The Rehabilitation & Modernization of Fitting Out Pier 2 at Portsmouth Naval Shipyard

A well-thought-out plan for inspection and repair, integrated with occasional re-examination of design needs, can sometimes obviate the need for replacement.

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Established in 1800, the Portsmouth Naval Shipyard in Kittery, Maine, is the oldest naval shipyard continuously operated by the U.S. government (see Figure 1). Beginning with the War of 1812, it has supplied the U.S. military during major national conflicts and it has been a part of historical events, including serving as the site for the signing of the Russo-Japanese War Peace Treaty. During World War II, it was instrumental to the war effort. Seventy-nine submarines were constructed at the shipyard between 1941 and 1945 (one more than at Electric Boat in Groton, Connecticut) and the shipyard holds the record for the number of submarines launched on a single day (four in January 1944). Today, with over 6,200 lineal feet of berthing with nine waterfront facilities (twelve berths) and three dry docks, the shipyard's main focus is the repair, overhaul and modernization of submarines. Vital to these operations is Fitting Out Pier 2.

Fitting Out Pier 2 is located at the southwest portion of the shipyard within the Controlled Industrial Area between two dry docks (see Figure 2). It consists of three pile-supported marginal wharves (Berths 11, 12 and 13) with 15-foot and 20-foot gauge portal crane rails and over 2,300 lineal feet of berthing for the fitting out of submarines and the mooring of support and housing barges. Berth 11 forms the southern side of Fitting Out

FIGURE 1. Aerial photograph of the Portsmouth Naval Shipyard.

Pier 2 and extends from Dry Dock 1 to Berth 12, which forms the western (outboard) end of the facility. Berth 13 forms the northern side and extends from Berth 12 to Dry Dock 3.

Based on archive drawings, Fitting Out Pier 2 was built in 1942 (see Figure 3) with construction completed just over one year after Pearl Harbor was attacked. The original construction consisted of a reinforced concrete deck with concrete-encased steel beam framing members (beams and pile caps), steel support piles and a timber fender system (see Figure 4). The piles were not designed with a corrosion allowance (i.e., they were not sized larger than structurally needed for design loads); rather they were encased in concrete (formed with a stay-in-place, light gauge, steel cylinder) for corrosion protection. Presumably this detail resulted, in part, from the steel demand for the war effort. Over the years, various projects have aimed to repair and modernize the facility. As a result, the facility now incorporates additional support piles, pile jackets, a cathodic protection system, and a steel and timber fender system. Table 1 summarizes the current wharf components.

Modification & Repairs (1959 to the mid-1980s)

Up until about 1997, the most significant modifications/repairs occurred on approximately twenty-year intervals and included installing a steel master pile fender system and installing jackets on the support piles. The steel master pile fender system was first integrated into the facility around 1959, along

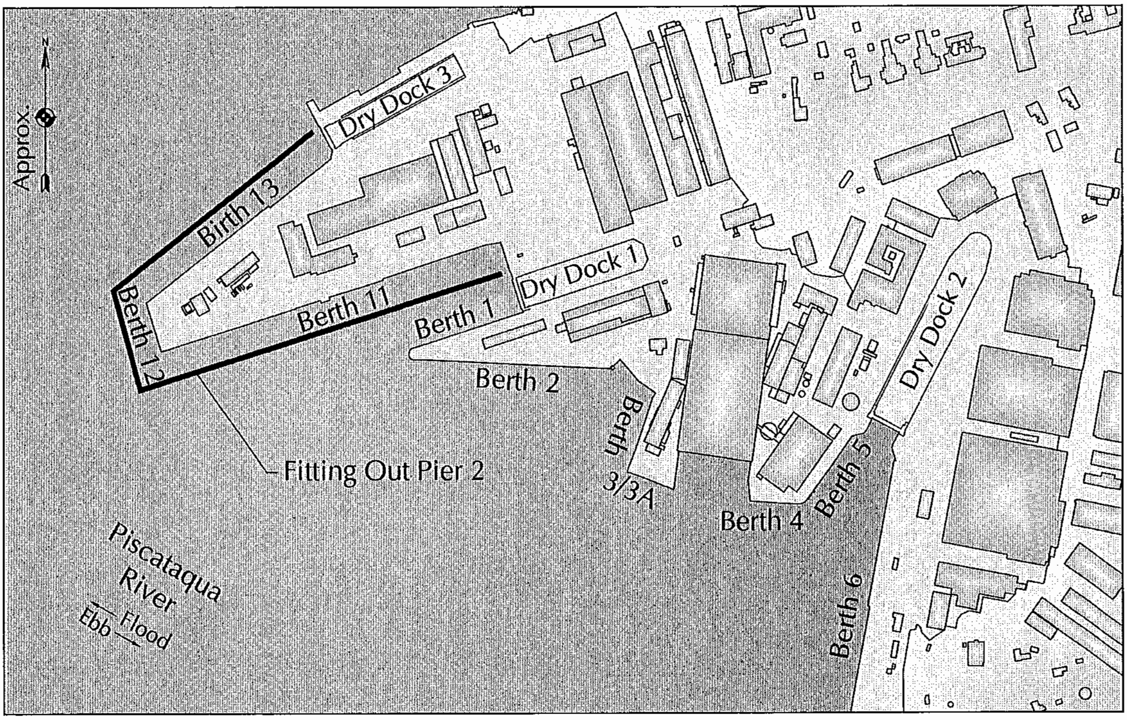

FIGURE 2. Key plan of Fitting Out Pier 2.

a 640-foot-long portion of Berth 11. It increased the overall deck width by about 5 feet and incorporated W14 steel members for the fender piles with a concrete shutter panel wall running between the piles at the mudline. The bottom of the concrete shutter panel was set between 36 to 38 feet below low water to allow for a "deepening of berth" and

