PD-

649-0114/53

PDAAP 070

ISN: 33967

AID Washington
USAID Mogadishu 1240 .5
Contract Number AFR 0114-C-00-4005-00
Project Number 649-0114

Somali Democratic Republic

Kismayo Port Rehabilitation

Special Studies Report

Parsons Brinckerhoff International, Inc.
Mogadishu • New York

3532

February 1984

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February 29, 1984

Mr. Julio Villafane
Chief, Office of Engineering
USAID Mission in Somalia
Via Afgoi
Mogadishu, Somalia

Ref: USAID Project No. 649-0114
Kismayo Port Rehabilitation
USAID Contract No. AFR-0114-C-00-4005-00
Special Studies Report

Dear Mr. Villafane:

Enclosed is the Final Report on the Special Studies required by Article I.B.I.c of our agreement. The recommendations presented in this report were discussed with the AID Mission in Somalia prior to the submission of this report in draft form. Acceptance of these recommendations by both the Mission and the Ministry of Public Works was relayed to us by telex dated 2/13/84. A summary of these recommendations follows:

1. For the sheetpile bulkhead use ASTM 572, Grade 60 high strength steel and prepare two designs so that both Bethlehem and U.S. Steel can prepare bids. The use of corrosive-resistant steel is not recommended.

2. A protective coating system using an organic zinc-rich primer and a coal-tar epoxy outercoat is recommended. Both sides of the sheet-piling will be coated to three feet below the dredged line.

3. A cathodic protection system, of the sacrificial anode type, is recommended using an aluminum/zinc/indium alloy for the water side and a magnesium/zinc/aluminum alloy for the landside.

4. A fender system using foam-filled floating fenders, 3 feet in diameter by 10 feet long, spaced at 30 foot centers is recommended. This system is cost effective, suitable for the tidal variations at Kismayo, and suitable for the range of vessels that are expected to call at the port. These fenders are available from several manufacturers in the U.S.

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5. The construction of two roll-on/roll-off ramps is recommended, one at the end of Berth 3 (within the apron of Berth 2), and the second near the east end of Berth 1 to allow vessels to moor perpendicular to the dock. The second ramp may also be used for certain side-ramp vessels.

6. A construction sequence starting at the easterly end of Berth 1 and proceeding in sequence with the construction of Berths 1, 2, 3, and 4 is recommended. This sequence is preferred over the reverse sequence as it provides the port with fully serviced berths, including electric power, water, fire protection and sewage treatment, at an early date. In either construction sequence the temporary relocation of the POL unloading station to Berth 3, and the molasses loading station to Berth 2, are required.

We have included with this report several appendices which include the calculations, back-up data, sub-consultant reports, and references used in arriving at these recommendations.

In response to the request contained in the telex dated 2/13/84 we have added additional information concerning the acceptability of Kismayo area aggregates for use in mixing structural concrete.

We are proceeding with the final designs and preparation of Contract Documents on the basis of the recommendations contained in this report.

Very truly yours,

PARSONS BRINCKERHOFF INTERNATIONAL, INC.

Warren M. Buser

Warren M. Buser
Project Manager

WMB/jm
Encl.

cc: Bureau of Science and Technology

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SPECIAL STUDIES REPORT

INTRODUCTION

In accordance with Article I.B.1.c of our contract with USAID, certain studies and comparative investigations were required prior to the start of final design. This report presents the results of these studies and investigations in the following format:

A. the scope of the study or investigation;
B. the conclusions or recommendations of the Preliminary Design Report (PDR); and
C. this study and its conclusions or recommendations.

In addition to these studies and investigations, it was necessary to obtain additional field data to supplement the information previously obtained by others and by PBI during the Conceptual and Preliminary Design phases. Including the recent boring and laboratory testing programs, data and information were obtained on the following:

- Subsurface data from borings and probings at the proposed new bulkhead line: Geodrill Limited completed field work in December 1983. Laboratory testing work is now underway.

- Geological data from quarry investigations: Crushed aggregate samples were obtained from the Police Check Point quarry and the Old Airport quarry in the Kismayo area; from the stockpile of the roadbuilding contractor at Brava (source - quarry near Merca); from the quarry south of Mogadishu. These samples were subjected to Los Angeles Abrasion Tests at the SDR Highway Department laboratory in Mogadishu. The results of these tests are presented in Appendix A and indicate that the aggregates tested from both quarries in the Kismayo area have superior hardness and toughness qualities compared with the Mogadishu and Merca samples. This result was anticipated by local engineers prior to the testing program.

  The test results on the Kismayo samples yield percent losses of 26.4% and 22.7% after 500 revolutions for the Police Check Point and Old Airport quarries respectively. In general, a loss of 40.0% after 500 revolutions is the maximum acceptable. The corresponding percent loss for the Mogadishu sample was 34.2%.

  For the recently completed Banana Wharf at Mogadishu aggregates from quarries in the Mogadishu area were used for the concrete mix. Concrete strength of 4,000 psi was specified and obtained for the marine work as confirmed by cylinder tests. Therefore, since the aggregate at Kismayo is superior to that from Mogadishu, it is concluded that concrete of adequate strength and durability can be obtained using locally available aggregates.

- Water quality data from tests on samples of the Juba River and the Harbor: Samples were obtained and sent to the University of Nairobi for testing. Additional samples will be obtained for future testing.

- Topographic survey of the port: This survey, including soundings beneath the wharf structure, was completed by Geodrill Limited in November, 1983. A topographic plan has been prepared.

- Location of disposal sites for demolition materials and excavated materials unsuitable for use in the completed facility: Sites at all quarries in the Kismayo area can be used for this purpose according to local officials.

- Location of sites for use as contractor's yard: Several sites were visited and a letter report submitted to USAID in December 1983. USAID is to execute agreements with SDR officials regarding the use of these sites.

- Traffic restrictions, if any, on hauling backfill, sand and stone materials from quarries to the port: Local officials indicated that there would be no restrictions on properly marked contractor vehicles.

- Condition of existing fender system and details of connections between various elements: This survey was completed by PBI personnel in December 1983. In general, the existing steel elements are in good condition and most can be reused, if desired.

- Details of operating characteristics and the proposed location of the newly purchased electric generator: The new generator was examined but its operating characteristics were not available. (It was not in working condition at the time of the visit.) It is our belief that this equipment will not provide satisfactory or reliable power for the Port.

- Details and operating characteristics of the molasses and POL systems: This information was obtained during a site visit in December, 1983 and will be utilized in the design of both temporary and permanent lines.

- Details and Condition Survey of the existing Navigation Aids, both on land and in the water: These nav-aids had previously been inspected in April, 1983 and were partially inspected again in December, 1983. All lights on the land-side facilities and all floating nav-aids should be replaced.

- Details of the existing sanitary facilities and piping that must be replaced in the various buildings: This information was obtained during visits in December, 1983 and January, 1984.

The results of these field investigations and site visits were applied to the studies and investigations of this report.

I BULKHEAD SECTIONS AND STEEL GRADES

A. Scope - Study and compare the various bulkhead sections and steel grades available that will economically meet the design requirements.

B. Preliminary Design Report - Two alternative bulkhead sections were investigated, reinforced standard sheet piling and the master-pile type. The PDR summary states "...reinforced sheeting using US standard PZ38 sheet piles with 5 in. by 1 in. plates welded to each flange of the sheet piles, was selected as being more economical than master-pile sheet pile type bulkhead." The PDR also recommended the use of corrosion-resistent steel.

C. Current Study, Conclusion and Recommendation - The PZ38 section is rolled by the United States Steel Corporation in steel grades ASTM690 (Corrosion-resistent - Grade 50) and ASTM572 (Grades 50 and 60). The Bethlehem Steel Company, however, no longer rolls PZ38 (MZ38) sections. Bethlehem now has two new sections which have superior strength/weight characteristics: PZ35 and PZ40, both available in the same ASTM and steel grades as the PZ38 section. For the same basic bending moment caused by soil pressures, but reduced to account for flexibility (Rowes reduction), the following results were obtained:

Section & Grade		Cover Plates in.x in.x feet	Laying Width inches	Total Weight (lbs.) per foot of wall
PZ35			22.60	
	50	4.25x2.25x40		3869
	60	4.25x1.125x32		2992
PZ38			18.0	
	50	5.0x1.125x36		3533
	60	5.0x0.375x32		3158
PZ40			19.69	
	50	4.50x1.50x35		3732
	60	4.50x0.50x24		2976

The listed material costs for the various steel grades, at the plant, are as follows:

ASTM690 Grade 50	$737/ton
ASTM572 Grade 50	$633/ton
ASTM572 Grade 60	$649/ton

The summary of the cost estimate for the bulkhead using the various sections, steel types and grades based on relative costs provided by the steel companies, is presented in the table below:

PILE SECTION & TYPE OF STEEL	UNIT PRICES (US$/TON) LABOR	MAT'L & EQUIP	TOTAL	QUANTITY (TON)	TOTAL COST (US$)
PZ38					
ASTM690/50	357	2195	2552	4055	10,348,360
ASTM572/50	357	2091	2448	4055	9,926,640
ASTM572/60	357	2107	2464	3625	8,932,000
PZ35					
ASTM690/50	284	2195	2479	4435	10,994,365
ASTM572/50	284	2091	2375	4435	10,533,125
ASTM572/60	284	2107	2391	3430	8,201,130
PZ40					
ASTM690/50	327	2195	2522	4285	10,806,770
ASTM572/50	327	2091	2418	4285	10,361,130
ASTM572/60	327	2107	2434	3420	8,324,280

The preceeding table indicates that the use of ASTM690 steel is considerably more expensive than using ASTM572 steel (16-34%), and that for all sections the use of Grade 60 steel is more economical. The PZ35 section is the most economical section with the PZ40 and PZ38 sections, 1.4% and 8.9% higher respectively. We recommend against using the ASTM690 corrosive-resistent steel because of its higher cost and other reasons presented in the section on protective coatings.

As indicated in an earlier paragraph, the PZ35 and PZ40 sections are made only by Bethlehem Steel and the PZ38 section only by US Steel. While the PZ35 and PZ40 sections appears to be the most economical, we recommend that two designs be prepared - one using either PZ35 or PZ40 and the other using PZ38 (MZ38), in order to obtain competitive bids. Because the laying width of these sections are quite different, it will be necessary to prepare two complete sets of plans showing not only the bulkhead itself, but all other elements that are dependent upon the width of the sheets and the spacing of the tie-rods.

II PROTECTIVE COATING SYSTEM

A. Scope - Compare various coating systems for the bulkhead structures and their susceptibility to damage during shipping, handling and driving.

B. Preliminary Design Report - The PDR made the following recommendation: "The selected protective system for the steel sheet pile wall is the combination of corrosion-resistent steel, coal-tar epoxy protective coating and cathodic protection." The results of additional investigations concerning the corrosion-resistent steel and the protective coating are presented in the following paragraph. The results concerning the cathodic protection system are presented in Section III.

C. Current Study, Conclusion and Recommendation - In Section I the cost of corrosion-resistent steel (ASTM690) was presented relative to the cost of ordinary high-strength steels to be 16-34% higher. The use of this steel was recommended in the PDR as a secondary protection measure. However, further investigation indicates that this grade of steel is only effective in delaying damage caused by corrosion and is most effective in the splash zone, but is no more effective over longer periods than ordinary steels. Furthermore, the use of this more expensive steel would have to be provided for the entire length of the sheet piling even though it is only needed in the upper portion - the splash zone areas. (It is not practicable to fabricate sheet piling using two different grades of steel.) A more economical solution was selected which uses a protective undercoating or primer and a protective outercoating for the exposed surface. The undercoating provides the secondary protective measure, in lieu of the corrosion-resistent steel, but only in the areas where required, thus providing cost-effective protection. Therefore, the use of corrosion-resistent steel is not recommended.

In order to provide an up-to-date recommendation and cost estimate of a protective coating system, we called on the Products Mechanical Corporation, Mr. Herbert Schmidt, President, to provide us with an investigation, recommendation and cost estimate. Their report and Mr. Schmidt's qualifications are included in Appendix B to this report.

The recommended protective system is as follows:

Steel Sheet Piling - Apply protective coating system to both sides of the bulkhead piling from top to 3 ft below the dredged line. The landside face is provided with this protective coating because of the probable corrosive nature of the available backfill materials. Use both the organic zinc rich primer undercoating meeting DOD P-23236 specifications and the coal tar epoxy polyamide outercoating, the latter the Corps of Engineers formula C-200, for the entire length to be coated.

It is recommended that the deadman sheeting receive only a shop coat of paint but no other protective coating.

Wales - The waterside wales should receive the same protective coating system as the bulkhead sheeting. The deadman wales need not be given more than an ordinary shop coat.

Tie-rods - The tie-rods, turnbuckles, and outer nuts and washers should be coated using two coats of a cold bitumastic coating. In addition, the tie-rods should be wrapped with a 15 pound coal tar-saturated pipe line felt.

Mooring Dolphin Piling - These piles should be coated to 5 ft below the dredged line using the same system as used for the bulkhead piling.

Fender Piles or Steel Elements - If these members are to be used in the final structure, they must be hand-scaled and wire-brushed to remove all loose rust and other deleterious matter. Brush-apply two coats of a cold bituminous coating. When dry, brush-apply two coats of a rubberized coal tar emulsion coating.

The quality of the application of these coatings is extremely important to the extended life of the bulkhead structure. It is therefore recommended that a qualified inspector be engaged to inspect all aspects of the applications in the shop, the packaging for shipment, the handling during shipment and, finally, the field touch-up.

The use of these protective coatings, together with the cathodic protective system described in Section III should extend the useful life of the steel to over 25 years.

III. CATHODIC PROTECTION SYSTEM

A. Scope - Compare different types and materials of sacrificial anode cathodic protection systems, the alternative locations and means of support.

B. Preliminary Design Report - Two cathodic protection systems - the sacrificial anode system and the impressed current system - were investigated. The sacrificial anode system was selected as it required less maintenance and could be designed for a designated life of 10, 20 or more years. Because it requires frequent maintenance and a reliable source of current, the impressed current system was eliminated from further consideration.

C. Current Study, Conclusions and Recommendations - The firm of Wilson, Walton International, Inc. and in particular Mr. Charles Potosnak, a corrosion specialist certified by the National Association of Corrosion Engineers, was called upon to provide us with an investigation, recommendation and cost estimate of a sacrificial anode system. Their report is included in Appendix C to this report.

Cathodic protection is effective only in those areas where the steel to be protected is fully immersed or always moist, such as the backfill areas in the tidal zone. The cathodic protection system is to provide protection to the steel structural elements that are exposed to corrosion through failure or damage to the protective coating system. (It had already been established, in the PDR, that the most cost-effective design was based on the combined protection provided by protective coating and cathodic protection systems, rather than cathodic protection for bare steel.)

