PIERS 57/58 MAINTENANCE PLAN UPDATE: WATERFRONT PARK CONDITION ASSESSMENT (WC2429)

July 2011

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July 2011

Prepared For:

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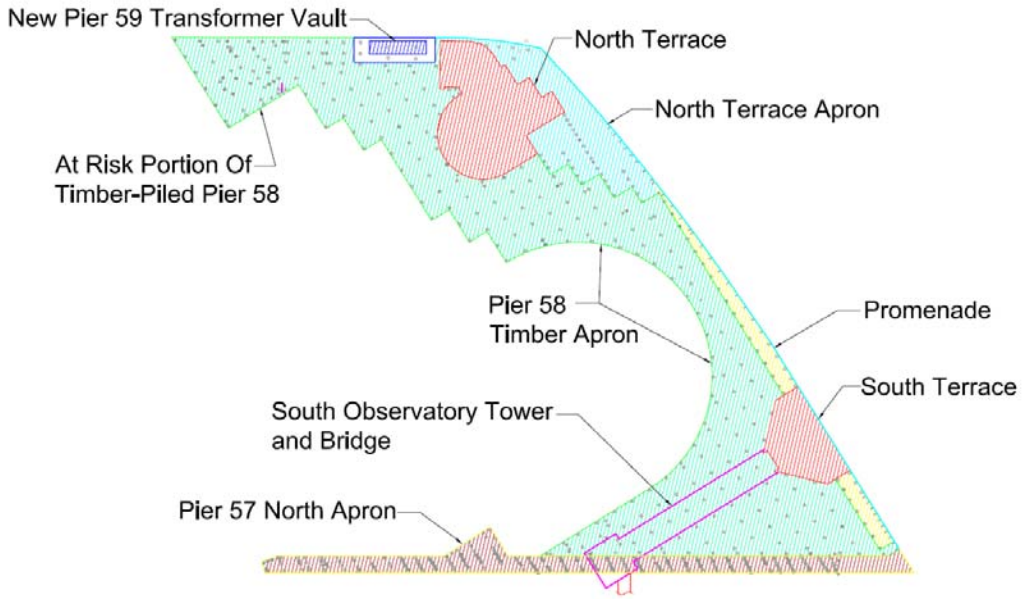


EXECUTIVE SUMMARY

This 2011 report reviews piles that support the concrete and timber portions of Pier 58 and those piles within Pier 57 that directly support the South Observatory Tower.

Seattle's Department of Planning and Development (DPD) requires an ongoing maintenance program of all piers in the Central Waterfront Fire District in accordance with Director's Rule 7-90. This rule requires that an updated statement of the pier's structural condition be completed every five years. The last report was completed in 2006 by Tinnea & Associates, LLC.

The 2006 Tinnea Report outlined recommendations that, if followed, would have returned the structure to a "near-design" level of safety. The 2006 report also allowed for the alternate imposition of load limits (without repairs) that provided "reasonably safe" conditions. Due to changes in the Central Waterfront area and seawall upgrades, as well as financial considerations, the city opted to forego repairs and imposed load restrictions, with the recognition that there was an increased risk of partial collapse in the event of an earthquake or large wind event.

We understand that the city intends to continue with the policy of maintenance deferral if possible. With that in mind, this executive summary focuses on the structural implications of no upgrades.

What Continues to Work at Pier 58

Many of the structural components continue to perform well despite deferred maintenance:

- The timber deck and framed sub-structure condition has not appreciably degraded since 2006.
- Concrete-constructed elements (North Terrace/Fountain and associated aprons, the Promenade and South Terrace) continue to need repairs outlined in the 2006 Tinnea report, although their vertical load carrying capacity has not significantly diminished in the past five years.
- Steel Monotube piles have diminished capacity but their rate of corrosion is not accelerating.

Problem Area #1: Creosote-Treated Timber Piles

The 341 timber piles supporting the main timber-deck portions of Pier 58 provide the vertical load-carrying capacity for Pier 58 as well as lateral resistance to earthquake, wind and wave actions. Over time the creosote treatment has washed out of the timber and the piles have lost effectiveness in limiting marine borer attack. Once a pile develops a large number of worm-holes the rate of decay accelerates and the pile will eventually fail.

The standard manner of rating timber piles is to assign a "percentage capacity remaining". A new pile will have a 100% rating. Once damage starts to accumulate the piles' ratings diminish. The Pier 58 pile ratings over the past ten years and projected forward 5 years are shown here:

	Approximate Average Pile Ratings					
Year Observed	○ 100%	◔ 90%	◔ 75%	◑ 50%	◕ 25%	● 0%
2000	84 (25%)	204 (60%)	37 (11%)	10 (3%)	4 (1%)	2 (1%)
2006	11 (3%)	189 (55%)	105 (31%)	27 (8%)	7 (2%)	2 (1%)
2011	0 (0%)	52 (15%)	161 (47%)	109 (32%)	16 (5%)	3 (1%)
2016 (projected)	0 (0%)	20 (6%)	100 (29%)	169 (50%)	37 (11%)	15 (4%)

The original piles had a rated live load capacity of around 20 tons and were capable of supporting 200 psf on the deck area. Even when deteriorated to a 25% rating they retain significant axial capacity (although less than the code-required 100 psf). In order to maintain the load carrying integrity of the pier, piles should be replaced when they reach a rating of 25%.

The original design of Waterfront Park would not meet today's seismic code requirements. As both the timber and non-timber piles decay, the risk of collapse as a result of a seismic or high wind/wave event increases. Since most of Pier 58's lateral capacity comes from the Monotube and steel piles, though, the incremental loss of lateral capacity in the timber piles is unlikely to significantly increase the likelihood of a general sway-type collapse (the expected failure is a localized vertical collapse). Eventually, though, the increased risk of lateral collapse, together with the loss of the vertical load-carrying capacity of the timber piles, will need to be addressed.

In 2006 there were a total of 9 piles (3%) that had a rating at or below 25%. In 2011 there are approximately 19 piles (6%). In 2016 there will be over 50 piles (15%). Within the next five years (by 2016) it is reasonable to expect that one or more of these piles will fail. Although not shown here, by 2021 there will likely be over 100 piles that are rated at or below 25% with almost certain failure.

We have studied the consequence of a failed single pile and have determined that the most likely outcome of this is a degree of sagging and reduced live-load capacity. As long as there are no large concentrated loads (from a vehicle, for instance) we do not expect that a collapse will occur as a result of a single pile failure. Our calculations suggest that the actual live load capacity is on the order of 20 psf when a single pile is removed; although this is less than the code-prescribed 100-psf this reduced capacity does not mean that a collapse will occur.

In order to continue to utilize the pier as park public space we recommend the following actions:

1. Impose a ban on all vehicular traffic. Install steel bollards at the access points. If access is needed require a review by a structural engineer prior to accessing.
2. Do not permit large gatherings of people for events.
3. Perform annual load tests of piles testing to 6,000# (approx 30 psf) to identify any failed piles. We recommend that testing begin this year to establish a baseline.
4. Perform annual row-throughs to look for pile damage beginning in May 2012.

If a failed pile is identified (as a result of the annual load tests or row-throughs) then access to that portion of the pier will need to be restricted. Given the current condition of the pier it is possible that the piling will pass this test for the next five years although the city must be prepared to take action if a pile failure occurs.

In the event of a high wind/wave event or an earthquake the pier could experience a partial collapse. The likely mode of failure will be a localized collapse and/or leaning.

Problem Area #2: South Observatory Tower and Bridge

There are two primary issues related to the South Observatory that should be addressed: pile support for the tower, and inadequate lateral (seismic) capacity.

The north apron on Pier 57 supports the tower and the west end of the bridge. The South Terrace structure supports the east end of the bridge. We understand that the north apron of Pier 57 may be deeded to that property owner.

Our inspection of the piles supporting the tower identified potentially inadequate piles – many have 25% ratings or less and need immediate replacement. The loads imposed by the tower are significant and a pile failure could result in collapse.

The other issue with the tower and bridge is inadequate seismic support. The Monotube piles supporting the South Terrace are severely corroded and of questionable capacity. These Monotube piles may fail when subjected to the high earthquake loads made worse by the heavy weight of the bridge.

Our recommendations for resolving the South Observatory issues are as follows:

1. Remove the South Observatory Tower and Bridge structure as was done at the north side in 2005, or
2. If bridge removal is not possible, then:
    a) Upgrade the pile support of the tower structure at the Pier 57 North Apron.
    b) Confirm that there is adequate connection to the Pier 57 deck structure for tower seismic forces.
    c) Confirm adequate separation with the upper floor of Pier 57.
    d) Upgrade the South Terrace structure to resist seismic forces from the bridge.

Conclusions and Recommendations

It is reasonable to allow continued public access to Pier 58 Waterfront Park but with no vehicle access. Load testing and row-through observation should be performed annually. The city should anticipate within five years that portions of the park may need to be closed due to a failed load test, in response to an earthquake or high wind/wave event, or because of the spontaneous loss of a pile due to deterioration.

By continuing to defer maintenance, the practicality of repairing the timber pier to a usable state is diminishing. The estimated cost of restoring the pier structure to near-code condition in 2006 was $0.7M-$1.5M. Today the cost of restoration is much higher due to escalation and continued decay. Within five – ten years, repair of the facility may no longer be practical.

Upgrade of the concrete components of the park (the water feature and the north and south terraces) will remain viable in lieu of replacement for many years although the upgrade would be costly. These components have reduced stability due to the on-going corrosion of the supporting Monotube piles. The delamination of the concrete framing described by Tinnea in 2006 continues to be a problem and these repairs are becoming more costly the longer they are deferred.