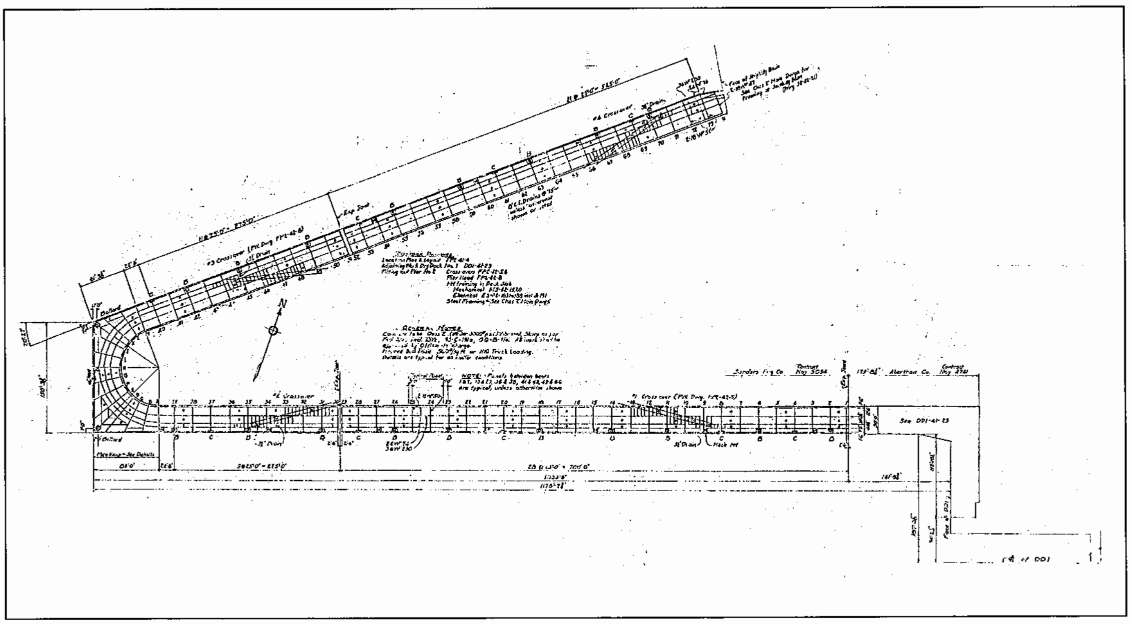

FIGURE 3. Layout of Fitting Out Pier 2 from a 1941 archive design drawing.

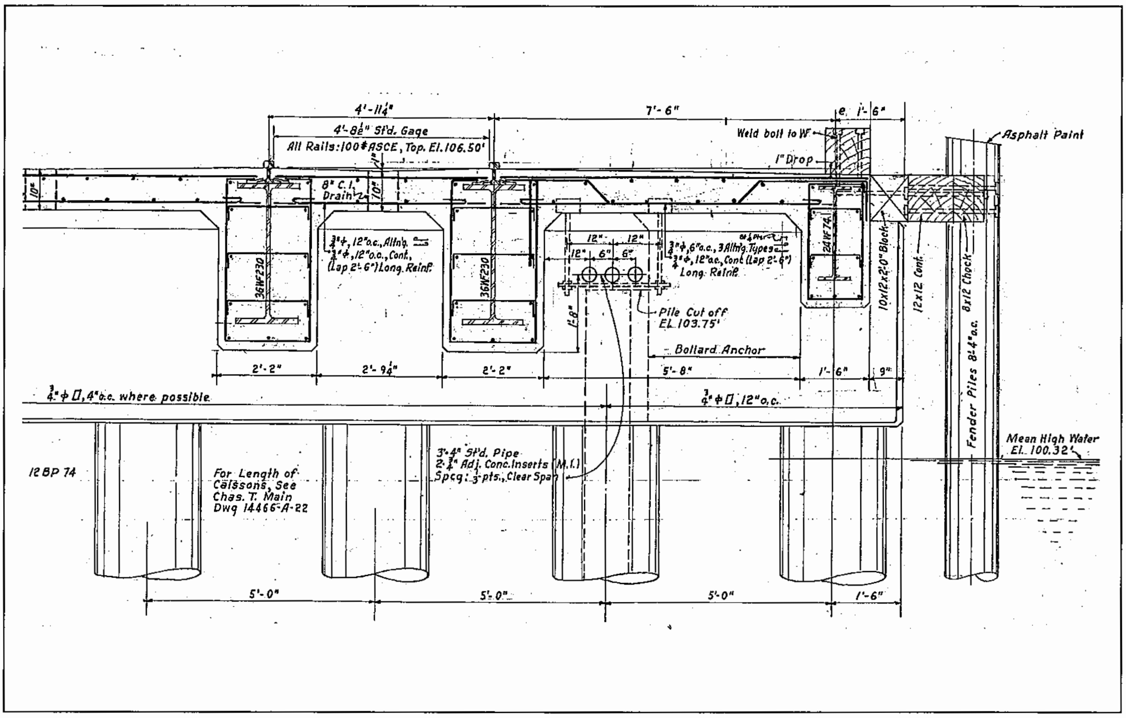

FIGURE 4. Partial section of Fitting Out Pier 2 from a 1942 archive design drawing.

undoubtedly more flexibility with operations. A similar steel master pile fender system and concrete shutter panels were installed along Berths 12 and Berth 13 about 1978. Around 1980, after nearly forty years of exposure to tidal water and the marine environment, concrete jackets were installed on most of the support piles (see Figure 5). The jackets were formed with a leave-in-place nylon fabric bag and extended from the bottom of the pile caps to a few feet below low water — typically a highly corrosive zone.

Some time during the early and mid-1980s, two repair projects addressed the deterioration of the concrete deck and concrete-encased framing members. Repair of the top of the deck ranged from replacing the top 3 inches of concrete to full-depth deck replacement. Under deck, the concrete encasements at approximately sixty pile caps and one hundred and thirty beams received epoxy mortar repairs.

Condition Inspection & Analysis (1994)

A 1994 abovewater and underwater condition inspection of the facility triggered a period of numerous repairs and modifications. This inspection flagged various areas of significant deterioration and possible insufficient capacity for the then-current operations. It prompted interim repairs, a detailed damage inspection (including a structural analysis of the facility) and subsequent repairs.

In broad terms, the 1994 inspection reported that the concrete-encased framing members were typically in fair condition with isolated segments along the wharf having moderate to major deterioration of the concrete (cracks, spalls). It also noted that the master piles along Berth 13 were in good condition with surface corrosion in the splash zone and minor to moderate corrosion in the tidal and submerged zones. The master piles along Berths 11 and 12, however, had a greater degree of deterioration with isolated master piles along Berth 12 having significant section loss (92 percent flange thickness loss, 42 percent web thickness loss) and knife edging of the flanges. Although the master piles also serve as support piles for the timber deck extensions, of greatest concern was the condition of the wharf's original support piles.

TABLE 1.
Wharf Components of Fitting Out Pier 2

Component	Berth 11		Berth 12	Berth 13
	Bent LKY to Bent W	**Bent W to Bent D″**		
Overall Length (ft)	247	1,045	166	910
Superstructure	38 feet wide (minimum) reinforced concrete deck (10 in.) supported by reinforced concrete-encased steel beams and pile caps. Where the steel master pile fender system exists (see Fender System summary below), a timber deck extends from the concrete deck to the outboard face of the wharf.			
Piles	Concrete-encased (2 ft, 4 in. diameter) steel H-piles with 4-ft diameter nylon bag formed concrete jackets extending from the pile caps down to a few feet below MLW, a vertical steel mid-bay pile between bents and two battered steel piles at the inshore end of the bents.			
H-Piles	10BP57	12BP74	12BP74	12BP74
Mid-Bay Vertical Pile	—	W14x283	W14x211	W14x211
Battered Pile	HP14x117	HP14x117	HP14x117	HP14x117
Bent Spacing	9 ft, 7 in. to 15 ft 1 in.	25 ft	25 ft	22 ft, 6 in. to 25 ft
Pile Spacing Within Bent	5 ft	5 ft	5 ft	5 ft
Fender System	Bents LYK to 12: Timber piles (8 ft, 4 in. on center), wales and chocks. Bents 12 to D″: Rock socketed steel master piles (W14x283 at each bent) and steel wales with timber rub strips and precast concrete shutter panels at the mudline.		Rock socketed steel master piles (W14xvaries at each bent) and steel wales with timber rub strips and precast concrete shutter panels at the mudline.	Bents M′ to 58: Rock-socketed steel master piles (W14x132* at each bent) and steel wales with timber rub strips and a SSP knee-wall system at mudline. Bents 58 to 69: Timber piles (8 ft, 3 in. on center), wales and chocks.