The elements to be provided with cathodic protection are those whose protective coating is subject to damage or deterioration and those that are most crucial to the stability of the bulkhead. For these reasons, the waterside face of the bulkhead sheeting, the bollard and bulkhead tie-rods, and the dolphin piles were selected for this protection. (The H-piles of the existing fender system, if reused in the new facility, would also require cathodic protection. These elements do not have a protective coating and the field application of a good coating is not practicable.)

For the waterside protection, high-efficiency aluminum/zinc/indium alloy is recommended and for the landside protection, applicable to the tie-rods, a high-efficiency magnesium/zinc/aluminum alloy is recommended. These materials are selected because of their proven cost effectiveness, availability, ease of installation and reliability. Anodes of these materials are available from several manufacturers in the US.

The cathodic protection anodes for the bulkhead piling would be installed in alternate bulkhead indentations. These anodes would be suspended from brackets welded to the webs of the piling. Anodes for these members are

readily accessible and can be replaced when required. However, because of the costs involved in replacement, the minimum design life considered is 10 years.

The capital cost of an anode designed for a 20-year life is slightl less than twice the cost of an anode designed for a 10-year life. However, the present cost of installing a 10-year life anode today, and replacing it with a 10-year life anode in 10 years time is less than the cost of installing a 20-year life anode today. Therefore, the economical program would be to install anodes with a 10-year life initially and to plan for replacement in 10 years. <u>However, to provide for the minimum life planned for this structure, it is recommended that the anodes be installed with a design life of 20 years</u>.

For the tie-rod elements, where the cathodic protection anodes are not readily accessible for replacement, anodes with a design life of 20 years will be provided. These anodes will be installed in the backfill material a short distance below and electrically connected to each tie-rod.

The cathodic protection system for the bulkhead and dolphin piles should be inspected annually. This inspection should determine the location of the anodes, the condition of the anode supports and the anodes themselves, and the size of the anodes should be measured. The latter information can be used to determine the remaining life of the anode.

The cathodic protection system, together with the proposed protective coating systems, should extend the useful life of the structure.

IV FENDERING SYSTEM

A. Scope - Compare the relative merits of relocating the existing fender system for use at the new bulkhead location, or utilizing a new fender system that is more appropriate for a sheet pile bulkhead structure.

B. Preliminary Design Report - Because the existing fender system is in generally good condition and was properly designed for the vessels expected to use the port, its reuse was planned. The existing system would be disassembled and the piles pulled. All structural elements would be stored at the rear of the port's storage area, where they would be inspected and repaired, as required. It was assumed that about 10 percent of the material of the existing system would have to be replaced.

The restored and repaired fender system would be reinstalled the same distance from the new bulkhead structure as it had been from the existing concrete deck, thus allowing the movement and energy absorption for which it was designed. The estimated cost for the reuse of this system, in-place, was US Dollars 600,000.

C. Current Study, Conclusions and Recommendations - The existing fender system was designed to absorb the energy of the berthing vessel without transmitting any loads to the existing pile supported dock. This was a proper design because the existing dock structure was in very poor condition. However, the new bulkhead structure with granular backfill behind the sheet piling is capable of withstanding fairly large lateral loads caused by ship berthing operations. Thus, without the restriction of a structure in poor condition, other types of fender systems can be considered.

The controlling design conditions for the fender system are as follows:

Largest Ship:	10,000 DWT; 13,300 Displacement Tons	
	Length 150m; Draft 8.3m	
	Velocity 0.1m/second	
	Energy 70.0 ft-Kips (9.6 ton-meters)	
	Angle of Approach 10-15°	
	Max Hull Pressure 25 tons/sq m (5Kips/sq ft)	
Smaller Ship:	Minimum freeboard 1m (3.3 ft)	
	Radius of Hull Curvature 80 ft	
	Deck Elevation	+ 4.5m
	Water Levels	
	Extreme High Water Level	+ 3.4m
	Extreme Low Water Level	0.0
	MHWS	+ 3.1m
	MLWS	+ 0.3m

The largest ship controls the maximum energy and forces induced during berthing, but smaller vessels can cause damage by snagging fenders during

both horizontal and vertical movements. Large vessels sometimes have vertical and/or horizontal protrusions which can also cause damage through snagging.

Thus, the most suitable fender system has the following characteristics:

Energy Absorption Capacity
Horizontal and Vertical Continuity
Smooth Outer Surface
Minimum Susceptibility to Damage
Low Annual Maintenance Cost

Six alternative systems were considered for this project:

1. Reuse and reinstallation of the existing system.
2. Use of the horizontal wales and sections of the steel piles from the existing system, and new rubber fenders placed diagonally at 10 ft centers.
3. Same as 2 except without the horizontal wales.
4. Addition of a concrete fascia wall on the sheet piling and the use of a diagonally draped, chain-supported, cylindrical rubber fender system.
5. Use foam-filled floating fenders 3 ft in diameter, 10 ft long, spaced at 30 ft centers. These fenders will be anchored by chain supports to the bulkhead piling.
6. Same as 2 except utilize the lower horizontal wales as supports for the bulkhead tie-rods, thus eliminating the need to provide double-channel wales at the outer wall.

These systems are illustrated at the end of this section. Energy and cost estimating calculations are included in Appendix D.

The estimated cost for these fendering alternatives are as follows:

	COST (US$)		
	LABOR	MAT'L & EQUIP	TOTAL
ALT. 1	452,000	400,000	852,000 *
ALT. 2	421,000	604,000	1,025,000
ALT. 3	327,000	557,000	884,000
ALT. 4	513,000	896,000	1,409,000
ALT. 5	196,000	507,000	703,000
ALT. 6	450,000	563,000	1,013,000

*To this must be added the cost of providing cathodic protection which amounts to US$ 266,000 for a 20-year design life.

Alternatives 1, 2, 4 and 6 are eliminated from further consideration because of high costs. Alternative 1, the PDR-recommended scheme, becomes very costly because of the need for a cathodic protection system to protect the relatively bare steel of the piles. It is not considered economical to set-up a field coating operation for these piles. The bulkhead coating work will be performed in the shop.

Alternative 2 is similar to Alternative 3 except it provides horizontal wales to distribute the reactions of fenders laterally among the sheet piles. This distributing element can be eliminated in the interest of economy; it was not essential to the design of either the fendering or the bulkhead sheeting.

Alternatives 3 and 5 are the remaining candidates for considerations. The advantages and disadvantages of each are presented below:

Alternative 3 - Rubber Fenders on Steel members installed diagonally directly on the sheet piling.

Advantages

1. Enables berthed ship to be closer to edge of dock apron.
2. Utilizes detail appropriate to a sheet pile bulkhead which has the capacity to withstand ship berthing forces.
3. Utilizes a substantial rubber element that is less susceptible to damage from ship berthing.

Disadvantages

1. More costly than Alternative 5.
2. Requires frequent maintenance of the steel members.
3. Can be snagged by ship protrusions.

Alternative 5 - Floating Fender using "Seaguards", or equal, a fender fabricated of closed-cell resilient foam protected by a smooth outer skin of filament-reinforced elastomer.

Advantages

1. It is economical.
2. It has high energy absorption and low reactive force on the bulkhead structure and vessel.
3. It has a smooth outer skin with nothing to snag hull protrusions.
4. Simple installation using chains attached to the bulkhead structure.
5. Bouyant even if outer skin is punctured.
6. Unsinkable - will not be lost even if one of the chains should break (as compared with other chain-supported systems).
7. By being bouyant, the fender is always in position to contact the vessel regardless of tidal variations.

8. Low maintenance cost as no steel structures involved, only chains.

Disadvantages

1. At low tide the vessels' curved sections at bow and stern could contact the concrete cap of the bulkhead.
2. During tidal cycle fender can float about 3 ft away from bulkhead.
3. During storms the floating fenders are vulnerable to damage and could possibly damage the protective coating on the sheet piling.

"Seaguard" floating fenders, or equal, are recommend for the Kismayo Port Rehabilitation. This recommendation is based on their lowest capital cost, low maintenance cost, and suitability for use in areas with relatively large tidal and ship size variations. We believe details can be developed during final design to reduce the movement of the fenders away from the face of the bulkhead. Also, when severe storms are expected these fenders can be removed from the water and stored on the dock for safety.

Bulkhead Structure—Fendering

Port of Kismayo Rehabilitation

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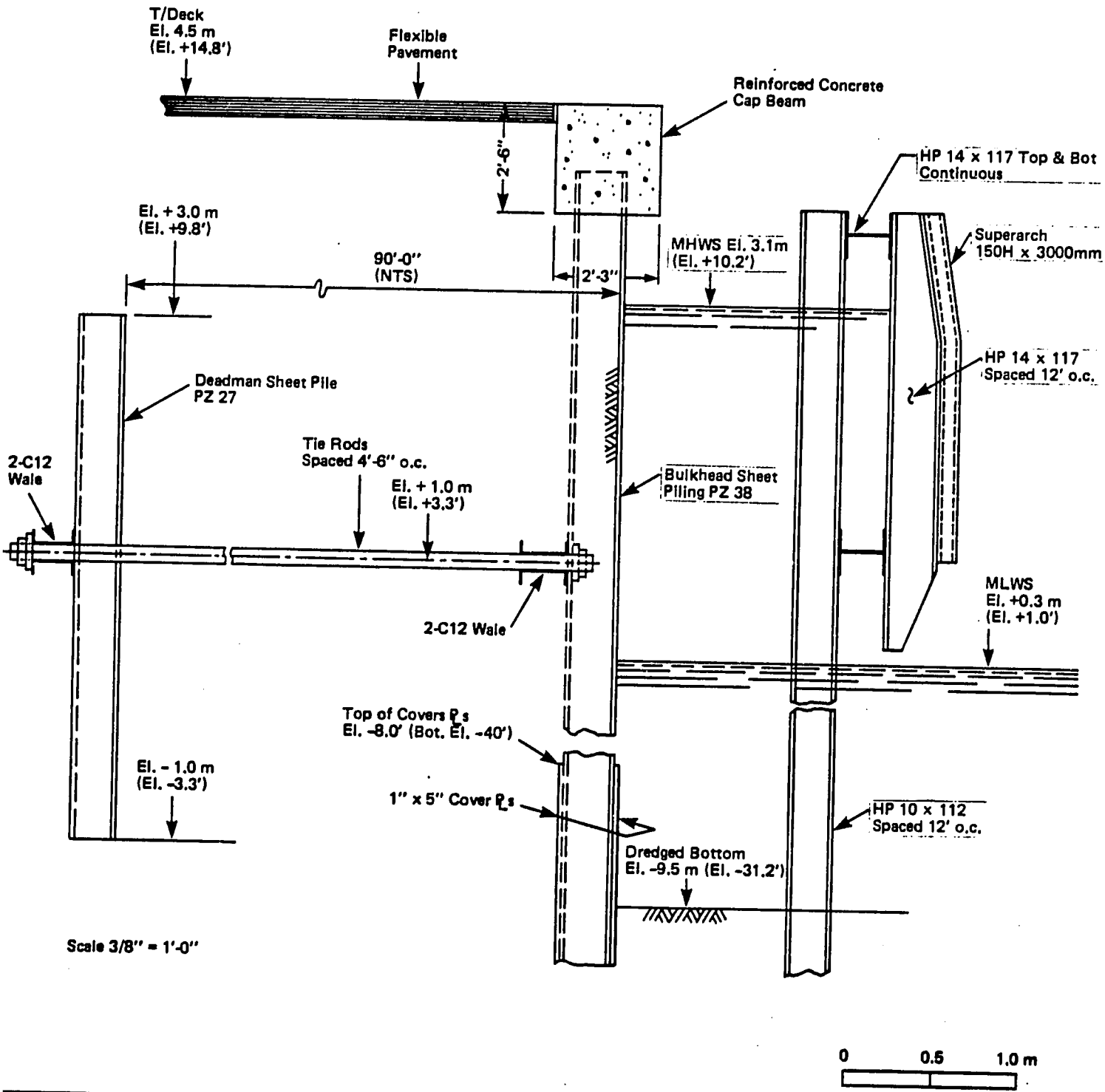
Alternative I



Bulkhead Structure—Fendering

Port of Kismayo Rehabilitation

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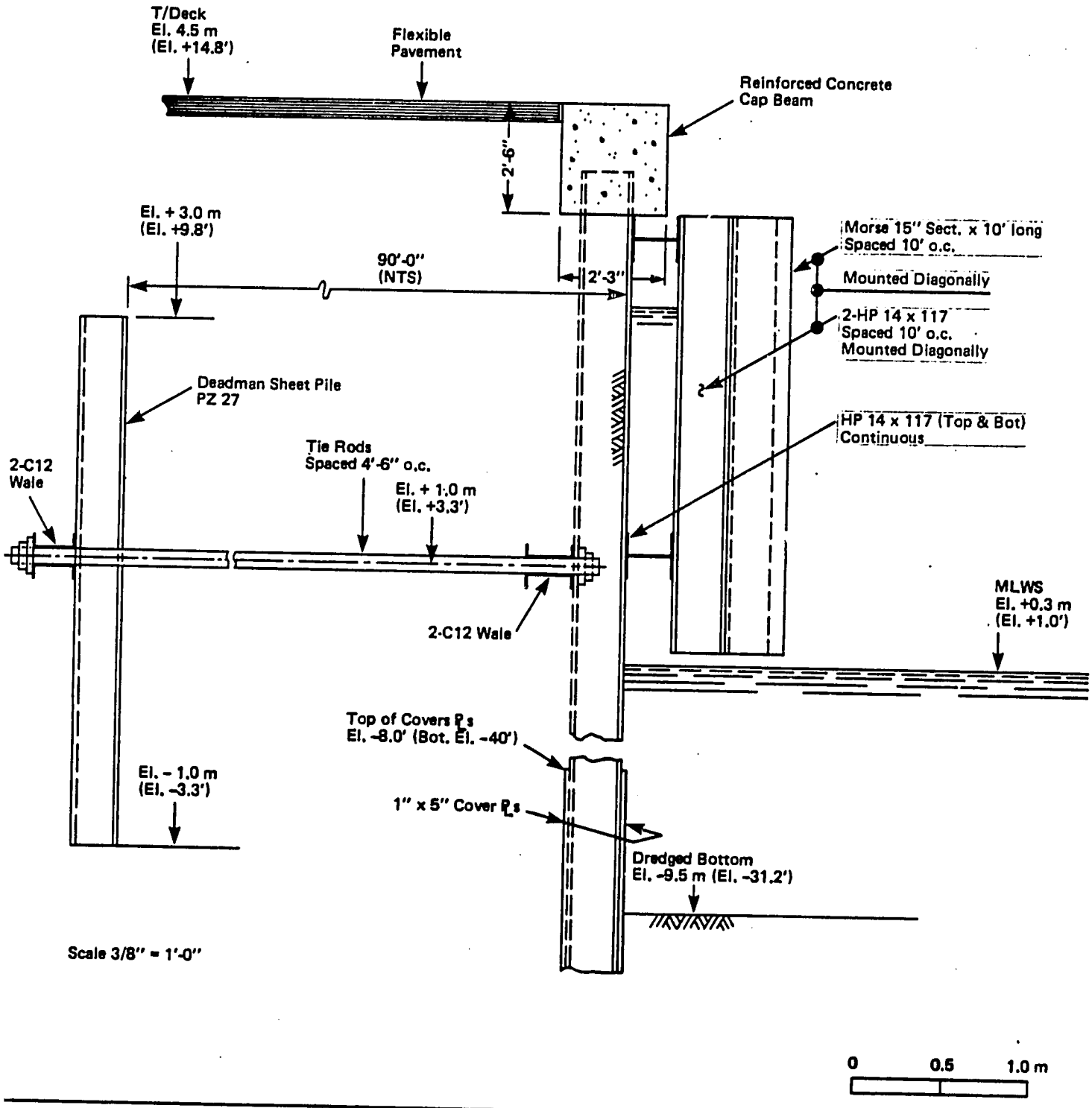
Alternative II