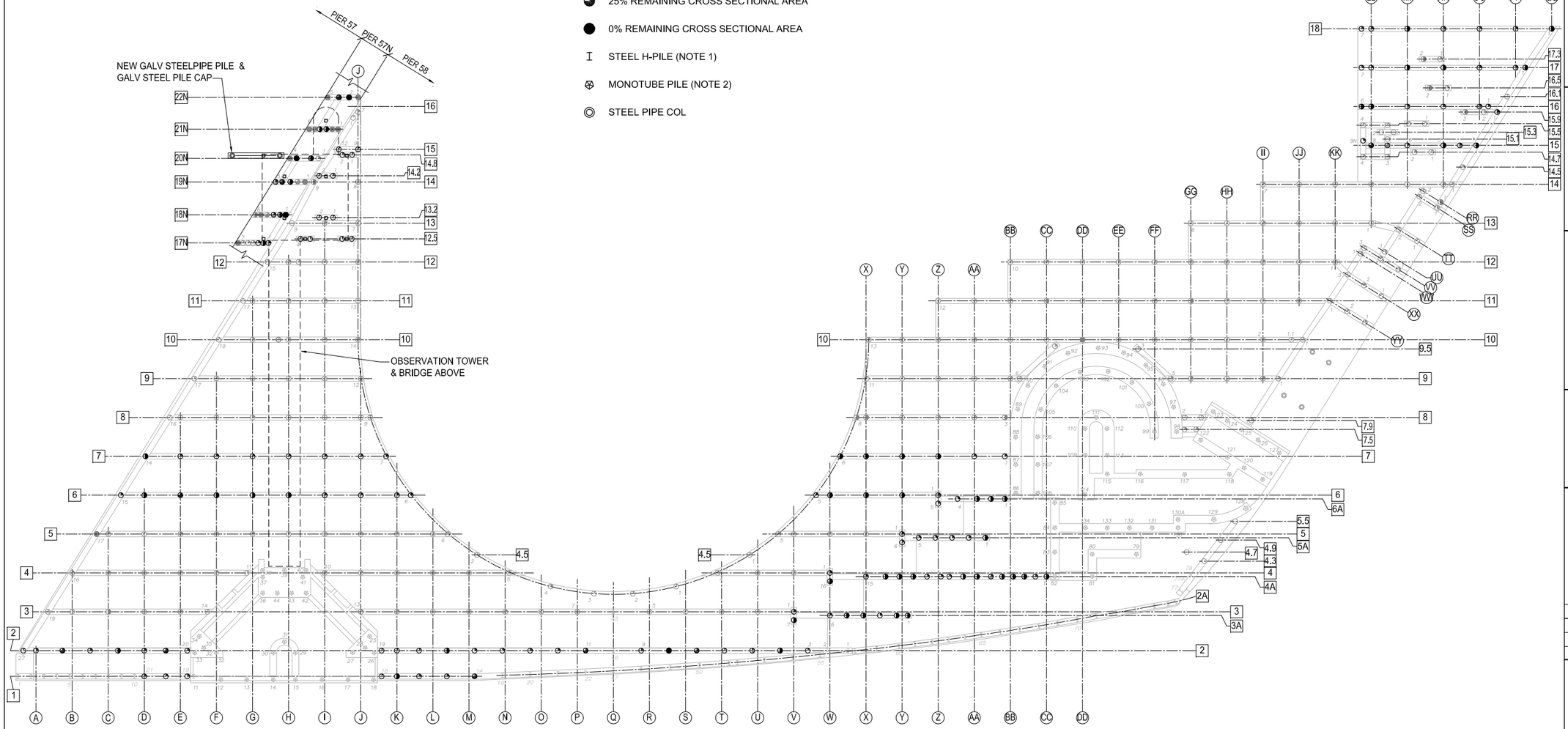
Planning should begin immediately for the removal of the South Observatory, or the upgrade of piles supporting this structure.

LEGEND

- TIMBER BEARING PILE (NO DATA)
- 100% REMAINING CROSS SECTIONAL AREA
- 90% REMAINING CROSS SECTIONAL AREA
- 75% REMAINING CROSS SECTIONAL AREA
- 50% REMAINING CROSS SECTIONAL AREA
- 25% REMAINING CROSS SECTIONAL AREA
- 0% REMAINING CROSS SECTIONAL AREA
- STEEL H-PILE (NOTE 1)
- MONOTUBE PILE (NOTE 2)
- STEEL PIPE COL

NOTES

1. H PILES #1 THRU #65 ARE HP10x42, #66 THRU #78 ARE HP10x157
   SOURCE: 1973 RECORD DWGS
2. MONOTUBE PILES ARE 12"DIA x 7GA (0.179")
   SOURCE: 1973 RECORD DWGS



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SEATTLE PARKS AND RECREATION

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NO.	REVISION – AS BUILT	DATE
3		
2		
1		

REVIEWED: PARK ENGINEER DATE

All work done in accordance with the City of Seattle Standard Plans and Specifications in effect on the date shown above, and supplemented by Special Provisions.

PIER 58

WATERFRONT PARK CONDITION ASSESSMENT (WC2429)

DESIGNED	MOB	DATE	6-29-2011
DRAWN	BDS	SHEET	OF
CHECKED			
ORDINANCE NO.		S1	
JOB NO.	P8050.00		
SCALE	AS NOTED		

PLAN

1"=20'-0"

3

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Photo 1: Minimal corrosion at the underside of the South Terrace

Photo 2: Minimal corrosion at underside of the South Terrace

Photo 3: Monotube piles supporting the horseshoe-shaped beams at the North Terrace

Photo 4: Severely corroded Monotube pile at the North Terrace

Photo 5: Corrosion of reinforcing steel on the sides of the horseshoe-shaped beams of the North Terrace

Photo 6: Corrosion of reinforcing steel on the sides of the horseshoe-shaped beams of the North Terrace

Photo 7: Tall Monotube piles at the North Terrace with severe corrosion in the splash zone

Photo 8: Severely corroded steel H-pile along the seawall at the North Apron

Photo 9: Steel H-pile supporting the promenade along the seawall where barnacles have been removed

Photo 10: Example of a 0% rated pile

Photo 11: Example of a 50% rated pile

Photo 12: Pier 58 split in timber pile cap at pile Grids 3/U (photo taken in 2006 – similar in 2011)

Photo 13: Pier 58 concrete pile cap and Monotube pile (photo taken in 2006 – similar in 2011)

Photo 14: Pier 58 crack in concrete pile cap at south terrace (photo taken in 2006 – similar in 2011)

Photo 15: Pier 58 concrete pile cap and Monotube pile (photo taken in 2006 – similar in 2011)

Photo 16: Pier 58 concrete north terrace apron and steel H-pile (photo taken in 2006 – similar in 2011)

Photo 17: Pier 58 concrete promenade and steel H-pile (photo taken in 2006 – similar in 2011)

Photo 18: Pier 58 concrete firewall (photo taken in 2006 – similar in 2011)

INTRODUCTION

Seattle Structural was contracted by the Seattle Parks and Recreation Department (PRD) to perform a condition assessment of Pier 57 North (57N) Apron and Pier 58 Waterfront Park. Seattle Department of Planning and Development (DPD) Director's Rule 7-90 calls for a maintenance program for wood piers based on a survey report that includes observation and evaluation of a representative sample of caps, stringers, and piles, although the number of piles need not exceed 20% of the total.

Pier 58 was built in 1974 using several different construction types. A Creosote-treated timber superstructure and piles accounts for 70% of the area. North and South Terraces were constructed with concrete superstructures supported by concrete-filled steel Monotube piles. The concrete apron adjacent to the North Terrace is supported by steel H-piles along the seawall and timber piles elsewhere. The concrete Promenade along the seawall also is supported by steel H-piles along the seawall and timber piles at the transition to the timber portions of Pier 58. A bridge spans from the South Terrace to the south observatory tower. Both are steel with concrete slabs. The north observatory tower and bridge were removed in 2006 when the Aquarium Pier 59 was renovated. The south tower has (10) steel columns of which (5) are supported at Pier 58, (4) on the Pier 57N apron, and one at Pier 57. Pier 57N is a timber apron with timber piles that was constructed before Pier 58 and was renovated in 1974 to support the tower columns. Pier 57 is privately owned and was constructed with a timber superstructure and piles perhaps 100 years ago.

This report is intended to address the survey report requirements of Director's Rule 7-90. Seattle Structural performed observations of portions of the superstructure and a number of piles above the waterline. Global Salvage & Diving (Global Diving) was sub-contracted to observe timber piles below the waterline. A representative number of piles and pile caps of Pier 58 were observed. Observations of the Pier 57N apron were performed only on timber piles and pile caps that support steel tower columns as ownership of this pier could be transferred to another party sometime in the near future and Seattle PRD would no longer be responsible for its maintenance.

Prior condition studies and the repair history of Pier 58 are listed below.

- 1989 – Arnold, Arnold & Associates condition assessment report
- 1992 – CH2M Hill condition assessment report
- 1996 – Sprinkler system replacement in accordance with drawings by Buffalo Design (architect) and Berona/Langebartel (sprinkler engineer)
- 1998-1999 – Tinnea, Echelon, and Tetra Tech condition assessment report
- 1999-2000 – Reid Middleton and Echelon condition assessment report
- 2004 – Repairs to North Terrace in accordance with 1998-1999 report by Tinnea, et al.
- 2006 – Tinnea, Seattle Structural, and Global Diving condition assessment report
- 2006 – Seattle Structural demolition/construction cost estimates

OBSERVATION METHODS

The following observation methods were used above the waterline by Seattle Structural:

- Visual observation of piles and superstructure from a small boat
- Sound with a hammer (for comparisons with visual ratings) 10% of the piles observed visually
- (1) Monotube pile was struck with the head and claw of a hammer at a location of severe corrosion to determine if base metal remained and to expose the concrete core, if possible
- Measure the dimensions of an H-pile in the tidal zone after removing barnacles
- Measure the flange thickness of an H-pile above the splash zone

The following observation methods were used below the waterline by Global Diving:

- Visual observation
- Sound piles with a hammer

The diver's helmet camera and microphone could be monitored in real time onboard the dive boat and were recorded on DVD for future reference.

SCOPE OF OBSERVATIONS

Seattle Structural observed the piles above the waterline at low tide in mid-May, 2011 when the water level was minus 3 feet based on the mean lower low water (MLLW) datum. The pier superstructure was observed at the same time and another time in early June when the tide was plus 4 feet.