Note: * Archive drawings indicate W14x127 sections, but based on measurements, the piles are W14x132.

The nylon fabric pile jackets installed in 1980 were generally intact with isolated areas of moderate deterioration. However, the original concrete encasements had significant deterioration. Nearly 30 percent of the piles along the facility had major or severe deterioration of the concrete encasement (see Table 2). Those piles with severe deterioration had extensive failure of the encasement that exposed the steel H-pile. Ultrasonic thickness measurements of the exposed steel piles indicated 10 to 20 percent thickness loss of the flange components and 10 to 25 percent thickness loss of the web components. Although these percentages are not indicative of an accelerated corrosion rate of unprotected steel in the marine environment, they were of concern because the piles were not designed with

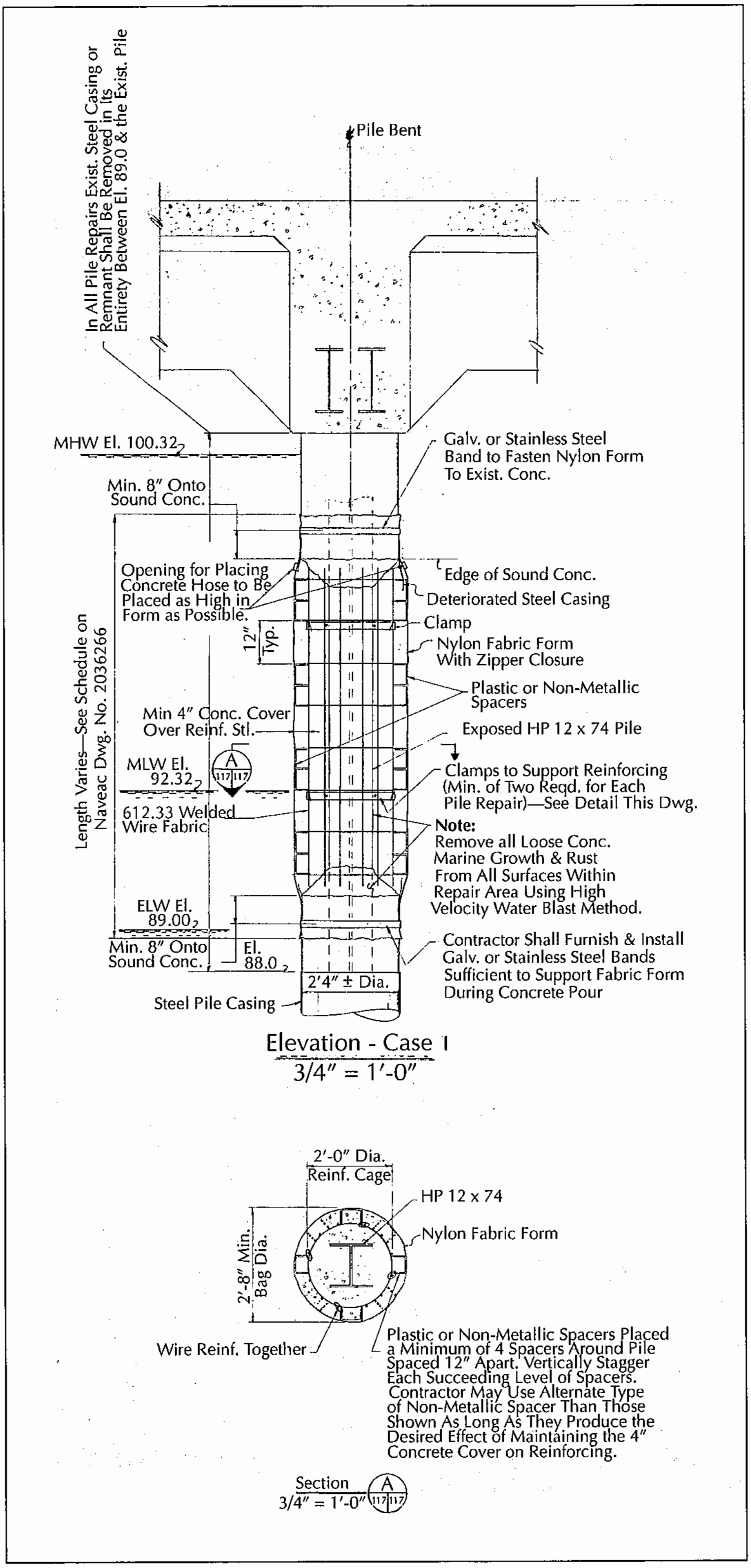

FIGURE 5. Pile jacket detail (from 1983 archive drawings).

a corrosion tolerance and the operations on the wharf created loadings that the original design did not necessarily accommodate. The concern was even greater for the isolated piles that had knife edges or buckled flanges. With the capacity and safety of the wharf under question until a damage inspection and structural analysis could be completed, interim repairs were designed.

Interim Repairs & Wharf Strengthening (1997 to 2000)

The interim repairs to the most severely deteriorated steel piles were completed in 1997. The repairs removed the concrete encasement and either the entire nylon fabric jacket (or a portion of the jacket) and installed anodes to the exposed steel pile in order to arrest pile corrosion (see Figure 6). In addition, the repairs included strengthening the H-piles with steel channels along the outside face of the flanges (see Figure 7). By completing these interim repairs on the piles with the most obvious immediate structural concerns, operations on the facility were allowed to continue.

By mid-year of 1997 the damage assessment of Fitting Out Pier 2 was completed. Structural analysis identified many piles along the crane rail beams as overstressed by the 20-foot-gauge portal crane operations and a presumptive

TABLE 2.
Significant Support Pile Deterioration Summary From the 1994 Inspection

Wharf Support Piles	Overall Wharf Facility		Breakdown					
			Berth 11		Berth 12		Berth 13	
Total Number of Piles*	868		508		56		304	
Major Deterioration**	125	29%	106	30%	4	54%	15	24%
Severe Deterioration***	130		46		26		58	

Notes: * Total number of piles as reported in the 1994 inspection report.
** As defined in the 1994 inspection report: "concrete deteriorated but not exposing steel pile."
*** As defined in the 1994 inspection report: "extensive concrete failure exposing steel pile."