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Bulkhead Structure—Fendering

Port of Kismayo Rehabilitation

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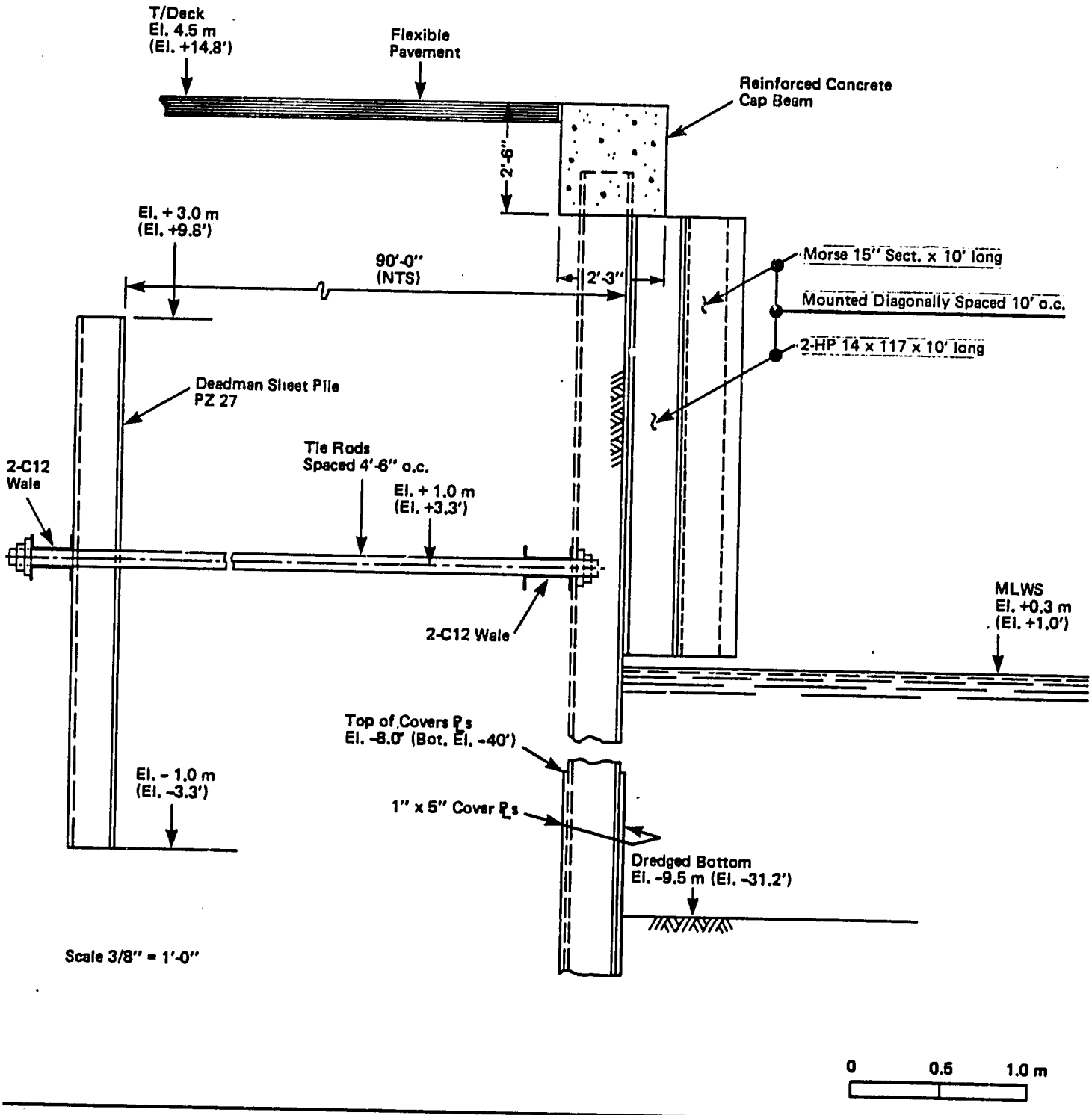
Alternative III



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Bulkhead Structure—Fendering

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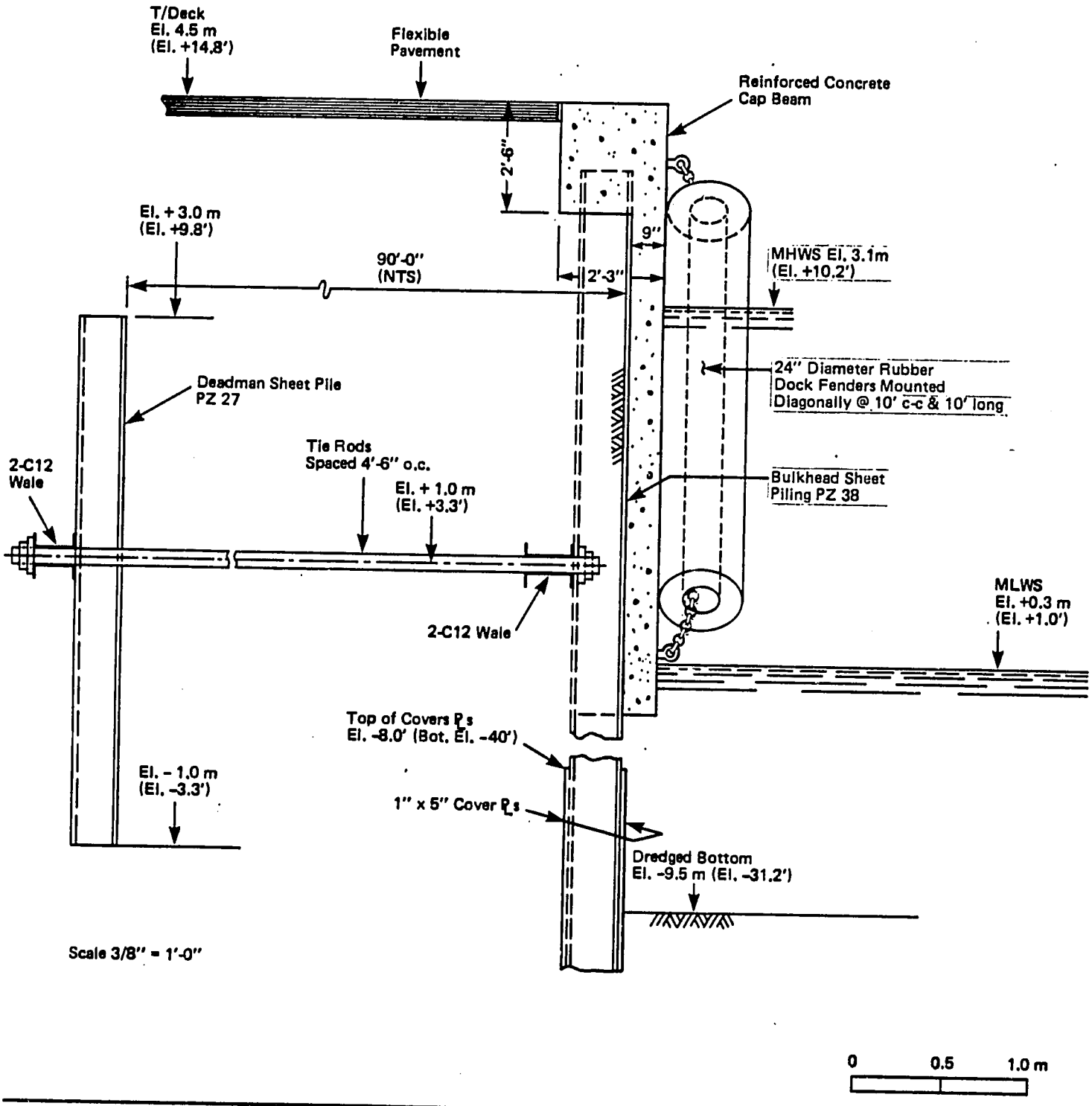
Alternative IV



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Bulkhead Structure—Fendering

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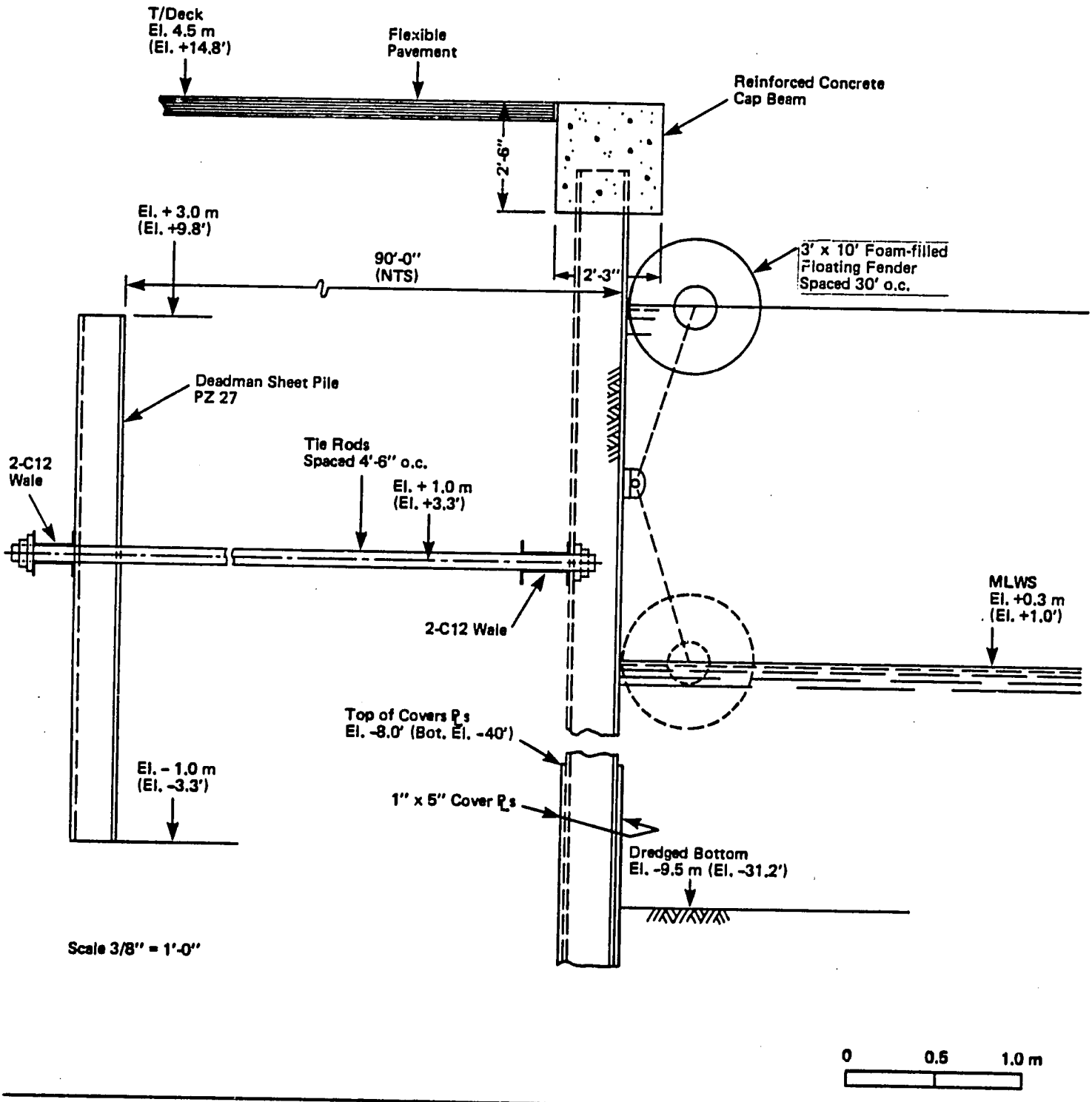
Alternative V



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Fender Alternatives

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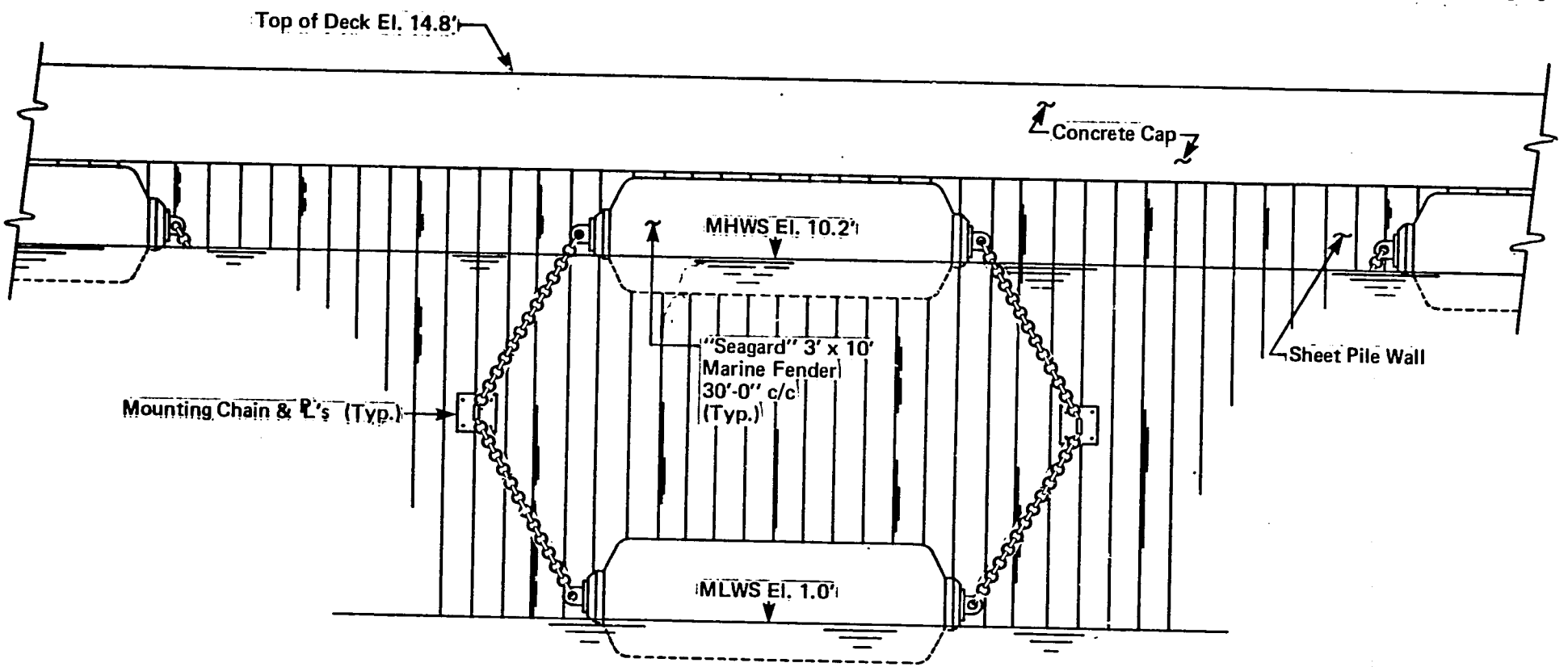
Alternative V