Seattle Structural observed the North and South Terraces, the concrete apron adjacent to the North Terrace, the Promenade, and the northwest area of Pier 58 adjacent to Pier 59 and furthest offshore. The northwest area was considered "at-risk", because more than one-third of the piles had ratings of 50% remaining capacity or less in the 2006 condition assessment. This group of piles was rated worse than other areas of Pier 58.

Seattle Structural also observed non "at-risk" portions of Pier 58, specifically, timber piles and pile caps on Grids 2, 6, 10, and 15, to get a representative distribution over the entire area. These grids are parallel to the seawall with Grid 1 being the closest to the seawall and Grid 2 being the first row of timber piles.

Global Diving observed the "at-risk" timber piles in the northwest area, the timber piles supporting the concrete apron of the North Terrace, the piles supporting the south observatory tower columns, and non "at-risk" timber piles along Grids 6 and 7. The divers could not observe all of the same non "at-risk" piles as Seattle Structural in the time available. It is more efficient for the divers to observe piles out and back along adjacent grids. The water level varied between plus 4 to minus 2 feet based on MLLW datum.

OBSERVATIONS

Pier 58

Timber Piles

Seattle Structural observed 158 of 341 timber piles at Pier 58 and Global Diving observed 106 piles which included an overlap of 88 piles. As much as possible, we sought to have Global Diving observe the same piles as Seattle Structural so pile ratings could be based on observation of the entire pile. We also wanted to compare the ratings above and below the waterline. Of the piles rated by both observers, Global Diving rated 97% of the piles the same or worse than Seattle Structural which is expected because most damage from marine borers occurs from the inter tidal zone down to a foot below the mudline. Seattle Structural observed 32 piles near the seawall that were completely or almost completely exposed down to the riprap at low tide, which makes a total of 138 piles that were observed from top to bottom or 40% of the Pier 58 timber piles.

The attached pile plan shows the ratings by Global Diving plus the piles along the seawall which were rated by Seattle Structural. The Seattle Structural and Global Diving personnel who observed and rated the piles this year, also observed and rated the piles in 2006.

The rating for each pile is reported in Appendix A for prior year studies as well as this year. In a pile-by-pile comparison, there are piles with better ratings this year compared to 2006, which can be attributed to the observation processes.

A summary of the pile ratings for this year and prior year studies are shown in Table 1. Based on the percentage of piles at each rating, the quantities are extrapolated for all 341 piles. While less than half the piles were observed this year in accordance with Director's Rule 7-90, nearly all piles were observed and rated in prior years. The quantities for prior year studies also were extrapolated for easier comparison of year-to-year results. Overall, the pile ratings are worse for each successive study. This trend is projected out to year 2016 to show how many piles will be in jeopardy in 5 years.

Table 1: Summary of Timber Pile Ratings for Pier 58

Year Observed	Pile Ratings						
	○ 100%	◔ 90%	◔ 75%	◑ 50%	◕ 25%	● 0%	Pile Qty
2000	84 (25%)	204 (60%)	37 (11%)	10 (3%)	4 (1%)	2 (1%)	341
2006	11 (3%)	189 (55%)	105 (31%)	27 (8%)	7 (2%)	2 (1%)	341
2011 (observed)	0 (0%)	21 (15%)	65 (47%)	44 (32%)	7 (5%)	1 (1%)	138
2011 (extrapolated)	0 (0%)	52 (15%)	161 (47%)	109 (32%)	16 (5%)	3 (1%)	341
2016 (projected)	0 (0%)	20 (6%)	100 (29%)	169 (50%)	37 (11%)	15 (4%)	341

Timber Pile Caps

The timber pile caps are above the splash zone and have no significant surface rot and no observable marine borer activity. The ends of some caps at the edge of the pier look "weathered" but they have no significant loss of capacity as the damage that exists is in a region of low stress. A pile cap near Grids 3/U has an inclined crack that has not changed significantly since 2006. The timber pile caps generally are in satisfactory condition.

Timber Superstructure

No significant deterioration of the deck or stringers was observed.

Fire Separation Walls

Damage to the timber fire separation curtain near Pier 59 along grids II and 11 was observed in 2006 and it is now missing completely. The concrete fire separation curtain along Grid Q is partially damaged and exposed rebar has corroded. Its condition is not significantly worse than 2006.

Steel H-Piles

The steel H-piles are corroded in the splash zone which is a couple feet below the bottom of concrete near the North Terrace and just below the bottom of concrete near the South Terrace which is lower than the North Terrace. The corrosion in the splash zone is 3-4 feet high. The corrosion of H-piles was more severe near the middle of Pier 58 between the North and South Terraces than the other areas.

The flanges and webs of the H-piles are corroded, but the corrosion appears to be more advanced along the edges of the flanges and less so at the webs and the flange-web intersection. The total thickness of the remaining steel and the rust is approximately 4 times the original flange thickness. Using a rule-of-thumb that rusted steel is 10 times thicker than the original base metal, 67% of the original flange section remains. Assuming that the loss is maximum at the flange tips and zero at the flange-web intersection, the H-piles have 88% of their cross sectional area remaining. The loss is not critical at this location of the pile, because it is an area of low stress.

The piles have rust stains along the edges of the flanges in the barnacle-encrusted tidal zone, which suggests that corrosion has occurred. Rust stains are less prominent on the webs and the flange faces. The barnacles were scraped off to expose the flange surface of one HP10x42 pile over an area 12 inches high. Primer paint was observed on 6”-9” of the width and still adheres to the steel over much of that area but easily flaked off near the edges on the exterior face. Rust has not built up along the edges of the flanges like it has in the splash zone above. The flange widths varied from a maximum of $10^1/_8$”, which is the original width, to a minimum of 10”. The flanges were thin at the edge and tapered to the original thickness over a width of ½” to 2”. Assuming that all H-piles have lost triangular cross sectional areas from each corner of all flanges along the full length of the pile, the remaining axial and flexural capacities are 90% of the original section. Steel H-piles completely exposed at low tide have section loss at the riprap where moment is highest due to lateral load. We were not able to determine whether or not piles that remain partially submerged at low tide have similar section loss at the mudline or riprap.

Monotube Piles

The Monotube piles at the North and South Terraces are 12-inch diameter, 7 gage (0.179-inch thick) steel. They are proprietary cylindrical piles fabricated with vertical fluting and filled with concrete after driving. All of the Monotube piles have corrosion in the splash zone and are barnacle encrusted in the tidal zone. The splash zone starts at or several feet below the bottom of the concrete at the North Terrace depending on the bottom of concrete elevation. It starts a couple feet below at the South Terrace. The corrosion in the splash zone varied in appearance from surface rust to cracked and flaky. The cracks ran vertically along the outer edge of the vertical flutes. The extent of the corroded areas varied from spots 4-12 inches in diameter randomly distributed, to a completely corroded surface encircling the pile for a few feet of the pile length. We were not able to break through the rust down to the concrete core by striking the rust with a hammer. The point of impact appeared shiny and gray like a freshly exposed steel surface.

Concrete Superstructure of the North Terrace and Apron

Parts of the North Terrace concrete superstructure are in the splash zone and the bottom half of the horseshoe-shaped concrete beams are submerged in high tide. The concrete beams in the splash zone have rust stains indicative of reinforcing steel corrosion. The corrosion almost certainly has advanced but it does not appear to be significantly worse than 2006. No significant rebar corrosion was observed in other areas of the North Terrace and its concrete apron which are above the splash zone.

Concrete Superstructure of the South Terrace

Some rust stains on the soffit of some beams that are nearest the water otherwise no significant corrosion was observed. Cracks were observed in the soffit of (2) concrete beams in 2006 have not increased in length. The cracks do not exhibit any rust stains, but corrosion or some other mechanism is causing the cracks.

Alaskan Way Promenade

No corrosion or other serious problems were observed.

Concrete Electrical Vault

A concrete electrical vault was constructed adjacent to Pier 59 at the north edge of Pier 58 in 2006 as part of the Pier 59 Aquarium Pile Replacement/Renovation. It is supported by 4 steel pipe piles. The concrete electrical vault and steel piles were not observed for this condition assessment.

Piers 57 and 57N

Observations of Piers 57 and 57N were concentrated on the timber beams, bent caps, and piles that support the south observatory tower. Pier 57 is privately owned. If ownership of Pier 57N is transferred from the City of Seattle to the owner of Pier 57, then elements of Pier 57N that support the tower would continue to be of concern to the City.

Timber Piles

Timber beams of Pier 57N support (4) steel columns of the south observatory tower. The beams are simple span members parallel to the stringers. Both are supported by the timber bent caps and piles. The beams are loaded mostly in shear and moderately in flexure as the tower columns are located near ends of the beams. The stringers are 2-span members with all stringers continuous over one bent cap and terminating at the bent caps on either side. Bent caps are supported by 4-7 piles. This framing system has less redundancy than the Pier 58 framing system for overloaded or weakened members to share their load with other members.

One of the tower corner columns supported by Pier 57N is heavily loaded as it also supports one corner of the bridge. It is nearly over Bent Cap 17N and is supported by (3) piles with a combined rating equivalent to (2) sound piles.

A column supported near Bent 18N has a pile with 0% rating directly below and (2) other nearby piles with a combined rating equivalent to 1¼ sound piles. The 0% rated pile has had the same rating since the year 2000 condition survey.

Pier 57 supports (1) column of the south tower. The timber bent cap and piles that had supported this column have been replaced with a galvanized steel wide flange bent cap and galvanized steel pipe piling as part of a renovation that was in progress in May 2011.

Timber Superstructure

No significant deterioration of the timber deck, stringers and beams of Pier 57N was observed.

ANALYSIS AND COMMENTARY

Overview

The types of decay and damage that timber piles can sustain were described in the 2003 report "Seattle Aquarium Pier 59 Upgrade Study" by Seattle Structural:

Pile decay and section loss can be attributed to a number of reasons.

Mechanical Damage	*The timber piles may have been damaged during their installation or later due to impact from equipment or debris. Especially at the east end, where the fill material is shallow and there is dumped construction debris, many of the piles exhibit mechanical damage at the mud line.*
Marine Borer Attack	*The piles are subject to damage by marine animals. The damage may be on the exterior or on the inside where the damage is unobserved.*
Fungal Decay and Biological Deterioration	*The original timber piles were treated with creosote to inhibit their decay. The leaching of preservatives into the saltwater over the years has allowed wood deterioration. This loss at the wood surface, where the creosote has leached out, results in the general loss of pile diameter. In many cases, the wood remains intact at the pile's interior, where there exists*

Marine borer attack is one of the two primary types of timber pile damage observed at Pier 58 and 57N. The timber pile ratings in the appendices are the pile areas remaining based on estimated losses due to marine borers.