1,000 plf berthing and mooring lateral load. (Although the available archive drawings did not specifically identify the various design live loads, it appeared that the structure was designed for a 15-foot-gauge portal crane [25 tons], railroad loading, AASHTO H-10 truck and a 500 psf uniform deck live load. The 20-foot-gauge portal crane was introduced to the structure around 1978.) The analysis incorporated section losses based on:

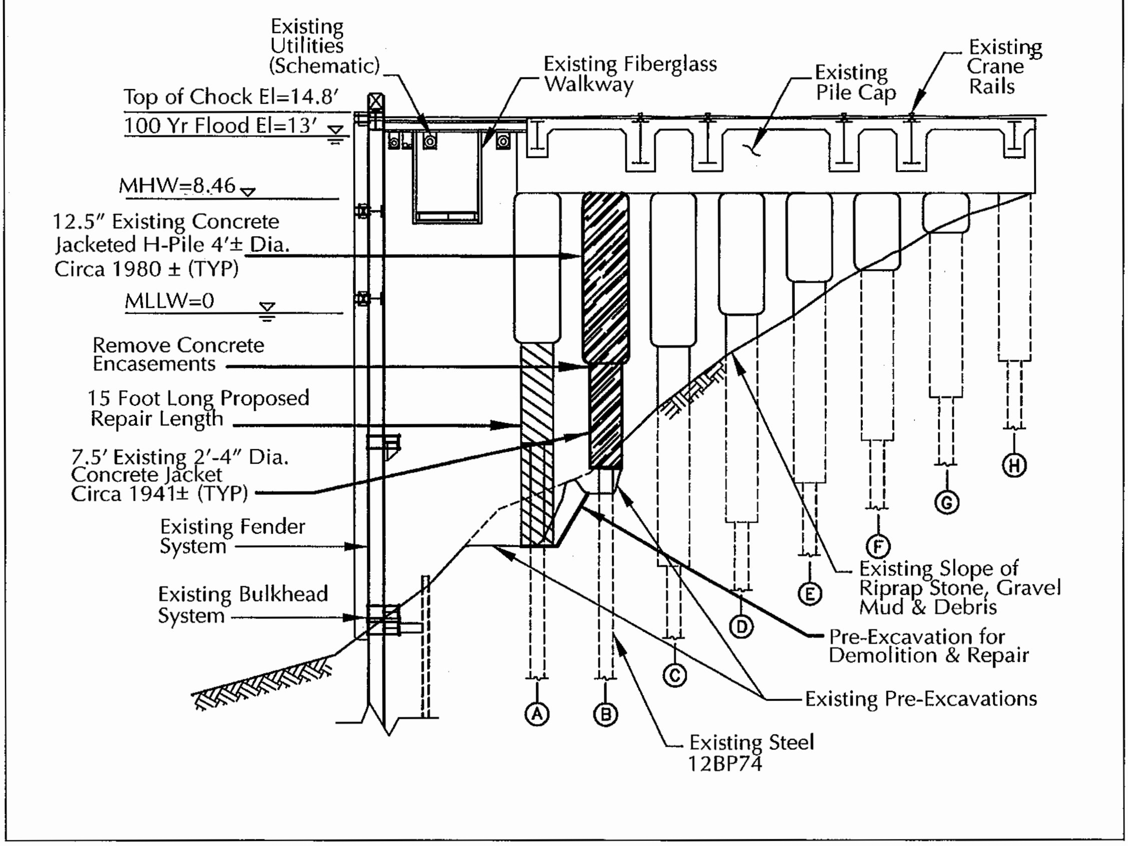

FIGURE 6. Concrete encasement/pile jacket repair (from a 1997 archive drawing).

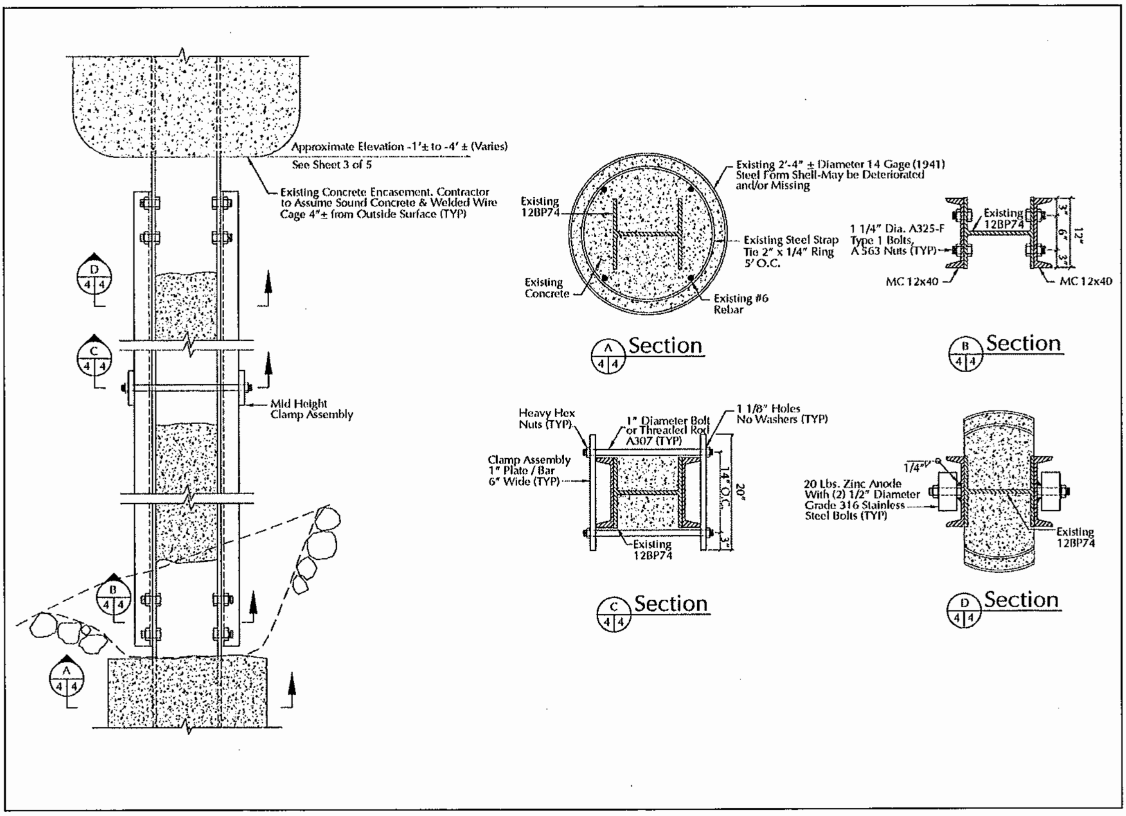

FIGURE 7. Steel pile repair detail (from a 1997 archive drawing).

- a minimum loss along the length of pile enclosed with the nylon fabric jacket as identified in a 1978 report that initiated the pile jacket repairs; and,
- section losses as gathered from the damage inspection.