Bulkhead Structure—Fendering

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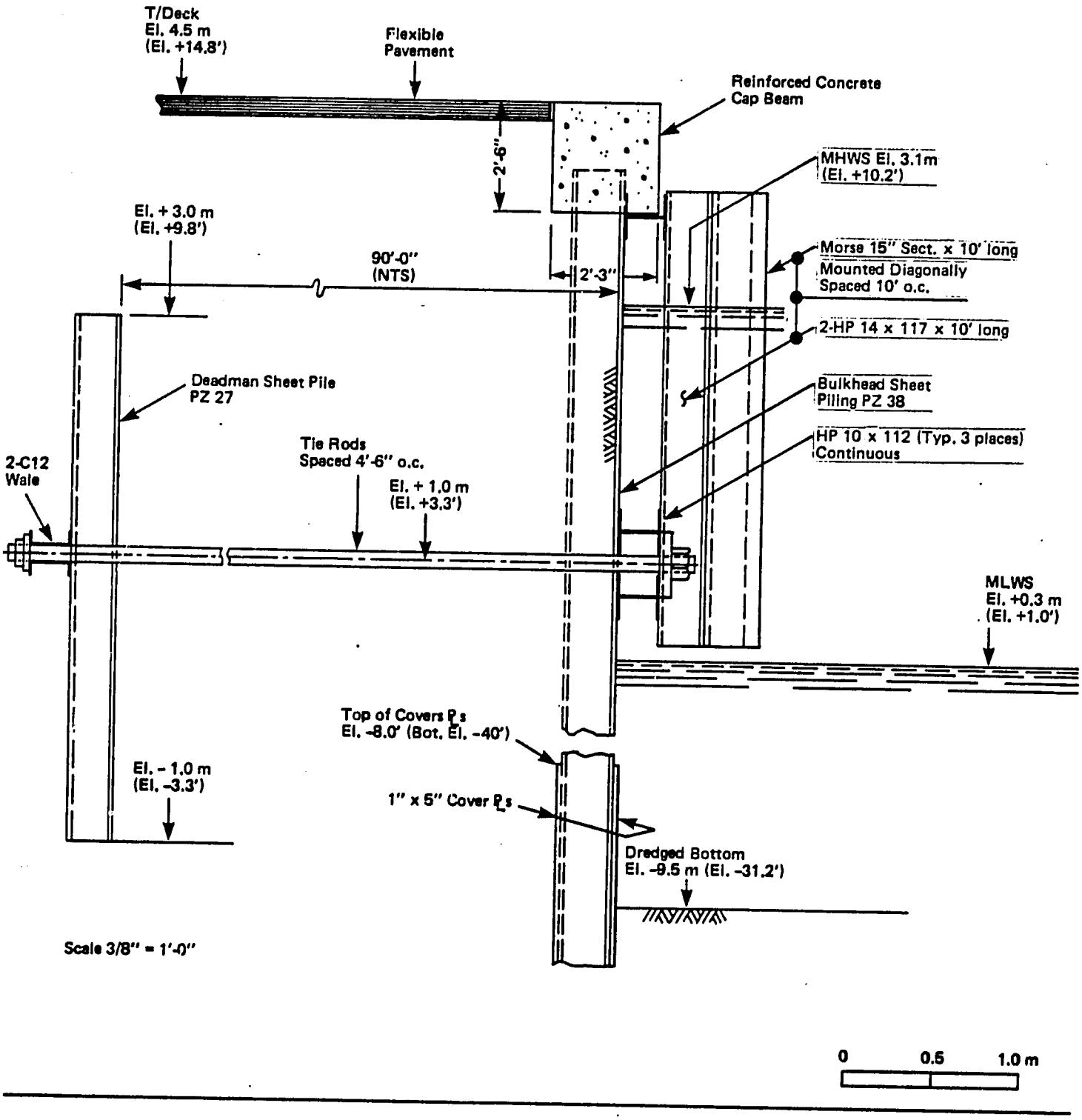
Alternative VI



V ROLL-ON/ROLL-OFF RAMP

A. Scope - Study the various types and characteristics of roll-on/roll-off vessels that are likely to call on the port and the effects on the ramp properties, i.e. slope, elevation, width, etc. Investigate alternative locations for ramp in consultation with the Somali Port Authority.

B. Preliminary Design Report - The proposed Ro-Ro ramp has been planned for the inshore end of Berth 3. It is actually located within the apron area of Berth 2, see plan. At this location, the ramp presents the least interference with port traffic while centrally located in the port area for access to storage areas and to the access roadway. Its slope will be about 10 percent. It will be suitable for stern (or bow) - unloading Ro-Ro vessels equipped with their own ramps.

C. Current Study, Conclusions and Recommendations - A study was made of Ro-Ro vessels that have called on Mogadishu and/or Kismayo and those that might call on these ports. From the Somali Port Authority we received a list of 18 Ro-Ro vessels that have called on these ports; of these all but one had stern ramps. The one exception, the Nape Verde, of Liberian registration, had side ramps.

From the Lloyds Register of Shipping, US Bureau of Shipping, we obtained a list of 25 vessels from four shipping lines that serve the East African area. Six of these vessels were included in the Somali Port Authority listing; of the remaining nineteen, we could obtain information about twelve. Of these twelve vessels, four had stern door ramps; four had stern doors; three had stern door ramps and side doors; and one had stern side doors. Thus, in summary, of a total of 37 Ro-Ro vessels, all but one had doors or doors and ramps at the stern.

<u>From the above information, it is recommended that the Ro-Ro ramp be provided to accommodate stern (or bow) loading vessels</u>.

The ramp location chosen in the PDR, at the end of Berth 3, was selected because of its relatively protected position and its central location within the port. However, other locations should also be investigated in consideration of the cargoes to be handled.

Ro-Ro cargoes consist mainly of the following:

Containers on wheeled vehicles
Vehicles and heavy equipment
Live animals.

Ro-Ro cargoes generally require a sizeable marshalling area to effect rapid loading and unloading, thus resulting in quick ship turnaround. For the containers, vehicles and heavy equipment, the area behind Berth 2 is a suitable marshalling area with ready access to both the Berth 3 ramp and the access roadway. Alternative areas are behind Berths 4 and 1.

For the live animals, the usual holding area has been behind Berth 4. An alternative holding area that could be used is the area behind Berth 2. The area behind Berth 1 is not considered suitable because of its proximity to the access roadway and the high traffic density in that area.

Stern (or bow) loading Ro-Ro vessels can be moored in either of two ways:

1. parallel to the wharf with the ramp or door accessing a ramp at right angles to the berth such as, mooring at Berth 3 with access to the ramp located in the apron of Berth 2, which is almost at right angles to Berth 3, or
2. perpendicular to the wharves containing the ramp.

In the latter case, the outer end of the vessel would be moored either with its own anchors, to an anchored buoy, or to a combination of both of them. Both of these methods of mooring are illustrated in Sketch 1, which shows the various alternative locations and moorings considered.

Sketch 1 indicates six alternative locations or orientations for Ro-Ro ramps and eight positions of the moored vessel. These alternatives will be discussed according to the designated moored vessel position.

1. This is the PDR-proposed ramp location with the vessel moored to Berth 3.
2. With the same ramp a vessel with skewed stern (or bow) ramp could load or unload while moored at Berth 2.
3. For vessels moored perpendicular to the wharf, a ramp at the east end of Berth 1 could be used. The mooring lines of such a moored vessel would not cause too much interference with harbor traffic. This ramp location provides ready access to the access roadway. It would not be suitable for animal loading.
4. Side door vessels could possibly use the Berth 1 ramp, provided they do not have too large a draft, as the harbor area east of the end of Berth 1 has not been dredged.
5. An alternative ramp could be provided from the east end of Berth 1, with the vessel moored entirely east of the berth. This alternative frees Berth 1 for other vessels but requires considerable dredging.
6. In this alternative, the vessel is moored perpendicular to the ramp at the west end of Berth 4. The ramp in this location would facilitate the loading of animals but the moored vessel presents considerable interference with vessels entering the harbor.
7. Mooring the vessel parallel to Berth 4 would require the construction off a platform or apron outside of the face of the bulkhead to receive the ship's stern (or how) ramp. This alternative eliminates the harbor traffic problem but limits the berthing space available for Berths 3 and 4. It prevents vessels from extending beyond the end of the berth.
8. Again, the vessel is moored perpendicular to the berth and causes excessive interference with harbor traffic.

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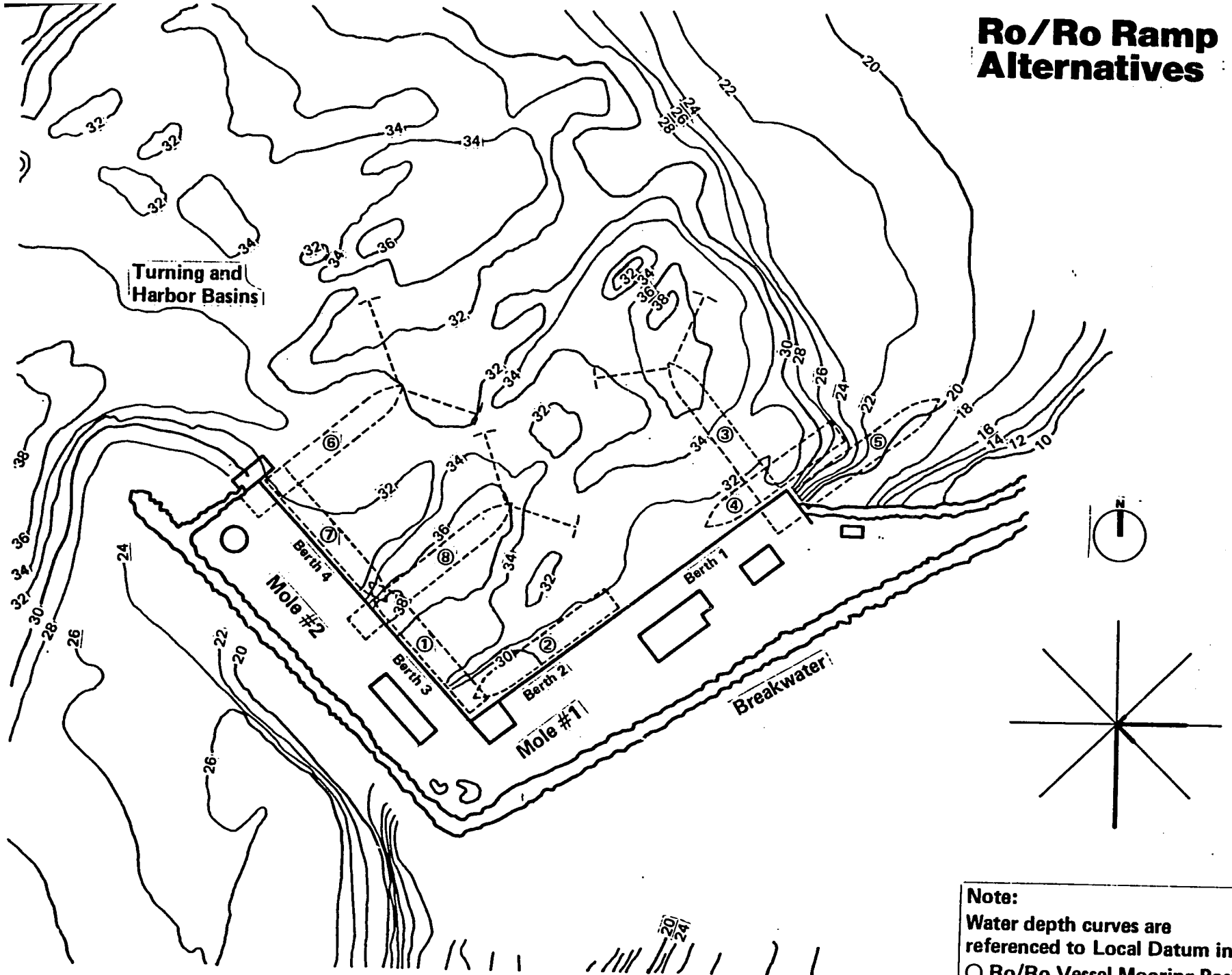
Based on the considerations presented above, it is concluded that the most acceptable ramp location is that for Berth 3 as proposed in the PDR. This ramp is fully protected from winds and waves, is reasonably accessible for both animals and vehicles, and could also be used for skewed ramp vessels. A second choice for the ramp location would be at the east end of Berth 1 for perpendicular mooring and for possible use by side door vessels. Vessels moored perpendicular to the berth at this location are subject to considerable wind forces during monsoon seasons and operations could be affected.

In order to provide as much flexibility for operations as reasonably possible, it is recommended that two Ro-Ro ramps be constructed, one for Berth 3 mooring and one for Berth 1, perpendicular mooring. In this way, the port can accommodate stern (or bow) ramp vessels, stern (or bow) skew ramp vessels, and to some extent, side ramp vessels. Ramps will be constructed with about 10 percent grades, will be 80 ft wide, and the outer edge of the ramp will be set at elevation + 2.5m or 2m below the apron level.

Ro/Ro Ramp Alternatives



Note:
Water depth curves are referenced to Local Datum in meters.
○ Ro/Ro Vessel Mooring Position

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VI BERTH CONSTRUCTION SEQUENCE AND RELOCATION OF POL AND MOLASSES LINES

A. Scope - Study of relocation of POL and molasses lines during construction period to provide for uninterrupted services; and study of pier construction sequences, allowing for a full utulization of two berths at any one time.

B. Preliminary Design Report - The construction sequence presented in the PDR proposed starting construction at Berth 4 and proceeding in order to Berth 1. Temporary relocation of POL and molasses lines would be required to facilitate uninterrupted service. Based on a starting date of September 1, 1984, the schedule for berth completion was presented as follows:

1st Berth (4)	February 1, 1986
2nd Berth (3)	May 1, 1986
3rd Berth (2)	February 1, 1987
4th Berth (1)	May 1, 1987

Project completed June 1, 1987.