The other common type of pile damage is fungal decay and biological deterioration. Global Diving found this type of damage on the surface of nearly all timber piles. The surface deterioration is noted in their report as punk $^{1}/_{8}$"-¼" deep. A ½" reduction in the diameter of a 12" pile reduces its axial capacity by 15% and its lateral load capacity in bending by 12%.

The types of pile failures that can occur are axial failure (buckling), flexural failure, or combined axial-flexural failure. Piles are tall, slender members that may fail at or a few feet above the mudline due to lateral buckling with the pile braced at the top by the superstructure and other, typically shorter piles that do not buckle. Flexural failures can occur due to wind, waves, or seismic forces with the piles acting as cantilevered members that develop their maximum flexural stress at the point of fixity below mudline. The types of failures are illustrated in Figure 1 which is taken from the 2003 report by Seattle Structural.

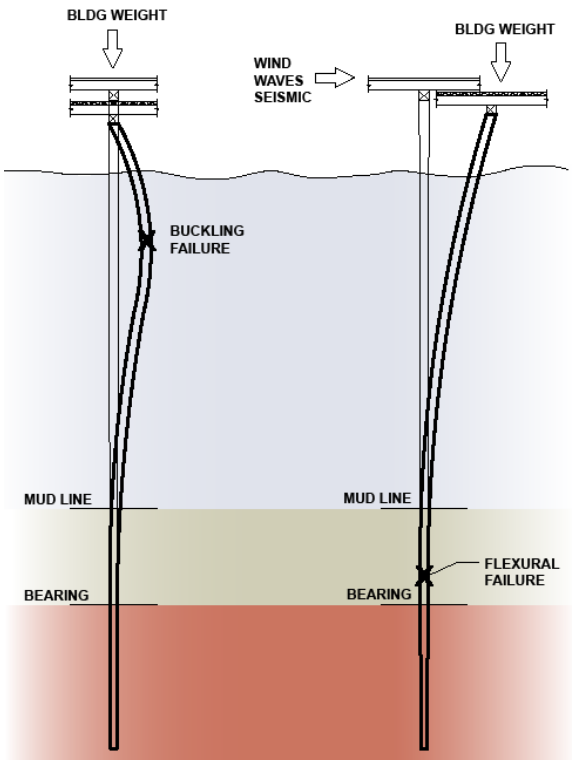

Figure 1: Types of Pile Failures

The typical pile size used in our analyses was 14 inches at the top and 12 inches at the mudline which are based on field measurements from previous studies. The report "Maintenance Program Pier 58/59 (WC 676)" by Echelon in 2000 noted on calculation page E12 that a 1995 pile inspection by Sunchaser measured the diameters of 96 piles. The average pile diameters were 12.3 and 14.4 inches at the tip and butt, respectively. Seattle Structural measured the diameter of 81 piles at the mudline during construction administration of the piling replacement and renovation of Aquarium Pier 59 in 2005. Steel replacement piles were erected on the stub piles that remained. The average least diameter of the piles at the mudline was 12.8 inches.

Pile lengths were determined from the 1973 construction drawings for Pier 58. Sounding elevations of the mudline are given on sheet A2. Top of pile elevations were obtained from the structural drawings and details. Typically piles are assumed to develop fixity 5-10 feet below the mudline. We used 7 feet below the mudline in our calculations for consistency with the calculations in the report by Echelon in 2000. The

average timber pile is 44 feet tall above the assumed point of fixity, the average Monotube pile is 42 feet, and the average steel H-pile along the seawall is 30 feet.

Pier 58

The seismic loading requirements in the current building code are more stringent than in 1973. If the timber structure were isolated from the other portions, our analysis indicates it could resist a design level earthquake because it has a large number of piles supporting a relatively small mass. The concrete portions have large masses and relatively few Monotube piles, steel H-piles and timber piles. Pier 58 as a whole does not have sufficient strength for a design level earthquake.

The prevailing wind and wave direction push Pier 58 toward the seawall. We do not anticipate a failure due to wind because of the sheltering provided by the seawall and adjacent structures. Wave forces could damage or fail an isolated timber pile that has been weakened by marine borers at or a few feet above the mudline.

The specified timber pile bearing capacity is 20 tons. A typical timber pile supports a dead load of 1.5 tons. A uniform design live load of 100 psf imposes an additional axial load of 7 tons.

The tower columns are each supported by 2 timber piles each at Pier 58. The pile ratings are 90% or better for all piles supporting tower columns. The most heavily loaded piles support the tower and the bridge.

Some or all of the H-piles once had a cathodic protection system that was not maintained and is no longer operational. The cathodic protection system probably delayed the onset of corrosion while it was functional.

Piers 57 and 57N

The tower columns supported by Pier 57N carry substantial axial load but they are not as heavily loaded as the columns which also support the bridge. The columns are supported by beams spanning between bents which bear on the pile-supported bent caps. The bents typically have 4-7 piles each, of which, (3) piles are more or less directly below the tower support beams. The other piles help to support the stringers and deck.

The load when shared by the (3) piles according to their capacity, is equivalent to 20 tons per pile for dead load plus the design live load of 100 psf. Assuming Pier 57N piles have the same initial 20-ton design capacity as the Pier 58 piles, the corner column has satisfactory support based on our observations of the current conditions. Similarly, the piles supporting one of the interior columns and piles supporting the stair column have sufficient capacity to support dead plus design live load even though some piles have lost significant cross sectional area.

Adjacent piles support the column dead load through cantilever action of the bent cap and continuity of the stringers, but there is little capacity remaining for any live load. A potential failure mechanism is settlement of the column and uplift at the other end of the bent cap. There has been no failure as it is unlikely the tower has been loaded with the 100 psf design live load as a realistic live load for people dispersed over a large area is 5 psf. Based on these observations we recommend replacement of piles directly under tower columns.

We expect that the new galvanized steel pile cap and piles which support one corner column of the tower are designed to support its load. No other tower columns are supported by Pier 57 piles.

CONCLUSIONS AND RECOMMENDATIONS

In consideration of tight budgetary constraints, the least cost actions that we recommend for Pier 58 are as follows:

1. Ban vehicular traffic to all areas of Pier 58. Post a notice of the vehicle ban. Enforce the ban by installing bollards at access points. If a vehicle needs access, a structural engineer should evaluate the proposed vehicle loading prior to approval and access.
2. Do not encourage large groups of people to congregate in any area of Pier 58.
3. Conduct annual row-throughs under the pier to identify apparent deficient piles and/or superstructure. A row-through was conducted this year for this report so the first annual row-through should begin in 2012.
4. Conduct annual load tests of piles and areas suspected of having deficient capacity. We recommend using a 6,000 lb vehicle (30 psf) to load the test areas. Measure the deflection of the deck to determine if there is any unusual or excessive movement. This test should be conducted or supervised by a structural engineer. The first test should be conducted in 2011 to have a baseline of deflection data for future reference.
5. Begin planning now for one of the following possible actions for the south observatory tower and bridge:
    a. Plan and budget for the removal the tower and bridge, or
    b. Plan and budget for maintenance of Pier 57N piles that support tower columns. We estimate (8) replacement piles are required at this time. This quantity will maintain the pier in a safe condition over the next 10 years. The approval process will be smoothest if the replacement piles are steel but the cost will be lower with treated timber piles.
6. The concrete superstructures of the north and south terraces, the north terrace apron, and the promenade will eventually need to be repaired, replaced, or demolished. The north terrace in particular has serious reinforcing steel corrosion that may not be accelerating at this time but is on-going. All of these areas are supported by Monotube piles and steel H-piles that have serious corrosion. The cost of repairs or replacement would be high.

APPENDIX A

Pier 58 Timber Pile Ratings

Appendix A: Pier 58 Timber Pile Ratings

BENT	PILE NO.	% CAPACITY REMAINING			REMARKS
		2000	2006	2011	
1	14	100%	NR	25%	
	15	100%	NR	75%	
	16	100%	NR	75%	
	17	100%	NR	50%	
	18	100%	NR	90%	
	19	100%	NR	75%	
	20	90%	NR	75%	
	21	90%	NR	75%	
2	3	90%	75%	90%	
	4	100%	25%	50%	
	5	90%	50%	90%	
	6	90%	90%	90%	
	7	90%	90%	25%	
	8	75%	75%	0%	
	9	100%	90%	75%	
	11	50%	25%	25%	
	12	90%	75%	75%	
	13	90%	75%	75%	
	14	90%	90%	75%	
	15	90%	75%	75%	
	16	90%	50%	50%	
	17	90%	75%	90%	
	18	90%	90%	90%	
	19	90%	90%	90%	
	20	90%	75%	75%	
	21	90%	50%	25%	
	22	90%	75%	75%	
	23	90%	75%	50%	
	24	90%	75%	75%	
	25	90%	50%	25%	
	26	90%	75%	75%	
	27	100%	90%	90%	
3A	1	90%	NR	50%	
	2	75%	90%	50%	
	3	100%	75%	75%	
	4	90%	90%	50%	
	5	90%	90%	50%	
	6	90%	90%	75%	
	7	100%	90%	50%	
3	1	100%	90%	75%	