With the portal crane loading and the reduced section for the deteriorated piles, the analysis indicated that even piles with no assumed loss of pile section (because the original concrete encasement was intact and no nylon fabric jacket was installed) were found to be overstressed and approaching yield. As a result, installation of additional piles along the crane rail beams was recommended.

Between 1998 and 2000, the recommended additional piles were installed. New vertical piles were installed at mid-bay between pile bents, approximately in line with the outboard (outermost) crane rail beam, and pairs of batter piles were placed at each bent adjacent to the existing support piles at the inboard (innermost) crane rail beam (see Figure 8). The new piles, designed for the operating portal cranes, reduced the load transferred to the original piles and, therefore, created, in effect, a corrosion allowance for the original piles (see Table 3). Nevertheless, a sacrificial cathodic protection system (zinc anodes) was incorporated throughout Fitting Out Pier 2.

Also during this period, other repairs and modifications were completed. Steel sheet piling was installed at isolated locations along the inboard edge of the wharf to help with the ongoing sinkhole problem at the facility. A new master pile fender system with concrete shutter panels was constructed over the 1959 system along approximately 770 feet of Berth 11. The new system created a removable timber deck just over 12.5 feet wide and approximately 1 foot above the top of the wharf. Other repairs and modifications included the repair and resurfacing of the top of the concrete deck, removal of abandoned under deck utility lines, installation of an under deck utility access walkway and repair of mooring hardware and timber fender systems.

Routine Inspection (2004)

A few years later, in 2004, routine inspections of the majority of the shipyard's waterfront facilities were completed. The inspection of Fitting Out Pier 2 found the facility in overall fair condition with continued deterioration of the original components (concrete-encased support piles and framing members, concrete deck) and the fender systems. Minor to advanced deterioration of the concrete pile encasements and the nylon fabric formed pile jackets had exposed between 27 and 55 percent of the original steel H-piles (see Table 4 and Figure 9). Of the exposed piles, approximately 60 percent had both the flanges and web exposed (see Figure 10) and 40 percent had only the flanges exposed.

The degree of deterioration of the exposed H-piles varied depending on the berth and on the zone in which the exposed steel occurred (see Table 5). Within the submerged zone and at the mudline, the piles had average thickness losses between 10 and 30 percent, and maximum losses as great as 40 percent (submerged zone) and 46 percent (mudline). Although the thickness losses were substantial, the resulting cross-sectional area losses were within the effective corrosion allowance that was created from the installation of the additional support piles between 1997 and 2000. The two outermost

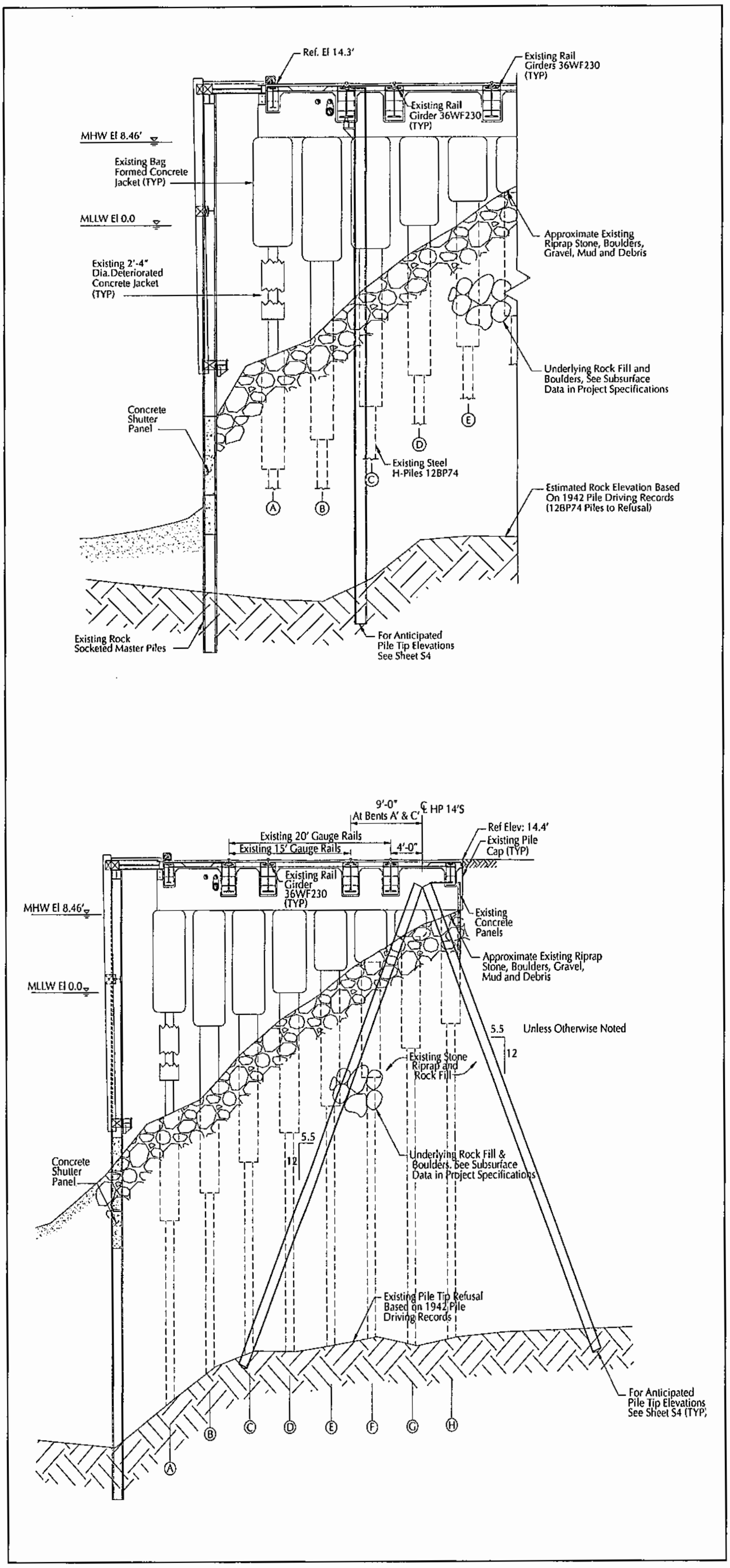

FIGURE 8. Interim repairs (from 1998 archive drawings).

TABLE 3.
Modified Corrosion Allowances for Fitting Out Pier 2

Pile Row	Maximum Allowable Cross-Sectional Area Loss* (%)
A	46
B	39
C	37
D	45
E	35

Note: * Based on the 1997 to 2000 rehabilitation projects and an allowable pile stress of 11 ksi for the original 12BP74 piles.