Thus, it was estimated to take 20 months to complete the first two berths, and 12 months to complete the second two berths. Since neither the POL nor molasses services could be interrupted for 12 months, the temporary relocation of these service stations is necessary.

The total construction time, including one month for final clean-up and demobilization, is 33 months.

C. Current Study, Conclusion and Recommendations - The starting date for construction is not presently known but the overall construction time is still planned at 33 months. The construction of a sheet pile bulkhead is most efficiently and cost-effectively accomplished by starting at one end and proceeding continuously to the other end of the bulkhead. This procedure is also necessary to ensure that two berths are always available for port operations. Thus, the only alternatives available are starting at Berth 4 or starting at Berth 1. The construction sequence step-by-step for each of these alternatives is described in detail:

Construction Sequence I Berth 4 to Berth 1

1. Set-up contractors on-site yard behind Berth 4.
2. Relocate molasses line to Berth 2.
3. Construct new mooring dolphin.
4. After completion of step 2, demolish Berth 4.
5. Simultaneous with step 4, start construction of new Berth 4, including electric and water distribution lines, manholes and ship service stations.
6. Demolish Berth 3.
7. Complete Berth 4, including all items of step 5 and the permanent molasses loading stations.

Berths available for operations during steps 1 - 6

Berth 1. Bananas, P.O.L. and General Cargo
Berth 2. Molasses, Animals* and General Cargo
*Holding pen behind Berth 2

8. Remove temporary molasses lines.
9. Install temporary POL lines to Berth 3 area.
10. Start construction of Berth 3, including electric, water, etc.
11. Demolish Berth 2.
12. Complete Berth 3, including all items of step 10 plus the temporary unloading station for POL.
13. Relocate contractor's on-site yard to behind Berth 2.

Berths available for operations during steps 7 - 11

Berth 1. Bananas, POL and General Cargo
Berth 4. Molasses, Animals* and General Cargo
*Holding pen behind Berth 4

14. Start construction of Berth 2, including electric, water etc., and Ro-Ro ramp.
15. Start construction and installation of electric generators, including conduit to distribution manholes.
16. Demolish Berth 1.
17. Complete Berth 2, including all items of step 14.

Berths available for operations during steps 14 - 17

Berth 3. Bananas, POL and General Cargo
Berth 4. Molasses, Animals* and General Cargo
*Holding pen behind Berth 4

18. Start construction of Berth 1, including electric, water, etc., fire protection water intake facility, water and fire pump buildings, permanent POL station and Ro-Ro ramp.
19. Construct mooring dolphin.
20. Complete Berth 1 and all items of step 18.
21. Remove temporary POL piping and repair pavement.
22. Complete electric generator station and distribution wiring.

Berths available for operations after completion:

Berth 1. Bananas, POL, Ro-Ro and General Cargo
Berth 2. Ro-Ro, Bananas, General Cargo and Animals* at Ro-Ro ramp
Berth 3. General Cargo
Berth 4. Molasses, Animals* and General Cargo
*Holding pen behind Berth 4

23. Remove contractor's yard.
24. Repair and restore all pavements.
25. Clean-up and demobilize.

Construction Sequence II Berth 1 to Berth 4

1. Set-up contractor's yard behind Berth 2.
2. Relocate POL unloading station to Berth 3.
3. Construct new mooring dolphin.
4. After completion of step 1, demolish Berth 1.
5. Simultaneous with step 4, start construction of new Berth 1, fire protection water intake facility, water and fire pump buildings, electric and water distribution lines, manholes, ship service stations and Ro-Ro ramp.
6. Demolish Berth 2.
7. Complete Berth 1, including all items listed in step 5.

Berths available for operations during steps 1 - 6

Berth 3. Bananas, POL and General Cargo
Berth 4. Molasses, Animals* and General Cargo
*Holding pen behind Berth 4

8. Remove temporary POL lines and repair pavement at Berth 1.
9. Start construction of Berth 2, including electric, water, etc., and piping for temporary molasses station.
10. Demolish Berth 3.
11. Complete Berth 2, including all items of step 9. (Ro-Ro ramp is not included at this time).

Berths available for operations during steps 7 - 10

Berth 1. Bananas, POL, General Cargo and Ro-Ro
Berth 4. Molasses, Animals* and General Cargo
*Holding pen behind Berth 4
(Neither electric nor water service will be available at this time).

12. Start construction of Berth 3, including completion of Ro-Ro ramp at Berth 2, electric, water, etc., and complete connection of temporary molasses line.
13. Complete construction and installation of electric generators (long lead item), including conduit to distribution manholes.
14. Relocate contractor's on-site yard from behind Berth 2 to behind Berth 4.
15. Demolish Berth 4.
16. Complete Berth 3 and all items of step 12.

Berths available for operations during steps 11 - 16

Berth 1. Bananas, POL, Ro-Ro and General Cargo
Berth 2. Molasses, Animals*, Ro-Ro and General Cargo
*Holding pen behind Berth 2
(Electric and water service will be available at Berths 1 and 2).

17. Start construction of Berth 4, including electric, water, etc., and install permanent molasses loading stations.
18. Construct mooring dolphin.
19. Complete Berth 4 and all items of step 17.

Berths available for operations after completion:

Berth 1. Bananas, POL, Ro-Ro and General Cargo
Berth 2. Ro-Ro, General Cargo and Animals*
Berth 3. General Cargo
Berth 4. Molasses, Animals** and General Cargo
*If animals use Ro-Ro ramp
**Holding pen behind Berth 4

20. Remove contractor's yard.
21. Repair and restore all area pavements.
22. Clean-up and demobilize.

The advantages and disadvantages of each Construction Sequence are presented below:

Construction Sequence I Berth 4, 3, 2 and 1 (as presented in PDR)

Advantages

1. Does not disturb current, most active operations, bananas and POL, which take place at Berth 1.
2. Starts construction away from Berth 1 and access roadway , thus avoiding potential traffic interference.

Disadvantages

1. Cargo operations in 1986-87, when greater cargo is anticipated, must pass the construction area at Berth 1 to reach the available berths for port operations.
2. The utility modifications will not be completed and available until the end of the construction period as most incoming servicing pass through Berth 1.

Construction Sequence II Berth 1, 2, 3 and 4

Advantages

1. The utility services, water and fire protection, will be available to Berths 1 and 2 at an early date.
2. Berth 1 will be available for cargo operations at the earliest date.
3. If two Ro-Ro ramps are to be constructed, one will be available at an early date.

Disadvantages

1. Most active, current activities must be relocated.

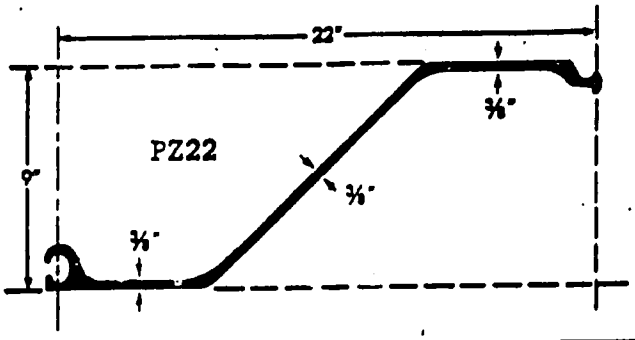
We recommend Construction Sequence II - starting construction at Berth 1 - which enable the early completion of the most active berths with a rehabilitated structure and modernized utility services, and will provide early modernized services to the Administration building.

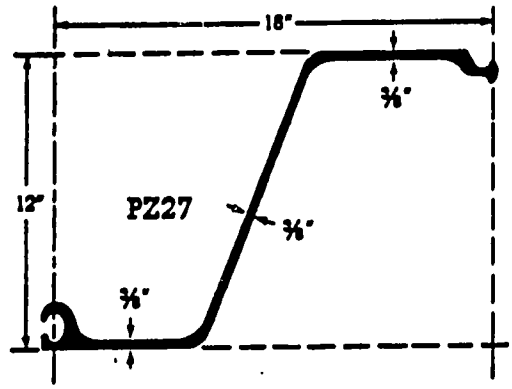
APPENDIX A

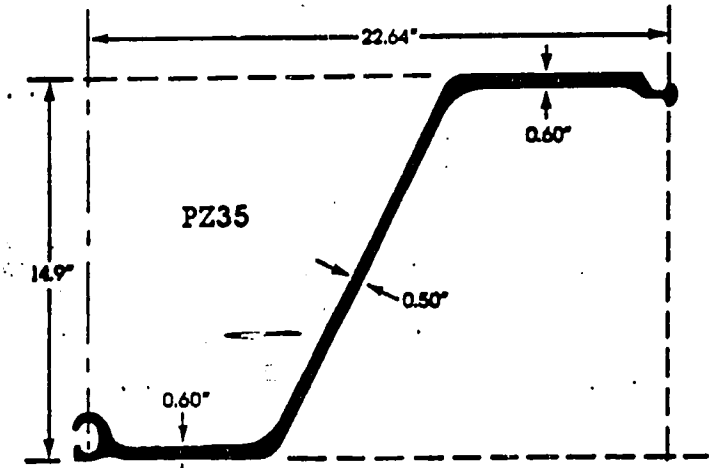
BULKHEAD SECTIONS

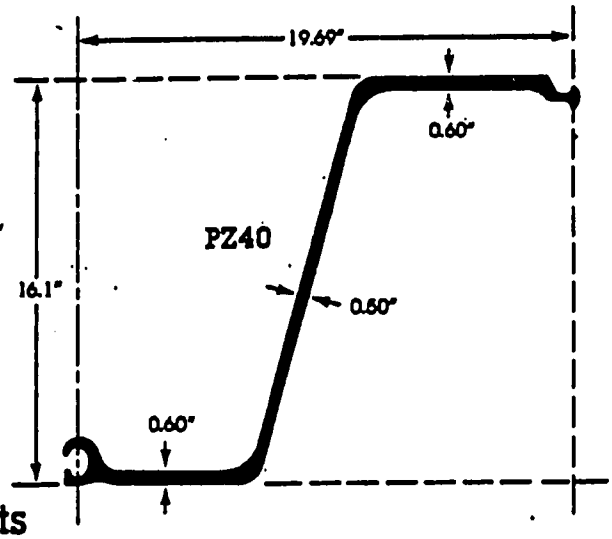
LABORATORY RESULTS
L.A. ABRASION TESTS

Now...
4 sheet piling sections from Bethlehem Steel









Properties and Weights

Section Designation	Area, sq in.	Nominal Width, in.	Weight in Pounds: Per lin ft of bar	Weight in Pounds: Per sq ft of wall	Moment of Inertia, in.⁴	Section Modulus, in.³: Single Section	Section Modulus, in.³: Per lin ft of wall	Surface Area, sq ft per lin ft of bar: Total Area	Surface Area, sq ft per lin ft of bar: Nominal Coating Area*
PZ22	11.86	22	40.3	22.0	154.7	33.1	18.1	4.94	4.48
PZ27	11.91	18	40.5	27.0	276.3	45.3	30.2	4.94	4.48
PZ35	19.41	22.64	66.0	35.0	681.5	91.4	48.5	5.83	5.37
PZ40	19.30	19.69	65.6	40.0	805.4	99.6	60.7	5.83	5.37

Note: All sections interlock with one another.

*Excludes bowl and ball of interlock.

For more information, call your nearest Bethlehem sales office. Or write Construction Products Sales, Bethlehem Steel Corporation, Bethlehem, PA 18016.

Bethlehem

Descriptive Sheet 3814
Printed in U.S.A.

Data current as of May 1983

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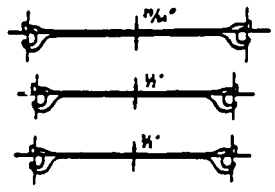
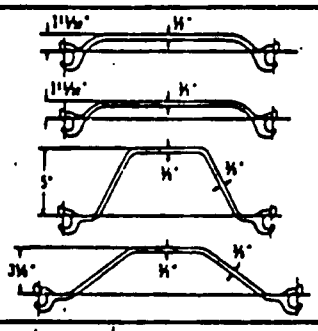
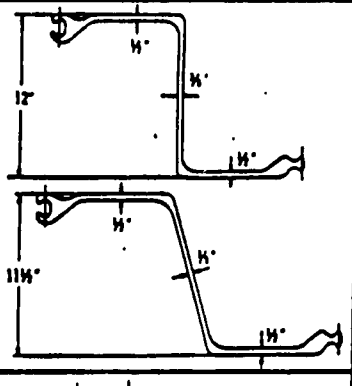
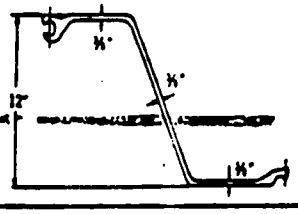
Steel Sheet Piling Sections

Profile	Section Index		District Rolled	Driving Distance per Pile	Weight Per Foot	Weight Per Square Foot of Wall	Web Thickness	Section Modulus Per Pile	Section Modulus Per Foot of Wall	Area Per Pile	Moment of Inertia Per Pile	Moment of Inertia Per Foot of Wall
				In.	Lbs.	Lbs.	In.	In.³	In.³	In.²	In.⁴	In.⁴
	Interlock with Each Other	PSX32	H.	16½	44.0	32.0	29/64	3.3	2.4	12.94	5.1	3.7
		PS32*	H.S.	15	40.0	32.0	½	2.4	1.9	11.77	3.6	2.9
		PS28	H.S.	15	35.0	28.0	⅜	2.4	1.9	10.30	3.5	2.8
	Interlock with Each Other	PSA28*	H.	16	37.3	28.0	½	3.3	2.5	10.98	6.0	4.5
		PSA23	H.S.	16	30.7	23.0	⅜	3.2	2.4	8.99	5.5	4.1
		~~PDA27~~	H.S.	16	36.0	27.0	⅜	14.3	10.7	10.59	53.0	39.8
		~~PMA22~~	H.S.	19⅝	36.0	22.0	⅜	8.8	5.4	10.59	22.4	13.7
	Interlock with Each Other and with PSA23 or PSA28	PZ38	H.	18	57.0	38.0	⅜	70.2	46.8	16.77	421.2	280.8
		PZ32	H.	21	56.0	32.0	⅜	67.0	38.3	16.47	385.7	220.4
	Interlocks with Itself and with PSA23 or PSA28	PZ27	H.	18	40.5	27.0	⅜	45.3	30.2	11.91	276.3	184.2

*Sections PS32 and PSA28 are infrequently rolled and we do not advise their use in a design unless an adequate tonnage can be ordered at one time to assure a minimum rolling.

Complete data regarding these sections will be found in a separate publication entitled "USS Steel Sheet Piling."

