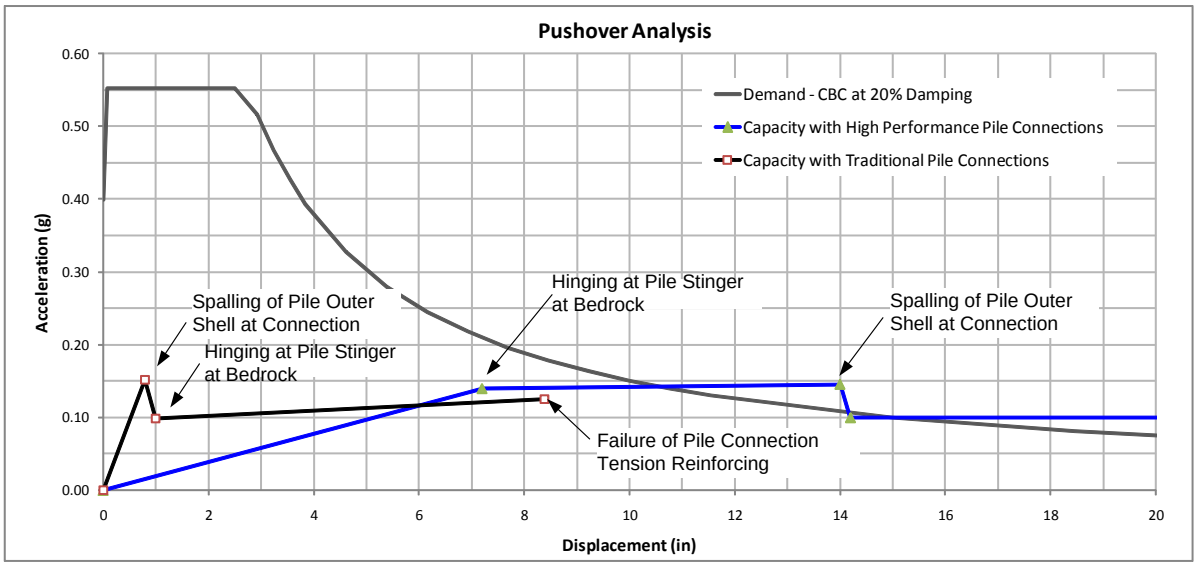

Figure 7: Pushover Analysis Including P-Delta Effects

The NEESR SRMPS pile test results shown in Figures 3 and 4 indicate that under cyclic loading, a major risk for a pile connection as it degrades is the dowel reinforcing failing in compression due to local buckling after the pile's concrete cover spalls.

As shown in Figure 7, the high performance pile connection permits enough rotation that the outer shell of the pile is not expected to spall in the design earthquake. The pile connection and pile cap will have little damage in the design earthquake.

SUMMARY

A damaged pier was repaired by replacing portions with new structure. The new structure was designed to meet current seismic design criteria. This required a high performance pile-to-pile cap connection. The high performance connection was designed using a fiber reinforced bearing pad, isolating the sides of the embedded pile, and unbonding the dowels for 24 inches of length. The high performance pile-to-pile cap connection used for this project added little additional cost to the project and significantly improved the seismic performance of the pile connection and the entire structure. We expect little damage at the pile connection during the design earthquake load.

We expect that similar connection details will provide similar benefits for other structural systems.

REFERENCES

Robert E. Harn (2004), "Displacement Design of Marine Structures on Batter Piles," 13th World Conference on Earthquake Engineering, Vancouver, B.C., Canada, August 1–6, 2004.

Robert E. Harn, "An Overview of Four Pier Facilities Designed Using MOTEMS Seismic Criteria," cited with permission from Robert Harn, 2010.

Robert E. Harn, Thomas E. Castor, and Michael G. Wray (2001), "Emergency Replacement of Ferry Berthing Structures at the Orcas Island Ferry Terminal," cited with permission from Robert Harn, 2010.

Michael Wray, Robert Harn, and John Jacob, "Port of Everett Rail/Barge Transfer Facility Seismic Design Everett, Washington," cited with permission from Robert Harn, 2010.