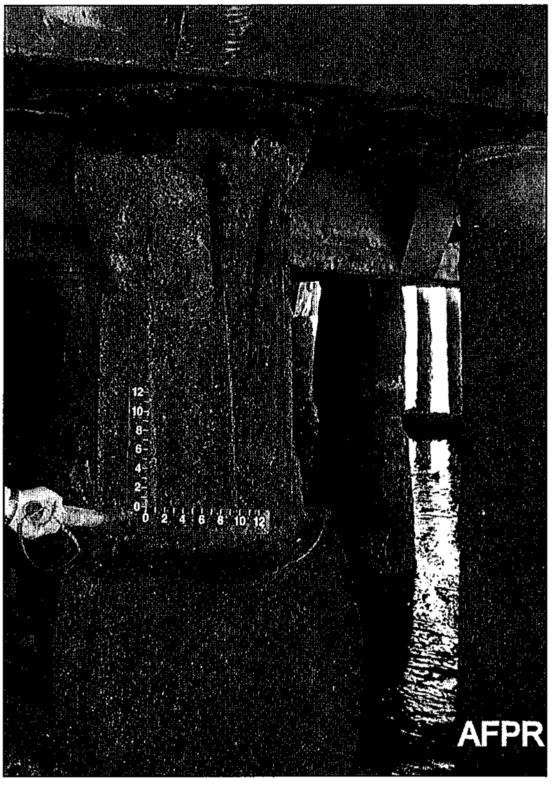

FIGURE 9. Pile jacket deterioration.

pile rows (A and B) had the greatest quantity of piles with both the flanges and web exposed. The average cross-sectional area losses for these piles were approximately 20 percent with maximum losses up to 40 percent — significant, but still within the created allowances (see Table 6).

The other piles for the facility had minor deterioration. The support piles that received the 1997 interim channel repairs did not have significant thickness losses to the channels. The mid-bay and batter piles installed between 1997 and 2000 had very minor protective coating deterioration in the splash zone. At a few isolated mid-bay piles, the protective coating had failed, resulting in minor surface corrosion of the steel piles. Overall, for the facility, voltage potential readings indicated that the piles had adequate to marginal cathodic protection.

Inspection of the superstructure revealed minor to advanced deterioration. The top of the concrete deck had the expected deterioration for the facility based on historical inspections and repairs. It consisted of widespread longitudinal and transverse cracks with delamination and spalls along the crane rails. The under deck, however, had significant deterioration of the pile caps and longitudinal beams.

TABLE 4.
Exposed Encased Steel H-Piles From the 1994 Inspection

Encased H-Piles	Berth 11		Berth 12		Berth 13	
	Qty	%	Qty	%	Qty	%
Total*	515	—	53	—	308	—
Total Exposed in 2004	139	27	29	55	83	27

Note: * As reported in the 2004 inspection report: Total number of original encased support H-piles. Does not include master piles, mid-bay piles or battered piles.

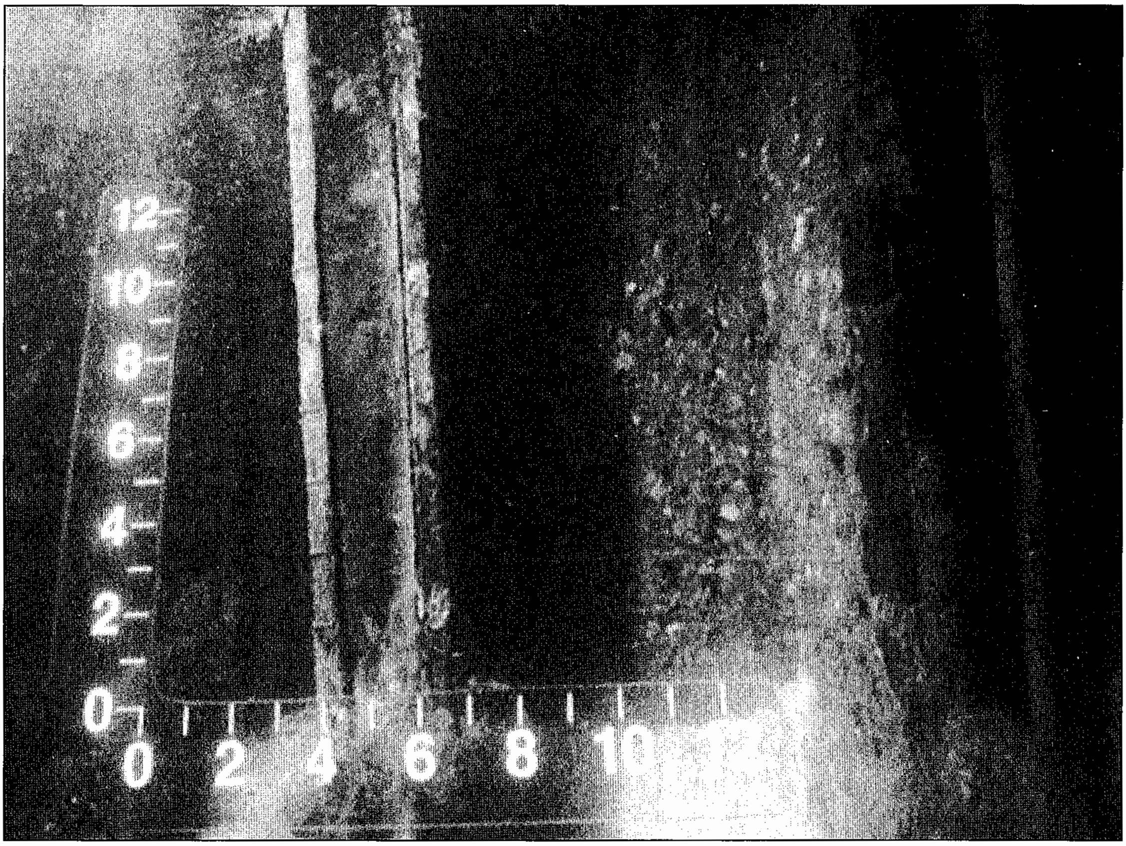

FIGURE 10. Underwater concrete encasement deterioration.

TABLE 5.
Exposed H-Pile Deterioration From the 2004 Inspection*

Corrosion Zone	Corrosion Loss (% of Thickness)					
	Berth 11		Berth 12		Berth 13	
	Web	Flange	Web	Flange	Web	Flange
Splash Zone						
Average	49**	42**	—	—	5***	5***
Minimum	49	42	—	—	5	8
Submerged Zone						
Average	7	19	27	28	18	11
Minimum	16	32	32	31	39	28
Mudline						
Average	13	9	23	24	20	15
Minimum	25	46	23	32	34	31

Notes: * Based on ultrasonic thickness measurements of the original concrete encased support H-piles that did not receive the 1997 interim channel repairs.

** Based on one splash zone ultrasonic thickness measurement of an H-pile with knife edging.

*** Based on two splash zone ultrasonic thickness measurements of piles that had their concrete encasement and jacket removed in 1997.