H—Homestead, Pa. (Pittsburgh District)
S—South Chicago (Chicago District)

Suggested Allowable Design Stresses—Sheet Piling

Steel Brand or Grade	Minimum Yield Point, psi	Allowable Design Stress, psi*
USS-EX-TEN 55 (ASTM A572 GR 55)	55,000	35,000
USS EX-TEN 50 (ASTM A572 GR 50)	50,000	32,000
USS MARINER STEEL	50,000	32,000
USS EX-TEN 45 (ASTM A572 GR 45)	45,000	29,000
Regular Carbon Grade (ASTM A 328)	38,500	25,000

*Based on 65% of minimum yield point. Some increase for temporary overstresses generally permissible.

U.S. STEEL PITTSBURGH (412) 433-1121
N.Y. (201) 843-0411

U.S. Steel

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Parsons Brinckerhoff International, Inc. Mogadishu, Somalia	A B R A S I O N LOS ANGELES TEST	TEST No. 1 Date 18-12-1983

TESTING METHOD: A S T M C 131 & 535

TEST FOR:

		Required C
☐ Coarse Aggregate		≤ 50%
☐ Base	Roads	≤ 40%
☐ Surface Dressing	Roads	≤ 35%
ROCKS, ROCKFILLS & FILTERS		
☐ Materials of Types I,II,III, V, VI & VII		≤ 35%
☐ Material of Type IV		≤ 50%

GRADING B

Weight and grading of test sample

Passing	Retained	weight	spheres	revolutions
3"	2 1/2"			
2 1/2"	2"			
2"	1 1/2"			
1 1/2"	1"			
1"	3/4"			
3/4"	1/2"	2500	11	500
1/2"	3/8"	2500		
3/8"	1/4"			
1/4"	No.4(4.75 mm)			
No.4-4.75mm	No.8(2.36 mm)			

Total weight W = 5000 Gr.

Weight of material coarser than no. 12 sieve W' = 3290

$W-W'$ = 1710

Los Angeles Coefficient $C = 100 \frac{W-W'}{W} C$ = 34.2 %

LOCATIONS OF CORRESPONDING WORKS AND REMARKS

MOGADISHU SAMPLE

Parsons Brinckerhoff International, Inc. Mogadishu, Somalia	A B R A S I O N LOS ANGELES TEST	TEST No. 2 Date 20-12-83

TESTING METHOD: A S T M C 131 & 535

TEST FOR:

		Required C
☐ Coarse Aggregate		≤ 50%
☐ Base	Roads	≤ 40%
☐ Surface Dressing	Roads	≤ 35%
ROCKS, ROCKFILLS & FILTERS		
☐ Materials of Types I,II,III, V, VI & VII		≤ 35%
☐ Material of Type IV		≤ 50%

GRADING B

Weight and grading of test sample

Passing	Retained	weight	spheres	revolutions
3"	2 1/2"			
2 1/2"	2"			
2"	1 1/2"			
1 1/2"	1"			
1"	3/4"			
3/4"	1/2"	2500		
1/2"	3/8"	2500	11	500
3/8"	1/4"	~~2500~~		
1/4"	No.4(4.75 mm)			
No.4-4.75mm	No.8(2.36 mm)			

Total weight W = 5000 Gr

Weight of material coarser than no. 12 sieve W' = 3683 "

$W-W'$ = 1137 "

Los Angeles Coefficient $C = 100 \frac{W-W'}{W}$ C = 22.7 %

LOCATIONS OF CORRESPONDING WORKS AND REMARKS

OLD AIRPORT KISMAYU SAMPLE

Parsons Brinckerhoff International, Inc. Mogadishu, Somalia	A B R A S I O N LOS ANGELES TEST	TEST No. 3 Date 20-12-83

TESTING METHOD: A S T M C 131 & 535

TEST FOR:

	Required C
☐ Coarse Aggregate	≤ 50%
☐ Base } Roads	≤ 40%
☐ Surface Dressing } Roads	≤ 35%
ROCKS, ROCKFILLS & FILTERS	
☐ Materials of Types I,II,III, V, VI & VII	≤ 35%
☐ Material of Type IV	≤ 50%

GRADING B

Weight and grading of test sample

Passing	Retained	weight	spheres	revolutions
3"	2 1/2"			
2 1/2"	2"			
2"	1 1/2"			
1 1/2"	1"			
1"	3/4"			
3/4"	1/2"	2500		
1/2"	3/8"	2500	11	500
3/8"	1/4"			
1/4"	No.4(4.75 mm)			
No.4-4.75mm	No.8(2.36 mm)			

Total weight W = 5000 Gr.

Weight of material coarser than no. 12 sieve W' = 3516 "

$W-W'$ = 1484 "

Los Angeles Coefficient $C = 100 \frac{W-W'}{W} C$ = 29.7%

LOCATIONS OF CORRESPONDING WORKS AND REMARKS

MERKA SAMPLE

34

Parsons Brinckerhoff International, Inc. Mogadishu, Somalia	A B R A S I O N LOS ANGELES TEST	TEST No. 4 Date 21-12-83

TESTING METHOD: A S T M C 131 & 535

TEST FOR:

		Required C
☐ Coarse Aggregate		≤ 50%
☐ Base	Roads	≤ 40%
☐ Surface Dressing	Roads	≤ 35%
ROCKS, ROCKFILLS & FILTERS		
☐ Materials of Types I,II,III, V, VI & VII		≤ 35%
☐ Material of Type IV		≤ 50%

GRADING B

Weight and grading of test sample

Passing	Retained	weight	spheres	revolutions
3"	2 1/2"			
2 1/2"	2"			
2"	1 1/2"			
1 1/2"	1"			
1"	3/4"			
3/4"	1/2"	2500		
1/2"	3/8"	2500	11	500
3/8"	1/4"			
1/4"	No.4(4.75 mm)			
No.4-4.75mm	No.8(2.36 mm)			

Total weight W = 5000 Gr.

Weight of material coarser than no. 12 sieve W' = 3680 "

$W-W'$ = 1320 "

Los Angeles Coefficient $C = 100 \frac{W-W'}{W}$ C = 26.4 %

LOCATIONS OF CORRESPONDING WORKS AND REMARKS

POLICE PIT SAMPLE
WEST OF ROAD

APPENDIX B

PROTECTIVE COATING

Report
References

Control of Corrosion of Ferrous Metals
Corrosion and Protection of Steel Piles
in a Natural Seawater Environment

PRODUCTS MECHANICAL CORP.

28 Cleveland Avenue
Glen Head, N.Y. 11545
(516) 671-2828
Lehigh Valley Facilities P.O. Box 159
Bath, Pa. 18014
(215) 759-6907

PROTECTIVE COATING SYSTEMS FOR STEEL SHEET PILING, WALES, TIE RODS AND ACCESSORIES

EVALUATION AND RECOMMENDATIONS

FOR PARSONS, BRINCKERHOFF QUADE & DOUGLAS, INC.

PORT OF KISMAYO
USAID - SOMALI DEMOCRATIC REPUBLIC
REHABILITATION OF BERTHS 1 - 4

JANUARY 13, 1984

QUALITY REPLICATION SPECIALISTS

37

HERBERT J. SCHMIDT, JR., P.E.
28 CLEVELAND AVENUE
GLEN HEAD, NEW YORK 11545

EVALUATIONS AND RECOMMENDATIONS

JANUARY 13, 1984

1.0 DESIGN ASSUMPTIONS

1.1 BULKHEAD WILL BE BUILT WITH EITHER PZ-35 OR PZ-38 REINFORCED STEEL SHEET PILING; 68.5' LONG. TOP OF PILES @ +13.3'. TIDE RANGE IS 3' - 4'. DREDGED WATER DEPTH @ -31.2'. BOTTOM OF PILES @ -55.2'. PILING TO RECEIVE A SHOP APPLICATION OF A SPECIFIED PROTECTIVE COATING SYSTEM.

1.1.1 BERTHS #1 & #2 @ 1,105.7'.
BERTHS #3 & #4 @ 922.0'.
TOTAL LENGTH = 2,027.7'.

1.1.2 SQUARE FOOT AREA TO BE COATED PER ~~LINEAR~~ SQUARE FOOT OF BULKH'D.
PZ-35 PILING @ 1.420/'.
PZ-38 PILING @ 1.690/'.

1.2 FENDER PILE SYSTEM CONSISTING OF ~~W 12X30~~ HP 10x112 H-PILES, WILL EITHER BE RELOCATED OR EXISTING H-PILES CUT AND WELDED HORIZONTALLY ONTO OUTBOARD FACE OF PILING. RUBBER FENDERS WILL BE ATTACHED TO H-PILES. H-PILES TO BE CLEANED AND COATED ON THE JOB SITE.

1.2 CONTINUED

1.2.1 SURFACE AREA @ 6 SQUARE FEET PER LINEAR FOOT.

1.3 WATERSIDE WALES CONSIST OF 2 - C12, SPACED SO AS TO PROVIDE ACCESS BETWEEN THEM FOR TIE RODS. WALES TO RECEIVE A SHOP APPLICATION OF A SPECIFIED PROTECTIVE COATING SYSTEM.

1.3.1. SURFACE ARE OF DOUBLE CHANNEL WALES @ 6.67 SQUARE FEET PER LINEAR FOOT.

1.4 TIE RODS WILL BE 3-1/4" DIAMETER FOR THE BULKHEAD AND 3" DIAMETER FOR THE BOLLARDS. LENGTH IS APPROXIMATELY 90'. TIE RODS, TURNBUCKLES, AND WATERSIDE NUTS AND PLATE WASHERS TO RECEIVE A SHOP APPLICATION OF A SPECIFIED PROTECTIVE COATING SYSTEM.

1.4.1 SURFACE AREA OF TIE RODS:

3" DIAMETER @ 0.79 SQUARE FEET PER LINEAR FOOT

3-1/4" DIAMETER @ 0.86 SQUARE FEET PER LINEAR FOOT.

1.0 CONTINUED

1.5 DEADMEN CONSISTING OF 13.1' LONG PZ-27 PILES AND 2 - C12 WALES. NO COATING REQUIRED.

1.6 24 MOORING ~~DOLPHINS~~ BOLLARDS WILL BE SUPPORTED ON 4 - HP14X73 H-PILES; 40' LONG; PER ~~DOLPHIN~~ BOLLARD. PILES TO RECIEVE A SHOP APPLICATION OF A SPECIFIED PROTECTIVE COATING SYSTEM.

1.6.1 SURFACE AREA @ 7.2 SQUARE FEET PER LINEAR FOOT.

2.0 PROTECTIVE COATING SYSTEM RECOMMENDATIONS

2.1 BACKGROUND

SINCE 1958, COAL TAR EPOXIES HAVE BEEN SUCCESSFULLY USED IN PROTECTIVE COATING SYSTEMS TO PROTECT EXPOSED, ALTERNATELY WET AND DRY, IMMERSED AND BACKFILLED STEEL PILING AND STRUCTURAL STEEL SHAPES FROM CORROSION. THESE SYSTEMS HAVE BEEN ESPECIALLY EFFECTIVE IN PROTECTING STEEL EXPOSED TO SALT AIR AND SALT WATER. THE ORIGINAL AMINE CURED COAL TAR EPOXIES WERE

2.1 CONTINUED

SOMETIMES FOUND TO POST-CURE AFTER APPLICATION AND INSTALLATION. THIS CAUSED EMBRITTLEMENT OF THE COATING AND THE POSSIBILITY OF SUBSEQUENT CRACKING OR CHECKING OF THE CURED COATING.

IN THE 1960'S, A HIGH STRENGTH, LOW ALLOY CARBON STEEL WAS DEVELOPED FOR SEA WATER EXPOSURE CONDITIONS, AND WAS MANY TIMES USED WITH THE COAL TAR EPOXY PROTECTIVE COATING SYSTEM. WHILE THE INITIAL RESULTS WERE ENCOURAGING, LONG TERM RESULTS DISCLOSED THAT THIS MORE EXPENSIVE ALLOY STEEL DID NOT PROVIDE THE EXPECTED EXTENDED SERVICE LIFE IN SEA WATER SPLASH ZONE AND TIDAL RANGE LOCATIONS.

2.2 RECOMMENDATIONS

2.2.1 IN THE 1960'S, A EPOXY POLYAMIDE COAL TAR PROTECTIVE COATING WAS DEVELOPED. IT WAS FOUND TO SIGNIFICANTLY REDUCE OR ELIMINATE THE POST CURE EMBRITTLEMENT PROBLEM. THE U.S. CORPS OF ENGINEERS ASSIGNED THEIR

2.2.1 CONTINUED

SPECIFICATION C-22 TO THIS COATING. COAL TAR EPOXY POLYAMIDE PROTECTIVE COATING MEETING SPECIFICATION C-200 IS RECOMMENDED FOR THE SUBJECT JOB.

2.2.2 IN ORDER TO ENHANCE THE LONGEVITY OF THE COAL TAR EPOXY PROTECTIVE COATING SYSTEM AND TO EXPLORE ALTERNATE COATING SYSTEMS, THE UNITED STATES NATIONAL BUREAU OF STANDARDS CONTRACTED WITH THIS REPORT WRITER'S FORMER COMPANIES TO APPLY A NUMBER OF DIFFERENT PROTECTIVE COATING SYSTEMS ON STRUCTURAL STEEL WHICH WAS THEN PLACED IN SEVERAL SEAWATER LOCATIONS. THEIR LATEST MONOGRAPH WAS PUBLISHED IN 1977 AND IS APPENDED TO THIS REPORT. AS CAN BE SEEN, BOTH AN INORGANIC ZINC RICH PRIMER AND AN ORGANIC ZINC RICH PRIMER WERE APPLIED UNDER A COAL TAR EPOXY COATING. THESE PRIMERS ENHANCED THE USEFUL LIFE OF THE COAL TAR EPOXY COATINGS. WHILE THE INORGANIC ZINC PEREORMED MUCH BETTER THAN

2.2.2 CONTINUED

ORGANIC ZINC, THE INORGANIC ZINC PRESENTS AN APPLICATION AND CURING PROBLEM TO MANY COATING APPLICATION COMPANIES. ADDITIONALLY, THE ORGANIC ZINC RICH COATINGS MEETING D.O.D. P-23236, HAVE BEEN SIGNIFICANTLY IMPROVED FROM THOSE USED IN THE 1960'S AND EARLY 1970'S. FOR THESE REASONS, THE ORGANIC ZINC RICH PRIMER IS RECOMMENDED FOR USE ON THE SUBJECT JOB.

2.2.3 THE LIFE OF ANY PROTECTIVE COATING SYSTEM IS DIRECTLY PROPORTIONAL TO NOT ONLY THE PROFESSIONALISM OF THE COATING APPLICATOR AND THE COATING MATERIALS USED, BUT TO THE QUALITY AND DEGREE OF CLEANLINESS OF THE STEEL SUBSTRATE. FOR THESE REASONS, A NEAR WHITE SANDBLAST FINISH IS RECOMMENDED FOR ALL SHOP COATING FOR THE SUBJECT JOB.