NR = not rated

Appendix A: Pier 58 Timber Pile Ratings

BENT	PILE NO.	% CAPACITY REMAINING			REMARKS
		2000	2006	2011	
3	2	90%	90%	NR	
	3	100%	90%	NR	
	4	100%	90%	NR	
	5	90%	90%	NR	
	7	90%	90%	NR	
	8	90%	90%	NR	
	9	90%	75%	NR	
	10	100%	90%	NR	
	11	100%	100%	NR	
	12	90%	75%	NR	
	13	90%	75%	NR	
	14	90%	90%	NR	
	15	90%	75%	NR	
	16	90%	90%	NR	
	17	90%	50%	NR	
	18	75%	90%	NR	
	19	90%	90%	NR	
3.5	1	100%	90%	NR	
	2	100%	90%	NR	
	3	90%	90%	NR	
	4	100%	75%	NR	
4A	1	90%	90%	50%	
	2	90%	90%	75%	
	3	90%	90%	50%	
	4	90%	NR	50%	
	5	90%	75%	50%	
	6	90%	25%	75%	
	7	90%	90%	50%	
	8	90%	90%	50%	
	9	90%	90%	75%	
	10	90%	75%	75%	
	11	100%	90%	75%	
	12	90%	90%	50%	
	13	90%	75%	50%	
	14	100%	75%	50%	
	15	90%	75%	75%	
	16	90%	25%	50%	
4	1	100%	90%	75%	
	2	100%	90%	NR	
	3	100%	90%	NR	

NR = not rated

Appendix A: Pier 58 Timber Pile Ratings

BENT	PILE NO.	% CAPACITY REMAINING			REMARKS
		2000	2006	2011	
4	4	100%	90%	NR	
	5	100%	90%	NR	
	6	90%	90%	NR	
	7	100%	90%	NR	
	8	90%	90%	NR	
	9	90%	75%	NR	
	10	90%	75%	NR	
	11	100%	90%	NR	
	12	90%	75%	NR	
	13	90%	75%	NR	
	14	100%	90%	NR	
	15	90%	75%	NR	
	16	100%	75%	NR	
4.3	1	90%	NR	NR	Pile F-4
4.5	1	100%	90%	NR	
	2	90%	90%	NR	
4.7	1	90%	NR	NR	Pile F-7
4.9	1	90%	NR	NR	Pile F-5
5A	1	90%	90%	50%	
	2	100%	75%	75%	
	3	100%	90%	75%	
	4	90%	75%	75%	
	5	90%	90%	75%	
	6	90%	90%	75%	
5	1	90%	90%	75%	
	2	100%	90%	NR	
	3	90%	90%	NR	
	4	100%	90%	NR	
	5	100%	90%	NR	
	6	90%	90%	NR	
	7	100%	90%	NR	
	8	90%	90%	NR	
	9	100%	90%	NR	
	10	90%	90%	NR	
	11	90%	90%	NR	
	12	90%	75%	NR	
	13	90%	90%	NR	
	14	90%	75%	NR	
	15	100%	90%	NR	
	16	90%	75%	NR	

NR = not rated

Appendix A: Pier 58 Timber Pile Ratings

BENT	PILE NO.	% CAPACITY REMAINING			REMARKS
		2000	2006	2011	
5	17	50%	0%	NR	
5.5	1	90%	NR	NR	Pile F-6
6A	1	90%	90%	50%	
	2	90%	90%	50%	
	3	90%	75%	50%	
	4	90%	75%	75%	
	5	100%	90%	75%	
6	1	25%	50%	75%	
	2	90%	75%	50%	
	3	75%	75%	50%	
	4	90%	90%	50%	
	5	50%	90%	75%	
	6	100%	90%	75%	
	7	90%	90%	75%	
	8	100%	90%	75%	
	9	90%	90%	75%	
	10	100%	90%	50%	
	11	100%	90%	50%	
	12	90%	75%	50%	
	13	75%	25%	25%	
	14	90%	75%	50%	
	15	100%	100%	75%	
7	1	90%	75%	75%	
	2	90%	75%	75%	
	3	90%	90%	50%	
	4	100%	90%	50%	
	5	50%	90%	50%	
	6	100%	90%	50%	
	7	100%	75%	75%	
	8	100%	90%	75%	
	11	100%	90%	75%	
	12	100%	75%	75%	
	13	90%	90%	75%	
	14	90%	75%	50%	
7.5	1	90%	75%	NR	
	2	90%	75%	NR	
7.9	1	NR	75%	NR	
8	1	90%	90%	NR	
	2	90%	90%	NR	
	3	90%	50%	NR	

NR = not rated

Appendix A: Pier 58 Timber Pile Ratings

BENT	PILE NO.	% CAPACITY REMAINING			REMARKS
		2000	2006	2011	
8	4	90%	75%	NR	
	5	90%	75%	NR	
	6	90%	90%	NR	
	7	90%	50%	NR	
	8	90%	50%	NR	
	9	100%	90%	NR	
	10	90%	90%	NR	
	11	100%	100%	NR	
	12	90%	90%	NR	
	13	90%	75%	NR	
	14	90%	90%	NR	
	15	90%	90%	NR	
	16	90%	90%	NR	
9	1	90%	75%	NR	
	2	75%	75%	NR	
	3	100%	100%	NR	
	4	75%	75%	NR	
	5	75%	75%	NR	
	6	90%	90%	NR	
	7	90%	75%	NR	
	8	100%	90%	NR	
	9	100%	90%	NR	
	10	90%	90%	NR	
	11	90%	90%	NR	
	12	90%	90%	NR	
	13	90%	90%	NR	
	14	100%	90%	NR	
	15	90%	100%	NR	
	16	100%	90%	NR	
	17	90%	90%	NR	
9.5	3	90%	90%	NR	
	4	90%	75%	NR	
10	1	75%	90%	NR	
	1.1	90%	90%	NR	
	2	75%	90%	NR	
	3	75%	90%	NR	
	4	100%	75%	NR	
	5	75%	90%	NR	
	6	25%	90%	NR	
	7	100%	0%	NR	

NR = not rated

Appendix A: Pier 58 Timber Pile Ratings

BENT	PILE NO.	% CAPACITY REMAINING			REMARKS
		2000	2006	2011	
10	8	100%	75%	NR	
	9	50%	100%	NR	
	10	90%	75%	NR	
	11	100%	75%	NR	
	12	100%	90%	NR	
	13	100%	90%	NR	
	14	90%	75%	NR	
	15	90%	75%	NR	
	16	90%	90%	NR	
	17	90%	90%	NR	
	18	90%	75%	NR	
	19	90%	90%	NR	
11	1	90%	90%	NR	
	2	90%	90%	NR	
	3	75%	90%	NR	
	4	90%	75%	NR	
	5	75%	50%	NR	
	6	90%	75%	NR	
	7	50%	90%	NR	
	8	100%	90%	NR	
	9	100%	50%	NR	
	10	90%	75%	NR	
	11	100%	90%	NR	
	12	90%	90%	NR	
	13	100%	100%	NR	
	14	90%	75%	NR	
	15	90%	75%	NR	
	16	90%	90%	NR	
	17	100%	100%	NR	
12	1	90%	90%	NR	
	2	100%	90%	NR	
	3	75%	75%	NR	
	4	75%	90%	NR	
	5	75%	90%	NR	
	6	100%	90%	NR	
	7	90%	90%	NR	
	8	100%	90%	NR	
	9	90%	75%	NR	
	10	90%	90%	NR	
	11	0%	90%	NR	

NR = not rated

Appendix A: Pier 58 Timber Pile Ratings

BENT	PILE NO.	% CAPACITY REMAINING			REMARKS
		2000	2006	2011	
12	12	90%	90%	NR	
	13	90%	75%	NR	
	14	90%	75%	NR	
	15	90%	90%	NR	
12.5	1	75%	90%	90%	
	2	100%	90%	90%	
	3	90%	90%	90%	
	4	100%	90%	90%	
13	1	90%	90%	NR	
	2	90%	90%	NR	
	3	90%	90%	NR	
	4	90%	75%	NR	
	5	100%	90%	NR	
	6	90%	90%	NR	
	7	50%	90%	NR	
	8	90%	75%	NR	
	9	90%	NR	NR	
13.2	1	90%	90%	90%	
	2	90%	90%	90%	
14	1	90%	75%	NR	
	2	90%	75%	NR	
	3	90%	90%	NR	
	4	90%	75%	NR	
	5	100%	90%	NR	
	6	90%	90%	NR	
	7	90%	75%	NR	
	8	90%	90%	NR	
	9	75%	50%	NR	
14.2	1	90%	75%	90%	
	2	90%	90%	90%	
14.5	1	90%	75%	NR	
14.7	1	90%	90%	NR	
	2	100%	75%	NR	
	3	0%	75%	NR	
	4	90%	75%	NR	
14.8	1	90%	100%	90%	
	2	100%	100%	90%	
15	1	75%	75%	50%	
	2	90%	50%	75%	
	3	90%	75%	50%	

NR = not rated

Appendix A: Pier 58 Timber Pile Ratings

BENT	PILE NO.	% CAPACITY REMAINING			REMARKS
		2000	2006	2011	
15	6	90%	75%	75%	
	7	75%	25%	90%	
	8	75%	75%	25%	
	9N	25%	75%	75%	
	9	90%	90%	90%	
	12	90%	100%	90%	
15.1	1	90%	50%	NR	
15.3	1	90%	NR	NR	
	2	90%	NR	NR	
15.5	1	75%	90%	NR	
	2	75%	90%	NR	
	3	75%	90%	NR	
	4	100%	90%	NR	
15.8	1	90%	90%	NR	
15.9	1	90%	50%	75%	
	2	75%	90%	NR	
	3	90%	50%	NR	
16	1	90%	75%	75%	
	2	90%	50%	75%	
	3	90%	90%	75%	
	4	90%	50%	75%	
	5	90%	75%	50%	
	6	75%	90%	50%	
	7	75%	75%	NR	
16.1	1	90%	90%	NR	
16.5	1	90%	75%	NR	
	2	75%	50%	NR	
17	1	75%	25%	50%	
	2	90%	50%	75%	
	3	90%	75%	75%	
	4	90%	50%	50%	
	5	90%	50%	50%	
	6	90%	75%	75%	
	7	100%	90%	75%	
17.3	1	90%	75%	NR	
	2	90%	50%	NR	
18	1	25%	50%	50%	
	2	50%	75%	75%	
	3	90%	75%	75%	
	4	75%	50%	75%	