TABLE 6.
A Comparison of H-Pile Area Losses

Pile Row	Maximum Allowable Cross-Sectional Area Loss* (%)	Cross-Sectional Area Loss Based on Measurements**	
		Average (%)	Maximum (%)
A	46	17	40
B	39	21	30

Notes: * Based on the 1997 to 2000 rehabilitation projects and an allowable pile stress of 11 ksi for the original 12BP74 piles.
** Based on the 2004 inspection.

Nearly all of the pile caps (approximately one hundred and thirteen) had fine longitudinal cracks or map cracking with rust staining and efflorescence present at approximately 30 percent of the pile caps. An additional 20 to 30 percent had large spalls with exposed reinforcing steel (see Figure 11).

Similar to the pile caps, approximately 30 percent of the longitudinal beams had fine to wide cracks with rust staining and efflorescence. An additional 11 percent had large concrete spalls with exposed reinforcing steel (see Figure 12). Although at least one of each type of longitudinal beam had spalls, the vast

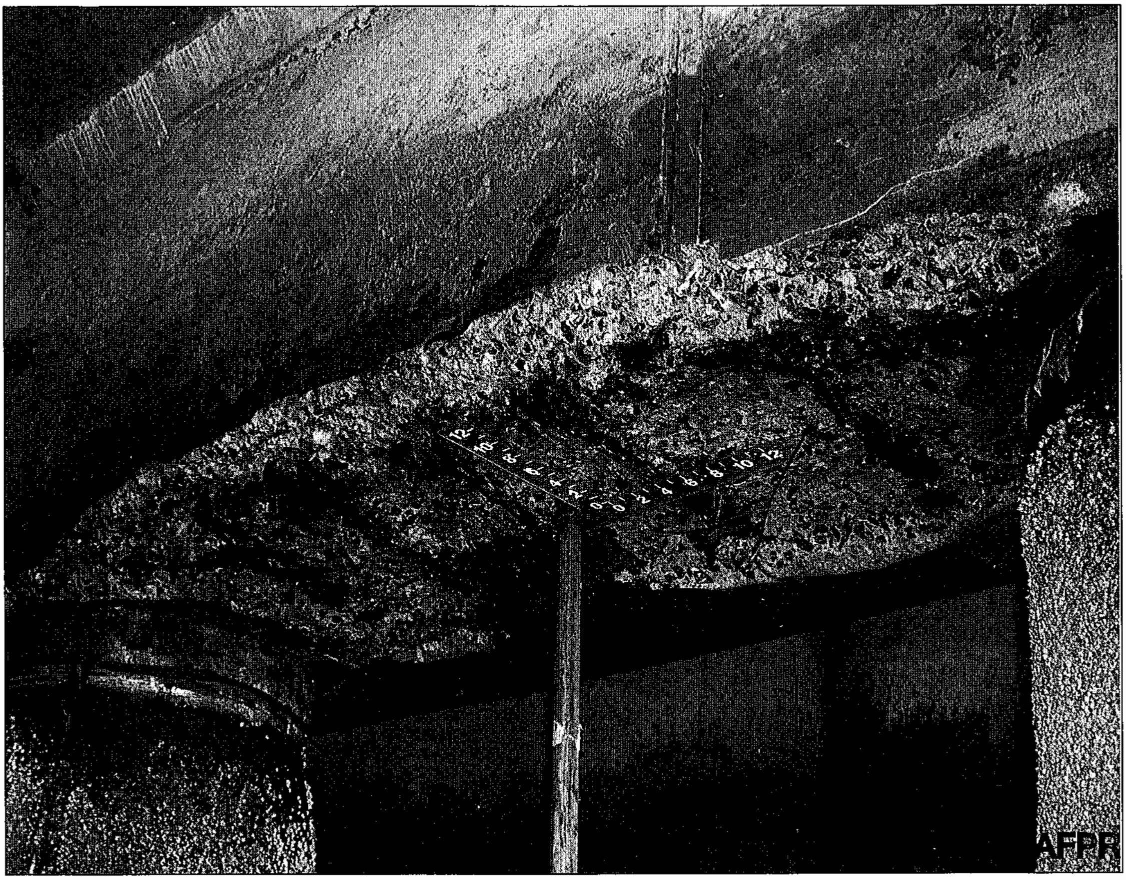

FIGURE 11. Concrete deterioration along the bottom of a pile cap.