2.2.4 IT IS ANTICIPATED THAT THIS RECOMMENDED PROTECTIVE COATING SYSTEM WILL EXTEND THE USEFUL LIFE OF THE STEEL OVER 25 YEARS.

2.2 CONTINUED

2.2.5 TIE RODS, TURNBUCKLES, AND WATER SIDE NUTS AND PLATE WASHERS SHOULD BE COATED IN ACCORDANCE WITH 2.2.1, 2.2.2 & 2.2.3.

2.2.5.1 AN ALTERNATE AND A VERY GOOD PROTECTIVE COATING SYSTEM FOR COATING THE TIE RODS IS BASED ON THE FOLLOWING COATING SYSTEM.

CLEAN IN ACCORDANCE WITH 2.2.3. APPLY TWO COATS OF A COLD BITUMINOUS COATING SUCH AS KOPPERS BITUMASTIC NO. 50. WHILE THE LAST COAT IS STILL TACKY, WRAP THE TIE RODS WITH A 15 POUND COAL TAR SATURATED PIPE LINE FELT, OVERLAPPING THE FELT FIFTY PERCENT. SECURE THE FELT AT THE ENDS OF THE TIE RODS. FIELD TOUCH UP EXPOSED THREADS AND ANY DAMAGE WITH THE SAME MATERIAL, AFTER INSTALLATION.

2.2 CONTINUED

2.2.6 EXISTING FENDER PILES WHICH ARE EITHER RELOCATED OR REUSED, ARE PRESENTLY PAINTED WITH A RED LEAD PRIMER AND TOPCOATED WITH AN ALUMINUM PAINT. THE REALITIES OF LOCAL CONDITIONS OBVIATE THE POSSIBILITY OF HAVING THIS STEEL CLEANED AND COATED UTILIZING THE MOST DESIRABLE CLEANING AND PROTECTIVE SYSTEMS. THEREFORE, WHEN THE PILES ARE PULLED AND BEFORE RELOCATING AND DRIVING, THEY SHOULD BE HAND SCALED AND HAND WIREBRUSHED TO REMOVE ALL LOOSE RUST AND OTHER DELETERIOUS MATTER. BRUSH APPLY TWO COATS OF A COLD BITUMINOUS COATING SUCH AS KOPPERS BITUMASTIC NO. 50. WHEN DRY, BRUSH APPLY TWO COATS OF A RUBERIZED COAL TAR EMULSION COATING SUCH AS KOPPERS BITUPLASTIC NO. 33.

2.2.7 QUALITY ASSURANCE AND QUALITY CONTROL THROUGH ALL OPERATIONS ~~IS~~ ARE ESSENTIAL TO OBTAINING AN EXTENDED LIFE PROTECTIVE COATING. IT IS RECOMMENDED THAT A QUALIFIED OUTSIDE INSPECTOR BE ENGAGED TO SUPERVISE ALL PHASES OF THE SHOP

2.2.7 CONTINUED

CLEANING, COATING, HANDLING, LOADING AND SHIPPING. THE COATED SURFACES MUST BE PROTECTED FROM DAMAGE BY THE USE OF SUITABLE PADDING MATERIALS. PROPER PACKAGING IS ESSENTIAL. STRONGBACKS WITH NYLON SLINGS SHOULD BE USED FOR LOADING AND OFF-LOADING COATED PILING, TIE RODS AND ACCESSORIES. DAMAGE TO THE COATED SURFACES OCCURS MOST OFTEN DURING LOADING ON SHIPBOARD AND OFF-LOADING AT THE DESTINATION. A QUALIFIED OUTSIDE INSPECTOR SHOULD BE HIRED TO SUPERVISE AND OVERSEE ALL PHASES OF THESE OPERATIONS. ALSO, PROPER LOADING AND PROPER SECURING OF THE COATED STEEL IS ESSENTIAL. BY EXERCISING REASONABLE CARE, THE COATED STEEL WILL ARRIVE AT ITS DESTINATION IN EXCELLENT CONDITION.

2.2.8 A SPLASH ZONE EPOXY COATING MAY BE USED FOR FIELD TOUCH-UP OF ANY ABRADED OR DAMAGED COATING. THE DAMAGED COATING SHOULD BE REMOVED UNTIL THE ~~REMAINING COATING IS FIRMLY~~ BONDED TO THE STEEL. THE SUBSTRATE SHOULD BE HAND WIREBRUSHED PRIOR

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2.2.8 CONTINUED

TO THE APPLICATION OF THE TOUCH-UP COATING MATERIAL.

3.0 COST PARAMETERS

3.1 IDEALLY, THE STEEL SHEET PILING SHOULD BE COATED ON BOTH SIDES FROM THE TOP TO 3.0' BELOW THE DREDGED WATER LINE. THE SURFACE AREA TO BE COATED, EXCLUSIVE OF THE BOWL AND BALL OF THE INTERLOCK IS:

1) PZ-35 2,027.7'X47.5'X1.420/'X2 SIDES = 273,5370

2) PZ-38 2,027.7'X47.5'X1.690/'X2 SIDES = 325,5470

AN EXCELLENT JOB OF CORROSION PROTECTION CAN BE ACHIEVED BY COATING THE OUTBOARD SIDE OF THE STEEL SHEET PILING AS DESCRIBED ABOVE, AND BY COATING THE INBOARD SIDE TO 5' BELOW THE MEAN LOW WATER LINE. THEREFORE:

3) PZ-35 2,027.7'X(47.5'+18.3')X1.420/' = 189,4600

4) PZ-38 2,027.7'X(47.5'+18.3')X1.690/' = 225,4840

IF BOTH SIDES ARE COATED 47.5', SUB-ITEMS 1) & 2), THE ESTIMATED UNIT COST IS $1.65 PER SQUARE FOOT OF COATED AREA. IF THE OUTBOARD SIDE IS COATED 47.5'

3.1 CONTINUED

AND THE INBOARD SIDE IS COATED 18.3', SUB-ITEMS 3) & 4), THE ESTIMATED UNIT COST IS $1.95 PER SQUARE FOOT OF COATED AREA.

1) $451,336.

2) $537,153.

3) $369,447.

4) $439,694.

3.2 WATER SIDE WALES TO BE COATED 100 PERCENT.

2,027.7'X6.670/' = 13,5250

ESTIMATED COATING COST IS $1.95 PER ~~LINEAR~~ SQUARE FOOT OF WALE.

13,5250 @ $1.95 = $25,374.

3.3 TIE ROD PROTECTIVE COATING SYSTEM PERFORMED IN ACCORDANCE WITH 2.2.1, 2.2.2 & 2.2.3 IS ESTIMATED TO COST $2.75 PER LINEAR FOOT. THERE ARE APPROXIMATELY 450 TIE RODS FOR THE BULKHEAD AND 48 TIE RODS FOR THE BOLLARDS. TOTAL IS 498 TIE RODS, 90' LONG.

498X90' = 44,820' @ $2.75 = $123,255.

498 NUTS TO BE COATED @ $9.50 = $4,731.

3.3 CONTINUED

498 PLATE WASHERS TO BE COATED @ $14.00 = $6,972.

996 TURNBUCKLES TO BE COATED @ $22.00 = $21,912.

TOTAL OF ABOVE = $156,870.

3.3.1 TIE ROD PROTECTIVE COATING SYSTEM PERFORMED IN ACCORDANCE WITH THE ALTERNATE SYSTEM DESCRIBED IN 2.2.5.1 IS ESTIMATED TO COST $2.50 PER LINEAR FOOT.

498X90' = 44,820' @ $2.50 = $112,050.

498 NUTS TO BE COATED @ $8.50 = $4,233.

498 PLATE WASHERS TO BE COATED @ $12.50. = $6,225.

996 TURNBUCKLES TO BE COATED @ $20.00 = $19,920.

TOTAL OF ABOVE = $136,203.

3.4 MOORING ~~DOLPHIN~~ BOLLARD HP14X73 H-PILES TO BE COATED 100 PERCENT.

24X4X40'X70/' = 26,8800

ESTIMATED COATING COST IS $1.65 PER SQUARE FOOT.

26,8800 @ $1.65 = $44,352.

3.0 CONTINUED

3.5 FENDER PILES ARE TO BE REUSED AND FIELD COATED IN ACCORDANCE WITH RECOMMENDATIONS CONTAINED IN 2.2.6. MATERIAL COSTS ARE EXPECTED TO BE APPROXIMATELY $0.45 PER SQUARE FOOT. THE SURFACE AREA OF A HP14X73 H-PILE IS 7.2 SQUARE FEET PER LINEAR FOOT. FIELD MEASUREMENTS WILL BE NECESSARY TO OBTAIN TOTAL LINEAR FEET TO BE COATED.

3.6 COATING FOR HP 14 x 73 MOORING DOLPHIN PILES IS ESTIMATED TO COST -
2 DOLPHINS X 4 PILES EA x 7 ft x 70 FT @ 1.65 = $6500.

4.0 SUMMARY

4.1 NO ALLOWANCE HAS BEEN MADE FOR EITHER FREIGHT FROM THE STEEL MILL TO THE COATING APPLICATORS PLANT, NOR FROM THE COATING APPLICATORS PLANT TO THE PORT FOR SHIPPING. NOTE: MOST COATING APPLICATORS HAVE PLANTS WITHIN TWENTY MILES OF THE STEEL MILLS.

4.2 ALL PRICES AND COST ESTIMATES ARE BASED ON CURRENT U. S. MATERIAL AND LABOR COSTS WITHOUT ANY ESCALATION FACTOR, AND AT A COATING APPLICATORS PLANT.

4.0 CONTINUED

4.3 NO ALLOWANCE HAS BEEN MADE FOR EXPORT PACKAGING.

4.4 NO ALLOWANCE HAS BEEN MADE FOR AN OUTSIDE INSPECTOR. COST FOR THIS SERVICE IN THE U.S. IS $250. TO $400. PER DAY.

4.5 ATTACHED IS A COPY OF THE JUNE 1977 U. S. DEPARTMENT OF COMMERCE / NATIONAL BUREAU OF STANDARDS MONOGRAPH 158, TITLED: CORROSION AND PROTECTION OF STEEL PILES IN A NATURAL SEAWATER ENVIRONMENT. YOUR ATTENTION IS DIRECTED TO TABLE 3. ON PAGE 34.

4.6 ATTACHED IS A COPY OF A REPRINT OF A SECTION OF PORT PLANNING, DESIGN AND CONSTRUCTION, A PUBLICATION OF THE AMERICAN ASSOCIATION OF PORT AUTHORITIES, TITLED: CONTROL OF CORROSION OF FERROUS METALS, WHICH WAS WRITTEN BY THE WRITER OF THIS REPORT. YOUR ATTENTION IS ESPECIALLY DIRECTED TO PAGES 451 THROUGH 458.

HERBERT J. SCHMIDT, JR., P.E.
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GLEN HEAD, NEW YORK 11545
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ACCOMPLISHMENTS

* INSTRUMENTAL IN CREATING NEW MULTI-MILLION DOLLAR INDUSTRY. ASSISTED GOVERNMENT AGENCY IN BRINGING THEIR NATIONAL EXPERIMENTAL AND EVALUATION PROGRAM INTO FULL COMMERCIAL USE.
* DEVELOPED TWO MARKETS. COATED PILING AND EPOXY COATED REBARS.
* DEVELOPED AND FINANCED SEVERAL MANUFACTURING FACILITIES TO SUPPORT MARKETS.
* PERFORMED R & D NECESSARY TO PROVIDE MANUFACTURING MACHINERY TO PROCESS PRODUCTS. AUTHORED NUMEROUS COATING SPECIFICATIONS.
* FOUNDED M C P FACILITIES CORPORATION IN 1969. SERVED AS PRESIDENT FOR THIRTEEN YEARS. ESTABLISHED THREE PLANTS LOCATED IN PENNSYLVANIA AND ILLINOIS.
* FOUNDED AND SERVED AS GENERAL MANAGER FOR SEVEN YEARS, THE PROTECTIVE COATING DIVISION OF STEELE & ASSOCIATES, INC. ESTABLISHED TWO PLANTS LOCATED IN NEW YORK AND PENNSYLVANIA.

PROFESSIONAL

* REGISTERED PROFESSIONAL ENGINEER IN CALIFORNIA, MASSACHUSETTS AND RHODE ISLAND
* SENIOR MEMBER - SOCIETY OF MANUFACTURING ENGINEERS
* CERTIFIED CORROSION SPECIALIST - NATIONAL ASSOCIATION OF CORROSION ENGINEERS

EDUCATION

* ILLINOIS INSTITUTE OF TECHNOLOGY - BSCE (MANAGEMENT)

Figure 7-1

Plan—Alternative Bulkhead Location No. 1

Port of Kismayo Rehabilitation

Parsons Brinckerhoff International, Inc.

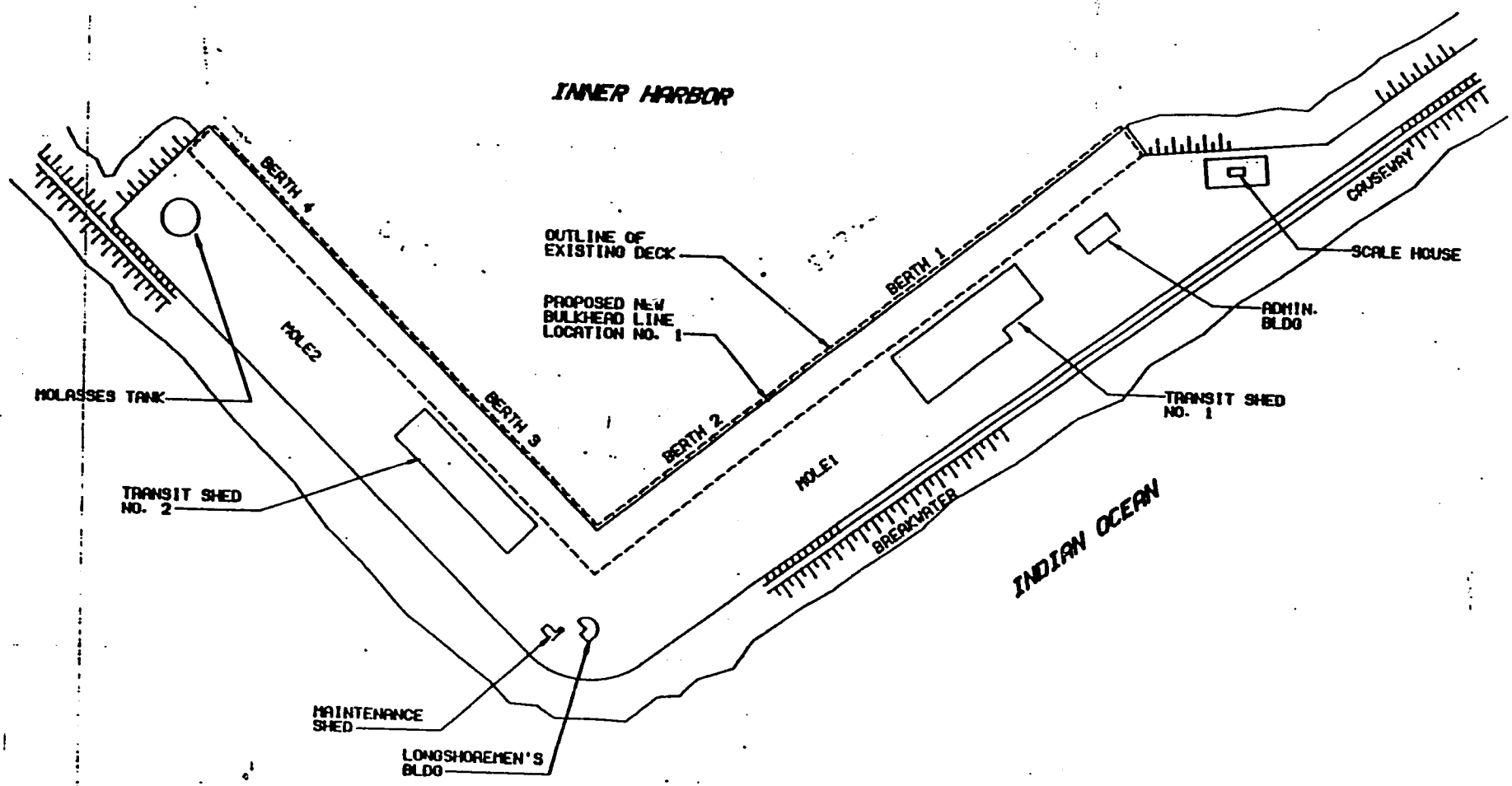

Figure 7-3

Cross Section Through Bulkhead—Location No. 2

Port of Kismayo Rehabilitation

Parsons Brinckerhoff International, Inc.