NR = not rated

Appendix A: Pier 58 Timber Pile Ratings

BENT	PILE NO.	% CAPACITY REMAINING			REMARKS
		2000	2006	2011	
18	5	90%	50%	50%	
	6	50%	75%	75%	
	7	50%	90%	75%	
RR	1	75%	50%	NR	
	2	90%	90%	NR	
SS	1	90%	75%	NR	
	2	90%	90%	NR	
TT	1	100%	90%	NR	
	2	90%	90%	NR	
UU	1	75%	75%	NR	
VV	1	90%	75%	NR	
	2	90%	75%	NR	
	3	75%	90%	NR	
WW	1	90%	75%	NR	
XX	1	75%	90%	NR	
	2	90%	75%	NR	
	3	100%	100%	NR	
YY	1	75%	75%	NR	
	2	75%	75%	NR	

NR = not rated

APPENDIX B

Pier 58 Steel Pile Ratings

Appendix B: Pier 58 Steel Pile Ratings

PILE NO.	PILE TYPE	% CAPACITY REMAINING		REMARKS
		2006	2011	
1	H	100%	75%	
2	H	75%	75%	
3	H	75%	75%	
4	H	75%	75%	
5	H	75%	75%	
6	H	75%	75%	
7	H	75%	75%	
8	H	75%	75%	
9	H	75%	75%	
10	H	75%	75%	
11	H	75%	75%	
12	Monotube	25%	25%	
13	Monotube	25%	25%	
14	Monotube	25%	25%	
15	Monotube	25%	25%	
16	Monotube	25%	25%	
17	Monotube	25%	25%	
18	Monotube	25%	25%	
19	H	25%	25%	
20	H	25%	25%	
21	H	25%	25%	
22	H	25%	25%	
23	no pile			
24	no pile			
25	Monotube	25%	25%	
26	Monotube	25%	25%	
27	Monotube	25%	25%	
28	Monotube	25%	25%	
29	Monotube	25%	25%	
30	Monotube	25%	25%	
31	Monotube	25%	25%	
32	Monotube	25%	25%	
33	Monotube	25%	25%	
34	Monotube	25%	25%	
35	Monotube	25%	25%	
36	Monotube	25%	25%	
37	Monotube	25%	25%	
38	Monotube	25%	25%	
39	Monotube	25%	25%	
40	Monotube	25%	25%	

Appendix B: Pier 58 Steel Pile Ratings

PILE NO.	PILE TYPE	% CAPACITY REMAINING		REMARKS
		2006	2011	
41	Monotube	25%	25%	
42	Monotube	25%	25%	
43	Monotube	25%	25%	
44	Monotube	25%	25%	
45	H	25%	25%	
46	H	25%	25%	
47	H	25%	25%	
48	H	25%	25%	
49	H	25%	25%	
50	H	75%	75%	
51	H	25%	25%	
52	H	25%	25%	
53	H	25%	25%	
54	H	25%	25%	
55	H	25%	25%	
56	H	25%	25%	
57	H	25%	25%	
58	H	25%	25%	
59	H	25%	25%	
60	H	25%	25%	
61	H	25%	25%	
62	H	25%	25%	
63	H	25%	25%	
64	H	25%	25%	
65	H	25%	25%	
66	H	25%	25%	
67	H	25%	25%	
68	H	25%	25%	
69	H	25%	25%	
70	H	25%	25%	
71	H	25%	25%	
72	H	25%	25%	
73	H	25%	25%	
74	H	25%	25%	
75	H	25%	25%	
76	H	25%	25%	
77	H	25%	25%	
77A	H	25%	25%	does not support pile cap - short pile
78	H	25%	25%	does not support pile cap
79	Monotube	25%	25%	

Appendix B: Pier 58 Steel Pile Ratings

PILE NO.	PILE TYPE	% CAPACITY REMAINING		REMARKS
		2006	2011	
80	Monotube	25%	25%	
81	Monotube	25%	25%	
82	Monotube	25%	25%	
83	Monotube	25%	25%	
84	Monotube	25%	25%	
85	Monotube	25%	25%	
86	Monotube	50%	50%	
87	Monotube	25%	25%	
88	Monotube	25%	25%	
89	Monotube	25%	25%	
90	Monotube	25%	25%	
91	Monotube	50%	50%	
92	Monotube	50%	50%	
93	Monotube	50%	50%	
94	Monotube	50%	50%	
95	Monotube	50%	50%	
96	Monotube	50%	50%	
97	Monotube	50%	50%	
98	Monotube	50%	50%	
99	Monotube	50%	50%	
100	Monotube	50%	50%	
101	Monotube	50%	50%	
102	Monotube	25%	25%	
103	Monotube	25%	25%	
104	Monotube	25%	25%	
105	Monotube	50%	50%	
106	Monotube	50%	50%	
107	Monotube	25%	25%	
108	Monotube	50%	50%	
109	Monotube	25%	25%	
110	Monotube	25%	25%	
111	Monotube	25%	25%	
112	Monotube	25%	25%	
113	Monotube	25%	25%	
114	Monotube	25%	25%	
115	Monotube	25%	25%	
116	Monotube	25%	25%	
117	Monotube	25%	25%	
118	Monotube	25%	25%	
119	Monotube	25%	25%	

Appendix B: Pier 58 Steel Pile Ratings

PILE NO.	PILE TYPE	% CAPACITY REMAINING		REMARKS
		2006	2011	
120	Monotube	25%	25%	
121	Monotube	25%	25%	
122	Monotube	25%	25%	
123	Monotube	25%	25%	
124	Monotube	25%	25%	
125	Monotube	25%	25%	
126	Monotube	25%	25%	
127	Monotube	25%	25%	
128	Monotube	25%	25%	
129	Monotube	25%	25%	
130	Monotube	25%	25%	
130A	Monotube	25%	25%	
131	Monotube	25%	25%	
132	Monotube	25%	25%	
133	Monotube	25%	25%	
134	Monotube	25%	25%	

APPENDIX C

Pier 57N Timber Pile Ratings for Piles Supporting the South Observatory and Bridge

Appendix C: Pier 57N Timber Pile Ratings for Piles Supporting the South Observatory and Bridge

BENT	PILE NO.	% CAPACITY REMAINING			REMARKS
		2000	2006	2011	
17N	1	50%	75%	75%	
	2	0%	75%	50%	
	3	100%	90%	75%	
	4	0%	75%	NR	
	5	90%	75%	NR	
	6	0%	90%	NR	
	7	90%	0%	NR	
18N	1	0%	0%	0%	
	2	90%	25%	50%	
	3	75%	25%	75%	
	4	50%	25%	NR	
	5	0%	0%	NR	
	6	75%	50%	NR	
19N	1	50%	0%	NR	
	2	75%	25%	NR	
	3	75%	25%	50%	
	4	75%	0%	25%	
	5	75%	50%	75%	
20N	1	90%	75%	NR	
	2	0%	0%	50%	
	3	90%	75%	0%	
	4	0%	0%	NR	
21N	1	0%	0%	NR	
	2	50%	0%	NR	
	3	90%	90%	50%	
	4	90%	90%	50%	
	5	75%	50%	NR	
	6	0%	0%	NR	
22N	1	0%	0%	NR	
	2	90%	50%	0%	
	4	0%	0%	25%	
	5	75%	0%	NR	

NR = not rated

APPENDIX D

Global Diving Wood Pile Inspection Log

GLOBAL
Diving & Salvage, Inc.

June 28, 2011

Seattle Structural PS, Inc.
1420 5th Ave
Suite 425
Seattle, WA 98106

Attn: Mr. Michael Braun
Re: Seattle Parks Pier 58 Waterfront Park Condition Assessment

On June 2, 2011 **Global Diving and Salvage Inc**. performed an underwater inspection of selected piles on Pier 58, Waterfront Park, Seattle, WA. Inspecting diver was Dan Gilchrist. Purpose of the inspection was to ascertain the condition of the piles as compared to a survey performed by Global Diving in March of 2006. Diver inspected piles as directed by the attending representatives from Seattle Structural PS, Inc.

The dive was performed from a dive support vessel using surface supplied dive gear with two way communications. A video camera and light was used to monitor the diver and to record his findings. Visibility at the time of the dive was approximately 8 feet.

The diver performed a Level I inspection, relying primarily on visual and/or tactile observations to make condition assessments. Individual observations on each pile inspected are included in the Wood Pile Inspection Logs attached. Bent and pile designation were determined using drawings supplied by Seattle Structural. Records of the dive are also provided in this report.

Submitted without prejudice
Global Diving & Salvage, Inc.

Mike Langen
Construction Division Manager

3840 W Marginal Way SW • Seattle, WA 98106 • WWW.GDIVING.COM • 24 Hr: (206) 623-0621 • Fax: (206) 932-9036

Association of Diving Contractors International
American Salvage Association
AGC of America
THE ASSOCIATED GENERAL CONTRACTORS OF AMERICA
Quality People. Quality Projects.

GLOBAL DIVING & SALVAGE,INC.

WOOD PILE INSPECTION LOG

W/O: 106298

Date: 6/2/11

Customer: Seattle Structural PS, Inc.

Location: Pier ~~58~~ 57, Seattle, WA

BENT	PILE	Damage Type	Damage Location	% Sound Wood	Time	DAMAGE/REMARKS	
15	1	/		90	1135	GOOD COND.	1/8 PUNK
	2	/		90	1136	" "	1/8 PUNK
	3	WORMS		85	1138	@ MUDLINE SMALL WORMS	1/4 PUNK
	4	/		85	1140	" "	1/4
14.2	1	WORMS		90	1142	INTERMITTEN WORM HOLES & @ MUDLINE	1/8
	2	WORMS		90	1143	@ MUDLINE & INTERMITTEN	1/4
13.2	1	/		90	1145	GOOD COND.	1/8
	2	WORMS		90	1147	@ MUDLINE INTERMITTEN	1/8
12.5	1	WORMS		85	1150	SMALL WORMS @ MUDLINE	1/4
	2	/		90	1152	GOOD COND.	1/8
	3	/		90	1154	GOOD COND.	1/8
	4	WORMS		85	1157	SMALL WORMS @ TOP	1/8

OVER

GLOBAL DIVING & SALVAGE,INC.