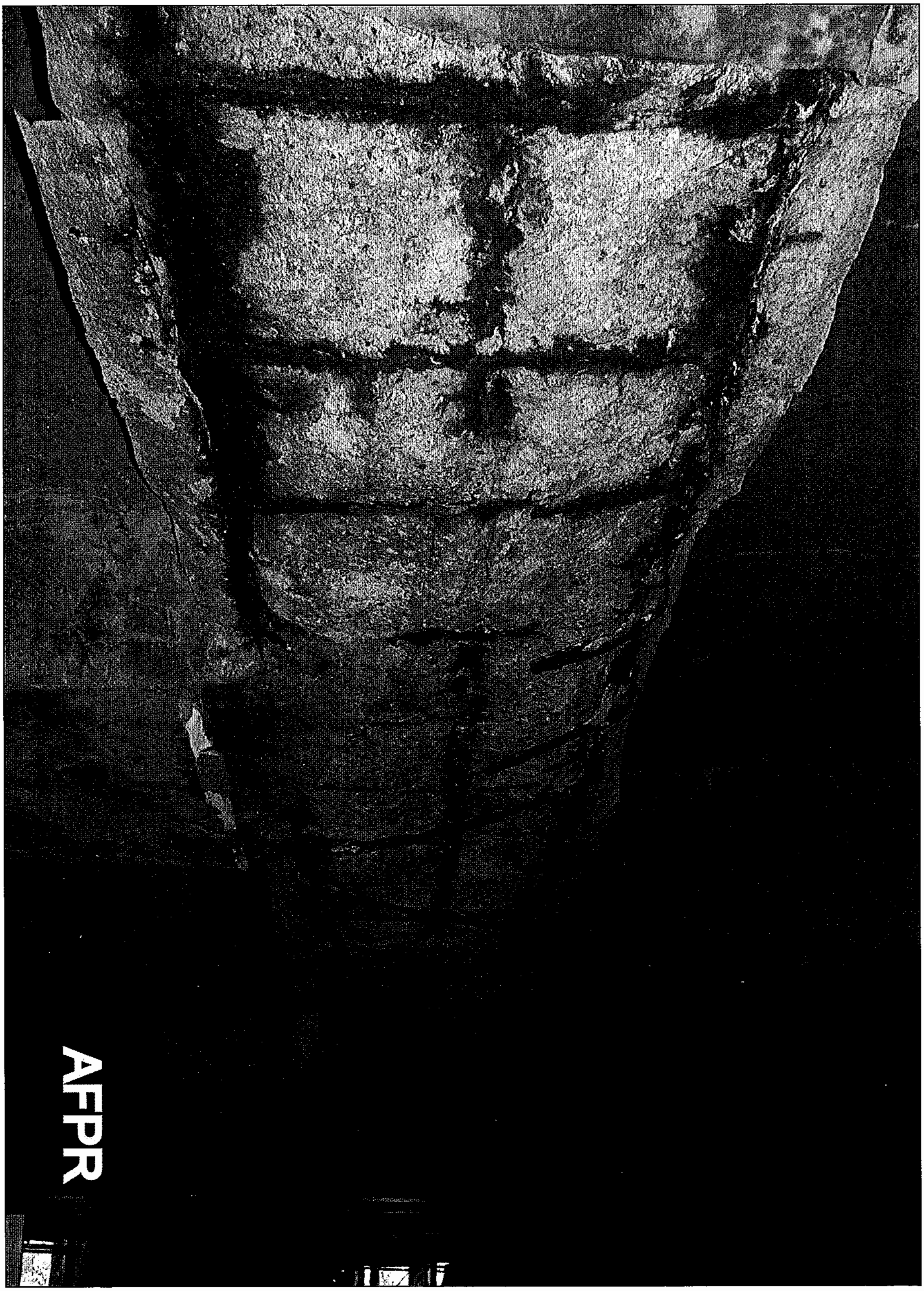

FIGURE 12. Concrete deterioration along the bottom of a longitudinal beam.

TABLE 7.
Longitudinal Beams From the 2004 Inspection

Longitudinal Beam	Total Quantity	Beams With Spalls	
		Quantity	Percentage
Outboard Fascia Beam	107	6	6
Common Rail Beam	98	50	51
Railroad Rail Beam	98	4	4
15-ft Gauge Crane Rail Beam	98	5	5
20-ft Gauge Crane Rail Beam	93	1	1
Inboard Fascia Beam	109	3	3
Total	603	69	11

majority of the spalls were located on the common crane rail beams (see Table 7). At three beams, the concrete spalls were significant enough to expose the bottom of the encased steel beam.

Inspection of the fender systems revealed various conditions depending on the type of system and when it was installed. The timber pile fender systems along Berths 11 and 13 were in poor condition with fungal decay above water and numerous failed piles below water. The 2000 master pile fender system along Berth 11 typically had minor deterioration, which consisted of isolated protective coating failures in the splash and tidal zones. The 1960 vintage master pile system along Berth 11, however, had complete loss of the protective coating with average flange and web thickness losses averaging between 10 and 25 percent for the typical corrosion zones. The steel master pile system along Berths 12 and 13 (1978 vintage) had coating loss and 5 to 10 percent average thickness losses. Although the master piles along all three berths had anodes, many were significantly consumed. Corresponding voltage potential measurements indicated some piles were cathodically protected while others were not.

Although all of the deterioration reported in the 2004 inspection report appears significant, none resulted in significant operational restrictions. Because of the previous modifications and rehabilitation projects, the overall capacity of the structure was not in question. However, the deterioration did heighten the fact that additional repairs were necessary before continued deterioration affected the encased steel beam framing members and steel support piles. Following completion of the 2004 inspection report, design repair projects commenced to address the fender system, steel pile and under deck deteriorations.

Current Repair Designs

Both the fender system and steel pile repair projects are typical maintenance projects. The fender system repair project replaces approximately eighty timber fender piles and associated timber framing elements (wales, chocks, blocking) along Berths 11 and 13. It also includes applying a new protective coating within the tidal and splash zones on the steel master piles of Berth 13. During the repair design process, coordination through the environmental department at the shipyard determined permissible preservative treatments for both the timber and steel piles, acceptable methods for cleaning the steel piles and required containment measures for cleaning and recoating the steel piles. Both chromated copper arsenate (CCA) and ammoniacal copper zinc arsenate (ACZA) were deemed acceptable preservative treatments for the timber members. Although sampling and testing of the steel pile surface profiles indicated water blasting as a suitable method for cleaning the steel piles, the required collection and filtering of the water precluded the method based on cost. The final accepted repair design for the steel piles incorporated an SSPS-SP10 cleaning (Steel Structures Painting Council SP10 corresponds to a near-white blast cleaning) using metallic grit, a coal tar epoxy-polyamide coating system and tarp-containment measures to reduce particulate emissions and to collect particulates and debris during both the cleaning process and the coating application.

The steel pile repair project restores adequate cathodic protection along all three berths of the structure. The project replaces existing consumed anodes and installs additional anodes at piles with deteriorated concrete encasements/jackets. The aluminum anodes are installed below water with welded connections between the anode, steel core material and the steel pile. Depending on the type of pile and extent of exposed steel along the pile, the anodes are either 2 feet long by 10 inches wide by 10 inches deep or 5 feet long by 8 inches wide by 8 inches deep. Based on the rate of consumption of the existing anodes and an assumed rate of concrete deterioration that exposes additional steel piles, it is estimated that the anodes will provide adequate cathodic protection for fifteen to twenty years.

Similar to the under deck repairs of the mid-1980s, the concrete repair project addresses the deterioration of the concrete encasements along the pile caps and beams. During the routine inspection of 2004, the presence of alkali-silica reaction (ASR) was suspected because of the appearance of the deteriorated concrete. As part of the repair design, concrete samples were tested and the presence of ASR was confirmed. Understanding that ASR in the parent concrete would compromise the longevity of concrete repairs, the repair design incorporates lithium-based products to help reduce the potential of ASR in the repair material and at the repair interface with the parent concrete and to help mitigate ASR within the parent concrete. A lithium-based coating applied to the parent concrete, combined with a lithium-based admixture in the repair material, is expected to extend the life of the concrete repairs. All totaled along the three berths, the project includes approximately 7,200 square feet of concrete repair area with average depths ranging between 3 inches (areas identified as imminent spalls) and 6 inches (areas with spalls at the time of the inspection).

The repair design drawings also identify locations for reinforcing steel repair and bottom flange beam repairs. For bidding purposes, approximately 3,000 pounds of reinforcing steel replacement (stirrups and longitudinal bars) and 3,850 pounds of steel repairs to the bottom flange of the beams with deterioration were estimated. Not knowing exactly what extent of internal deterioration will be uncovered during removal processes, the repair design drawings include guidance for determining when to complete additional reinforcing steel and bottom flange repairs.

Continued Service Life

By the time the three repair projects are completed, the pier likely will be nearing the end of the recommended Routine Inspection interval. Depending on funding, it is conceivable that the inspection will be completed before some of the repairs. Undoubtedly, whether or not all of the repairs are completed, the next inspection will identify additional repairs simply due to the age of the facility. At sixty-four years old, continued maintenance and repair of Fitting Out Pier 2 are necessary to extend its service life. Fortunately, the previous repair and maintenance projects upgraded the capacity of the original structure, incorporated corrosion allowances and established a performance history. By understanding the life of the structure and its repairs, regular inspections and maintenance will ensure that Fitting Out Pier 2 will continue to meet the needs of the Portsmouth Naval Shipyard and the U.S. military.

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