WOOD PILE INSPECTION LOG

W/O: 106298 ~~104704~~

Date: 6/2/11

Customer: Tinnea & Associates

Location: PIER 57 SEATTLE, WA

BENT	PILE	Damage Type	LOCATION Face	LOCATION Elev	TIME	DAMAGE / REMARKS
17N	1	75%			1203	1/4 punk small worms @ mudline
	2	50%			1204	1/8 punk A lot of worms @ mudline, Hole @ 19' 6"
						Long penetrates 5", intermitten worms towards surface
	3	75%			1210	1/4 punk worms @ bottom sprak. @ mudline
18N	2	50%			1213	1/4 punk Split @ mudline up to 12' anothe small on on S. side
	3	75%			1215	1/4 punk 3"x 4" Hole @ mudline / Small worms overall
19N	5	65%			1223	1/4 punk sprak. worms overall
	4	20-30			1225	1/4 punk 7"x 3" pent. 6"
	3	40-50			1228	1/4 punk mudline worms A lot of worms overall
20N	2	60-65			1246	1/4 punk mudline worms, inter. worms holes
	3	Ø			1249	1/4 punk Sprak. worms overall
21N	3	40-45			1252	1/4 punk Sprak. worms
	4	40-45			1255	1/4 punk Sprak. worms & @ mudline
22N	2	0-15			1302	1/4 punk Southside Hole @ 15' 6"x3"x4" Deep, 3FT + Northside
	3					3"x3" Hole 4'+ Hole 4"x3" + @ mudline 3"x2" Hole

KEY: CH-Chips (<1/2"X1/2"X1/2"); CON-Concrete; DAM-Damage; FC-Full Circle; HLF-Hair Line Fracture; L.E.-Lifting Eye
M/L-Mudline; SP - Spall; W/L-Waterline

GLOBAL DIVING & SALVAGE,INC.
WOOD PILE INSPECTION LOG

W/O: 106298 ~~104704~~

Date: 6/2/11

Customer: Tinnea & Associates

Location: PIER 57 SEATTLE WA

BENT	PILE	Damage Type	LOCATION Face	LOCATION Elev	TIME	DAMAGE / REMARKS
22N	3	25-30%			1305	1/4 PUNK VERTICAL SPLITTING @ MUDLINE SOME SMALL WORMS
						SPRAK. OVERALL

KEY: CH-Chips (<1/2"X1/2"X1/2"); CON-Concrete; DAM-Damage; FC-Full Circle; HLF-Hair Line Fracture; L.E.-Lifting Eye
M/L-Mudline; SP - Spall; W/L-Waterline

GLOBAL DIVING & SALVAGE, INC.

WOOD PILE INSPECTION LOG

W/O: 106798

Date: ~~13~~ 2-Jun-11

Customer: City of Seattle / Seattle Structural

Location: Pier 58 - South of Concrete Firewall at Grid Q

BENT	PILE	Damage Type	Damage Location	% Sound Wood	Time	DAMAGE / REMARKS
S 7	1			1/4 punk 70%	1331	28' Good Cond.
	2			1/4 punk 65%	1334	mudline worms, Spraf worms ~~throughout~~ overall
	3			1/4 70%	1336	" "
	4			1/4 70%	1338	" " Spraf worms overall
	5			1/4 70%	1341	" "
	6			1/4 70%	1345	" "
	7			1/4 75%	1348	
	8			1/4 60%	1351	Spraf worms overall
6	~~9~~ 10			1/4 75%	1357	o/d stbd pile
	~~10~~ 9			1/4 60-65%	1400	worms above waterline, Spraf worms
	~~11~~ 8			1/4 10-15%	1403	@ mudline South side & N.E. side big holes, consistant going up
	~~12~~ 7			1/4 45-50	1406	Just below surf. worms from mudline 5' up worms
~~5~~	~~1~~ 6			1/4 60%	1410	mudline worms, change out DVD
	2 5			1/4 60%	1418	North side 6' bad worms + @ mudline
	3 4			1/4 65%	1420	mudline worms
	4 3			1/4 70	1423	mudline worms
	5 2			1/4 70	1426	mudline worms

2

GLOBAL DIVING & SALVAGE,INC.

WOOD PILE INSPECTION LOG

W/O: 106298

Date: 6/2/11

Customer: Seattle Structural PS, Inc.

Location: Pier 58, Seattle, WA

BENT	PILE	Damage Type	Damage Location	% Sound Wood	Time	DAMAGE/REMARKS
18	7	Ø	10' of Surf	80	0816	Barnacle/ Growth 1/4 mudline Good
	6	worm	10' off B	75		mud line Good 1/4 / 10' from Surf 1 tellow
	5	worm	30'	50-60	0823	30' worm Dam N.W. / mudline worms 1 tellow
	4	worm		70	0827	@ mudline small worm
	3	worm	7' off B	70	0831	7" off Bottom worm
	2	worm		65-70	0833	@ mudline worm
	1	worm		60	0835	worm holes @ mud pile
17 1	8	worm		40	0839	6' off B slot of D on the pile mid
2	2	worms		70	0841	8 25' from Surf. Dam / mud line too worms
3	8	Ø	Ø	80	0843	mudline Good
4	4	worms		60	0845	6' off Bottom small worms @ @ mudline S.W face
5	3	worms		60	0848	3' off B.
6	4	worms		70	0851	from mudline to 6' off B. all worms
7	4	Ø	Ø	70	0854	— mudline Good
16 7	8			45-50	0857	9' off B 1" in down to mud line
	6			60	0900	
	5			75-80	0902	@ mudline worms

@ waters line heavy marine growth 1/4 pinnacle

1/4 pinnacle

GLOBAL DIVING & SALVAGE,INC.

WOOD PILE INSPECTION LOG

W/O: 106298

Date: 6/2/11

Customer: Seattle Structural PS, Inc.

Location: Pier 58, Seattle, WA

BENT	PILE	Damage Type	Damage Location	% Sound Wood	Time	DAMAGE/REMARKS
16	4	worms		70	0905	@ mudline worms / 10' ~~+~~ from surf worms
3	~~5~~	worms		70	0907	@ mudline worms
2	~~6~~	worms		75	0909	@ mudline worms
15.8 1	~~7~~	worms		80	0911	@ mudline
15	1	worms		60	0915	~~[illegible]~~ ~~[illegible]~~ ~~[illegible]~~ @ 21' down to mud
	2	worms		75	0918	@ ~~[illegible]~~ from mud to 9' off B. ~~[illegible]~~ N.W. side
	3	worms		60	0921	@ 18' west face worm D / mudline up to 6' worms
	4	worms		70	0924	6' from mudline small worms
	5	worms		90	0926	Small worms @ mudline
	6	worms		30	0928	5' off mud and @ mud / real spongy
	7	worms		65	0930	~~[illegible]~~ from mudline to 7' " "

1/4" panel

Pile Report Pier 58.xls

GLOBAL DIVING & SALVAGE,INC.

WOOD PILE INSPECTION LOG

W/O: 106298

Date: 6/2/11

Customer: Seattle Structural PS, Inc.

Location: Pier 58, Seattle, WA

BENT	PILE	Damage Type	Damage Location	% Sound Wood	Time	DAMAGE/REMARKS
6	1	WORMS		75	0958	14') N. SIDE 3' OFF B
6A	1	WORMS		75	0959	MUDLINE WORMS
6A	2	WORMS		75	1000	MUDLINE WORMS
6A	3	WORMS		60	1001	MUDLINE WORMS 6' UP FROM MUD N. SIDE
6A	4	WORMS		40	1003	WHOLE PILE WORMS
5A	5	WORMS		60	1014	@ MUDLINE
5A	4			75	1011	MUDLINE
5A	3	WORMS	S	65	10009	@ MUDLINE
5A	2	WORMS	W	70	1008	@ MUDLINE
5A	1			70	10:5	
4	1			75	1017	@ MUDLINE
4A	1	WORMS	E & N	50	1018	@ MUDLINE TO SURFACE
4A	3	WORMS		75	1020	" "
4A	4	WORMS		50	1021	" "
4A	5	WORMS		50	1022	" "
4A	6			40	1022	@ MUDLINE
4A	7			75	1024	@ MUDLINE

WORMS @ MUDLINE BOTH SIDE 5A #6 5 #7

1/4 JUNKED

GLOBAL DIVING & SALVAGE,INC.

WOOD PILE INSPECTION LOG

W/O: 106298

Date: 6/2/11

Customer: Seattle Structural PS, Inc.

Location: Pier 58, Seattle, WA

BENT	PILE	Damage Type	Damage Location	% Sound Wood	Time	DAMAGE/REMARKS
4A	8	worms		75	1025	@ mudline
	9			65	1025	@ mudline
	10			60	1026	@ mudline
	11			100	1027	@ mudline
	12			65	1028	@ mudline
	13			50	1028	@ mudline
	14			50	1029	@ mudline
	15			60	1030	@ mudline
	16			70	1031	@ mudline
	17			60	1033	@ mudline
3	1			75	1037	only in 5' of water
3A	1			40	1038	
3A	2			70	1039	
3A	3	worms		70	1039	@ mudline sponging
3A	4	worms		60	1040	@ mudline only 3' of water
3A	5	worms		70	1043	@ mudline small
3A	6	worms		50	1043	@ mudline
3A	7	worms		50	1044	@ mudline

1/4 punch

APPENDIX E

Pier 57, 58, and 60
Corrosion & Condition Investigation Report
Executive Summary
by Tinnea & Associates
July, 2006

Executive Summary

Condition inspections were performed on Piers 57, 58 and 60 as part of an ongoing maintenance program by the City of Seattle Department of Parks and Recreation (Parks). The inspection team was headed by Tinnea & Associates, LLC, and included a structural engineering firm, Seattle Structural PS, Inc. (Seattle Structural) and an underwater inspection firm, Global Diving and Salvage, Inc (Global Diving).

Key findings can be found below and are organized by facility. All estimates are expressed in 2006 dollars and are rough order of magnitude (ROM) construction costs. If Parks would prefer project costs for the final report the team will need to be provided with appropriate multipliers.

Seattle Structural estimates typical pile replacement at $4,000 per pile using timber piles and $10,000 per pile using steel piles. When considering extending service life to 25 years, Seattle Structural estimates that Parks should expect the existing timber piles on Piers 57, 58 and 60 to deteriorate at rate a rate that will necessitate replacing approximately 25% of those piles by the end of each 5-year inspection cycle.

Immediate Recommendations

Load Restrictions

If no repairs are made, the following immediate load restrictions are recommended.

Pier 57 North Apron

Seattle Structural recommends restricting vehicle traffic to the Pier 57 North Apron. The east end of the apron should be restricted with vehicle wheel load limits of 1,000 pounds per wheel. Pedestrian access to the west end is acceptable, but vehicle access should be prohibited.

Pier 58

Vehicle access to the portions of the timber Pier 58 with deficient piles should be restricted. As vehicle accessibility is from the Pier 57 North Apron, implementation of the load limits recommended above will limit the size of vehicles on the timber portions of Pier 58.

Pier 60

Seattle Structural recommends that the timber areas of Pier 60 should be restricted to pedestrians only. Vehicles should not drive or park on Pier 60, particularly in the areas, such as near the Director's parking space, where Global Diving rated the pilings with 0% remaining capacity. Only two piles in the area of the north loading dock show significant loss, so deliveries can continue.

Repairs or Demolition

Pier 57 North Apron

Limiting loads will allow extending the apron's use until the 2009-2010 biennium. Some North Apron pile caps, beams, and joists are shared with the contiguous commercially-owned Pier 57. This means that work on the Seattle-owned portion of Pier 58 will structurally affect the adjacent privately-owned property. The City should inform those commercial significant others of the load limit recommendations. Seattle Structural estimates that to bring the North Apron up to near-design capacity will require replacing 90 piles at a cost ranging from $360,000 for timber pile replacements to $900,000 for steel pile replacements. To demolish and replace the North Apron is estimated to cost about $1,100,000.

Pier 58 – Timber Areas

It would be necessary to replace from 10 to 35 timber piles to bring the timber portion of Pier 58 to near-design capacity. Enforcing Pier 57 North Apron load limits allows reasonably safe deferral until the 2009-2010 biennium.

Pier 58 – Terraces & Promenade

To repair cracks and delaminations in several North and South Terrace concrete beams is estimated to cost $35,000. Given previous problems encountered with full-section localized corrosion of rebar on beams supporting the Pier 58 North Terrace, concrete repair areas should be checked for localized rebar corrosion prior to issuing construction documents.

Seattle Structural recommends strengthening all the Monotubes®, with reinforced concrete jackets at a cost of $340,000. They also recommend coating the H-piles in the upper tidal and splash zones for an estimated cost of $100,000. The total recommended costs to provide an approximate 5-year life upgrade is $475,000.

In lieu of these immediate repairs, Parks could implement a program of load restrictions and restricted access. The costs for such a program would be minimal, but the City should understand that in doing so they incur a seismic risk as the potential would remain for partial or total collapse of the concrete structure(s) during an earthquake and the possibility of collateral damage to the surrounding timber structure.

Pier 58 – Terraces & Promenade Demolition

Parks could demolish parts or all of the reinforced concrete North and South Terraces. If portions are retained, they should be repaired as discussed above. The cost for this will be less than $475,000 and depends on what is retained or if timber decking is used to fill-in the terrace footprints or if Parks opts to leave the area open, like the area in front of Pier 60, and install pedestrian railings.

Pier 60 – Timber Piles and Decking

Finger Pier: At Parks' request, Seattle Structural recommends that no repairs are required. There is damage to the cross-bracing which could result in Finger Pier failure during an earthquake. Otherwise the Finger Pier should be structurally sound for pedestrian access. The Finger Pier should be re-inspected in 2008.

Alaskan Way Apron: Seattle Structural recommends replacement of the 9 deficient piles adjacent to the Aquarium Director's assigned parking place. The cost for this replacement is estimated to be $40,000 for timber piles or $100,000 for steel piles.

Pier 60 – Concrete

Decking and Support Beams: There is significant damage present due to reinforcement corrosion that has occurred since the 1998/9 inspection. Tinnea & Associates is evaluating if a remote galvanic cathodic protection (CP) system is a viable method to protect embedded prestressing steel in the precast panels. The panels are only submerged a part of each day, hence the requirement for testing. If a remote CP system is feasible, then Tinnea & Associates recommends its installation at an estimate of $210,000 including concrete repairs and if the work is completed sometime between now and July of 2007. Delaying the installation of the CP system allows corrosion to continue and the rate of spalling and delaminating will accelerate, perhaps dramatically, and increase repair costs. If no corrective work is performed, the concrete decking and reinforced concrete support beams should be inspected at regular intervals no greater than two years in length starting in 2008.

Concrete Piles: No action required at this time.

Action Items for Next Biennium (2009-2010)

Pier 57 North Apron

The Parks Department should anticipate implementing replacement of piles to maintain operability or the apron's demolition with or without replacement. Based on the recent inspection, Seattle Structural finds that 90 piles currently require replacement. They also estimate that within five years an additional 60 piles will decay to levels that require replacement.

Pile Replacement

If the 60 pile 5-year deterioration estimate is prorated to 3-years, an estimated 36 piles will deteriorate in the interim between this report and the 2009-2010 biennium. At that time an estimated 126 piles would require replacement. If timber piles are used as the replacement, the estimated costs are $504,000. Pile replacement costs estimates using steel pile replacements are $1,260,000. Again, these estimates are in 2006 dollars.

Pier 57 North Apron Demolition with Replacement Option

Seattle Structural estimates costs to demolish the Pier 57 North Apron, including environment containment and mitigation, at $100,000. They estimated replacement at $1,000,000. Continued service also incurs the costs of periodic condition surveys. Demolition may require the cooperation of the private owners of the contiguous commercial area of Pier 57.

Pier 58

Decision Point on Pier 58

To return Pier 58 to full design capacity will require from $707,000 to $1,545,000 or more. As stated above, Seattle Structural estimates demolition for the entirety of Pier 58 would cost less than the $475,000 for the recommended short term repair recommendations, to perhaps as low as $300,000. Therefore, it appears that the next biennium is a Pier 58 future use decision point. The pile replacement and strengthening, outlined below, should be considered as part of a 25-year life option. Continued maintenance deferral will very likely lead to further load restriction recommendations and continued seismic risk exposure.

Timber Piles

It is estimated that by 2009 between 58 and 83 piles timber piles will be deficient. If timber piles are used as replacements, the estimated cost ranges from $232,000 to $332,000. To make the replacement with steel piles the cost estimates range from $580,000 to $830,000. Further, Parks should expect that to sustain near-design capacity that every five years an additional 80 timber piles will need replacement. Those replacement costs are estimated at $320,000 to replace with timber piles or $800,000 if using steel piles. Parks will also have the cost of 5-year periodic condition surveys.

Monotubes® and H-Piles

If not yet completed, Parks should strip the corroded sections of all 84 Monotubes® and strengthen them with reinforced concrete jackets at an estimated cost of $340,000. Until restored, the corrosion damage of the Monotubes® presents the risk of partial or total collapse of the two reinforced concrete terraces during an earthquake. If Parks wishes to extend the life of Pier 58 beyond this point the removal of the corroded section at the top of all 48 H-piles and welding in new duplex-coated splices is recommended. The cost to do this is estimated to be $240,000.

Monotube® and H-pile Cathodic Protection

Both the H-piles and Monotubes® previously enjoyed cathodic protection from an impressed current CP system. The limited damage observed from mean tide level down, reflects the fact that the CP system provided significant corrosion control to the Monotubes and H-piles over a

portion of Pier 58's life to date. Damage to cables and equipment at multiple locations requires the CP system be restored. Tinnea & Associates estimates the costs for a replacement impressed current CP to protect the H-piles and Monotubes® at $100,000.

Timber Deck Floor and Support Beams

No necessary action foreseen at this time.

Reinforced Concrete Terrace Support Beams

If the crack and concrete repairs recommended above were not previously completed, they should be completed at this time. Increases in damaged areas will increase the restoration cost estimates. Also, as mentioned above, prior to issuing construction documents for the Terrace crack repairs, it should be determined if localized corrosion is a problem where the cracks intersect the steel reinforcement.

Pier 58 Cost Summary

Total costs to return Pier 58 to approximate original design capacity, including restoring the previous CP system in the 2009-2010 biennium, run from $807,000 to $1,047,000 to replace timber piles with timber piles, and from $1,115,000 to 1,545,000 for steel replacement piles. Note that the CP system cost estimate does not reflect providing any protection to steel piles that may be used to replace existing timber piles.

Pier 60

Timber Piles/Deck

Finger Pier Cross-Bracing: Seattle Structural recommends the replacement of cross-bracing on the finger pier by 2009. The cost is estimated at $12,000.

Alaskan Way Apron: Seattle Structural recommends replacement of the 9 deficient piles adjacent to the Aquarium Director's assigned parking place. The cost for this replacement is estimated to be $40,000 for timber piles or $100,000 for steel piles. Replacement of other Finger Pier and Apron timber that likely became deficient during the deferral is estimated at $84,000 if timber piles are used and $210,000 if steel piles are used.

Continued Timber Pile Replacement: Parks should expect to replace about 35 of the existing timber piling every five years. Cost estimates to make these replacements with timber piles is $140,000 and $350,000 for the steel pile option. Parks would also have the costs related to 5-year periodic condition surveys.

Concrete Piles

No action required for this biennium. The next 5-year interval condition survey for the concrete piles should be completed by the end of 2011.

Substructure Concrete Decking and Support Beams

As previously stated, Tinnea & Associates is currently checking on the feasibility of installing remote galvanic anodes to the soffit of the deck floor and the support beams. The estimated cost for installation of the CP remains $135,000 in today's dollars. However, with deferral of the CP system installation, the cost for concrete repairs will increase, pushing the total estimated cost for CP and repairs to $285,000 or more. This does not include the cost of periodic inspection.

Should a remote CP system not be feasible, then either a thermal sprayed zinc metallized coating CP system or an expanded zinc mesh jacketed CP system would be required. Such a system would protect the decking and the support beams. The tides will significantly limit construction access and increase costs. It is estimated that either a metallized zinc or jacketed CP system would cost $1,300,000. Also, these estimates do not include costs associated with periodic inspection.