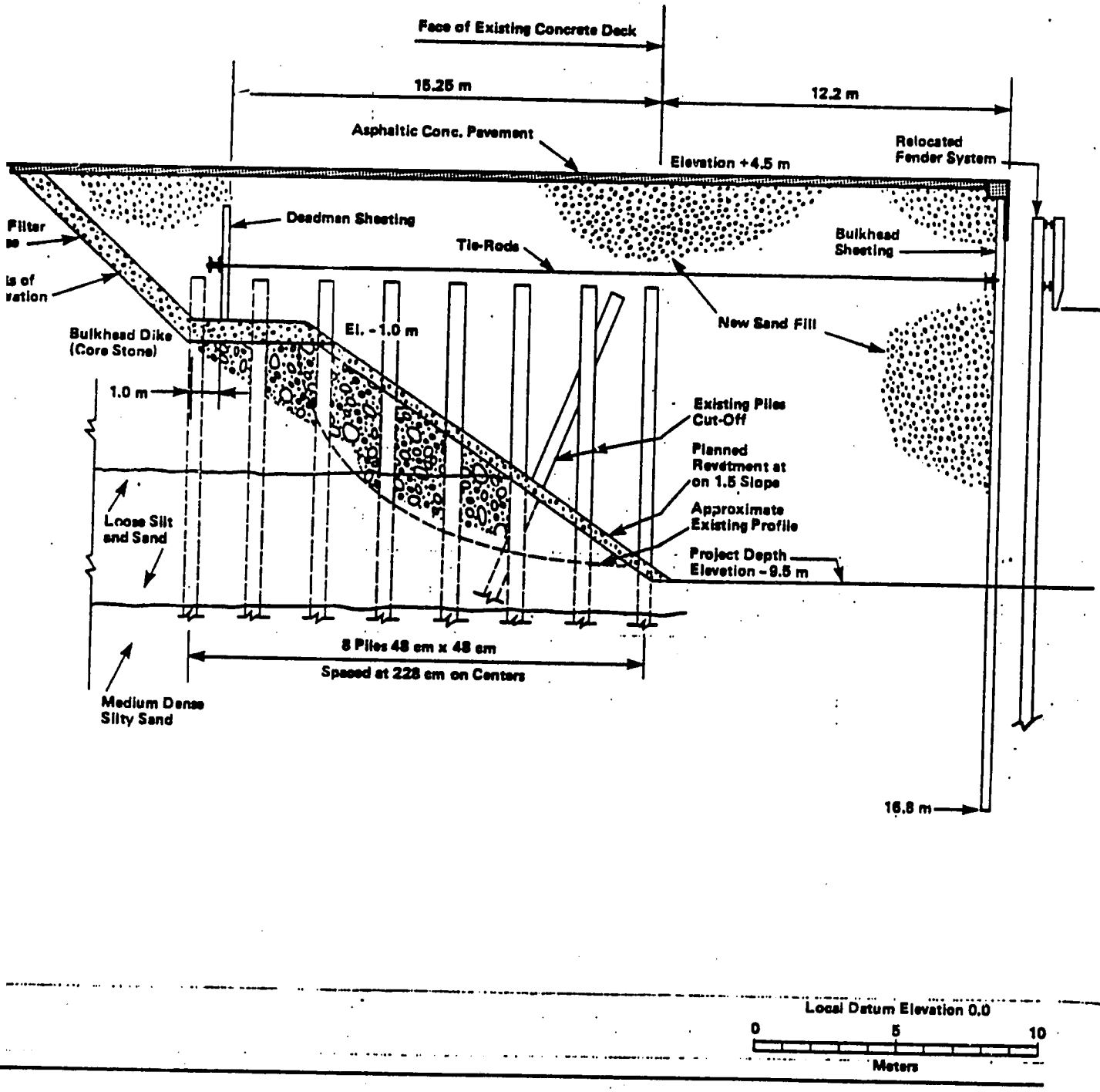

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Figure 7-5a

Bulkhead Structure—Details Sheet No. 1

Port of Kismayo Rehabilitation

Parsons Brinckerhoff International, Inc.

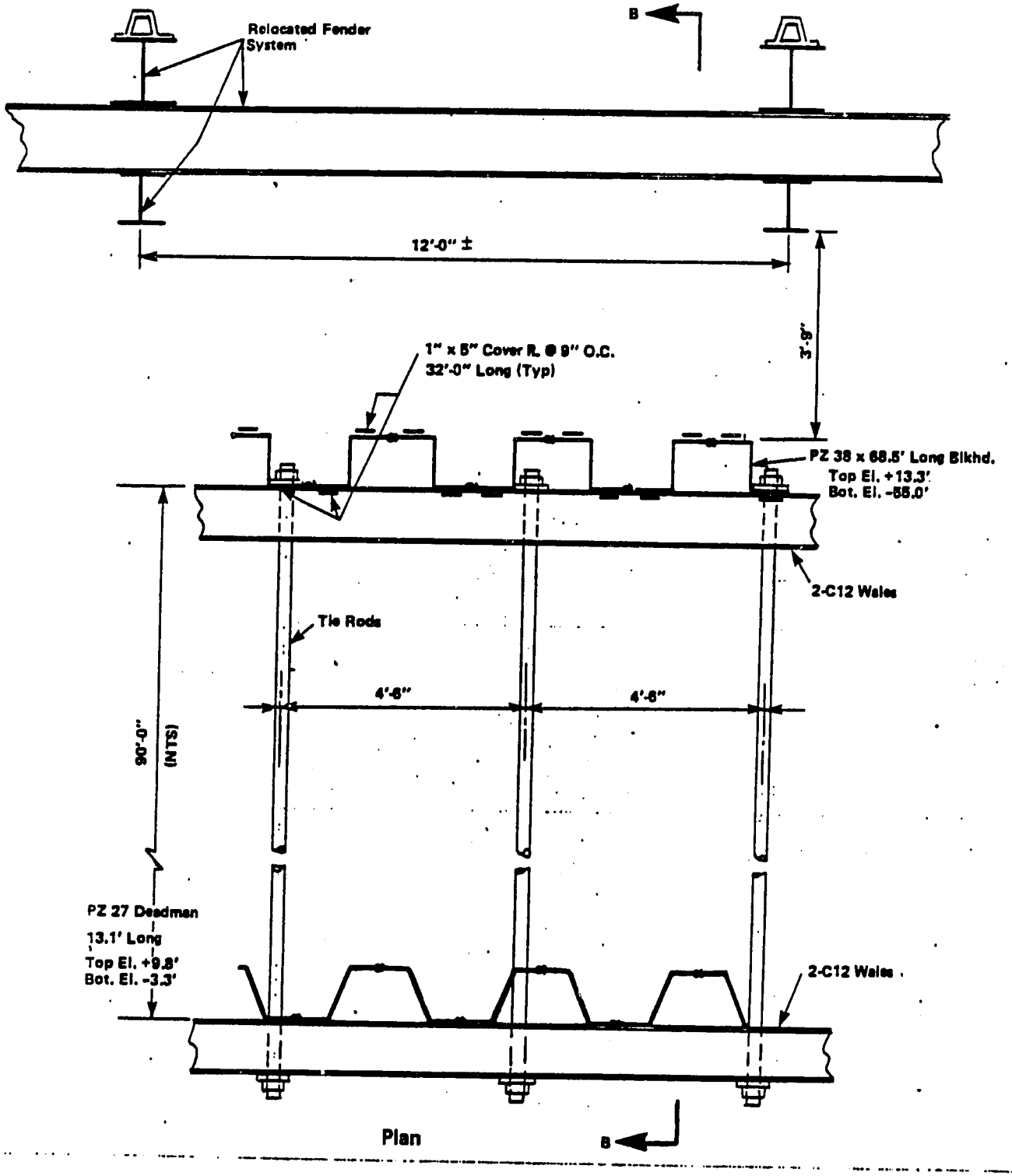
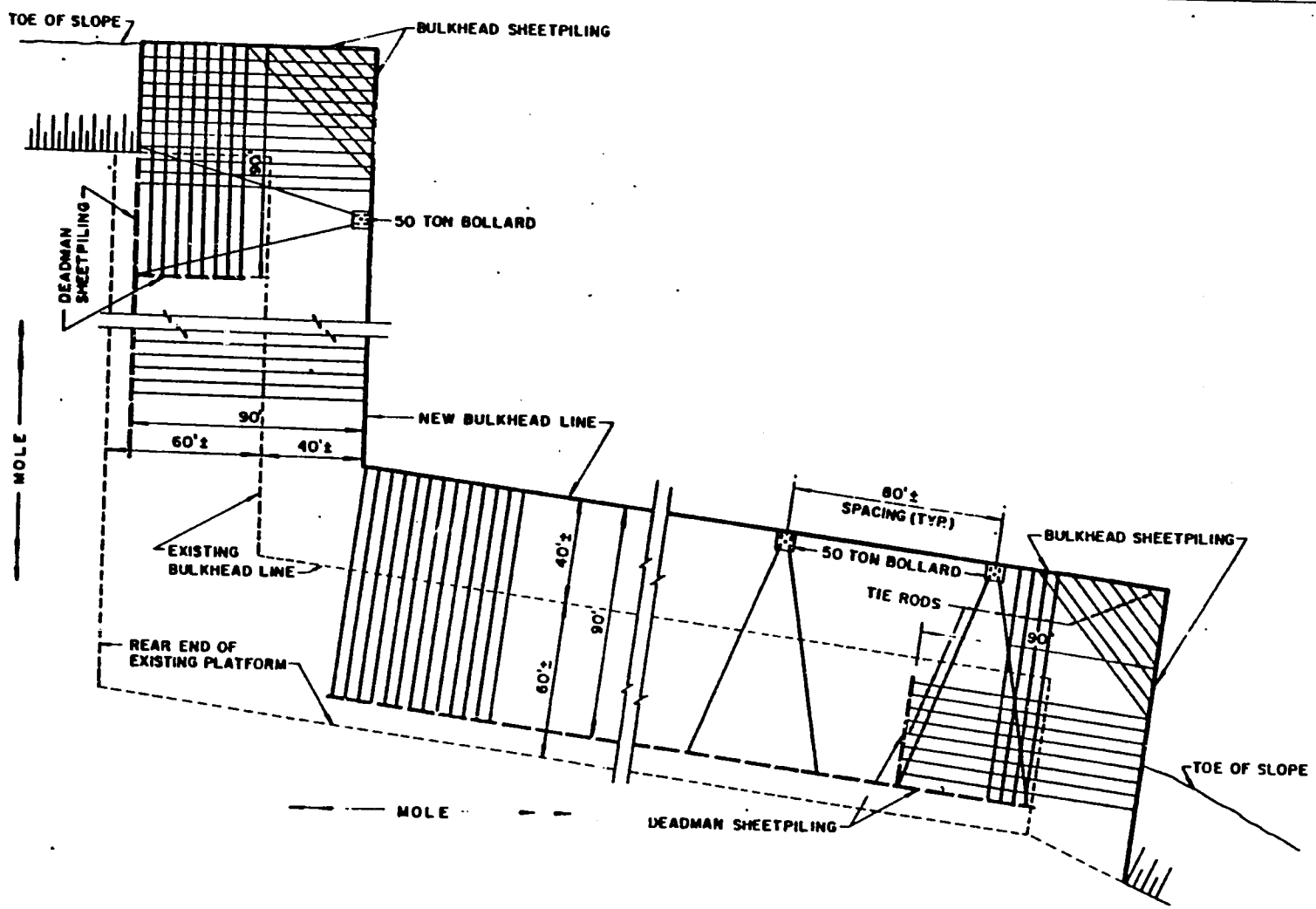


Figure 7-4

Detailed Plan of Bulkhead—Location No. 2

Port of Kismayo Rehabilitation

Parsons Brinckerhoff International, Inc



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NBS MONOGRAPH 158

U.S. DEPARTMENT OF COMMERCE / National Bureau of Standards

Corrosion and Protection of Steel Piles in a Natural Seawater Environment

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The National Bureau of Standards[1] was established by an act of Congress March 3, 1901. The Bureau's overall goal is to strengthen and advance the Nation's science and technology and facilitate their effective application for public benefit. To this end, the Bureau conducts research and provides: (1) a basis for the Nation's physical measurement system, (2) scientific and technological services for industry and government, (3) a technical basis for equity in trade, and (4) technical services to promote public safety. The Bureau consists of the Institute for Basic Standards, the Institute for Materials Research, the Institute for Applied Technology, the Institute for Computer Sciences and Technology, the Office for Information Programs, and the Office of Experimental Technology Incentives Program.

THE INSTITUTE FOR BASIC STANDARDS provides the central basis within the United States of a complete and consistent system of physical measurement; coordinates that system with measurement systems of other nations; and furnishes essential services leading to accurate and uniform physical measurements throughout the Nation's scientific community, industry, and commerce. The Institute consists of the Office of Measurement Services, and the following center and divisions:

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[1] Headquarters and Laboratories at Gaithersburg, Maryland, unless otherwise noted; mailing address Washington, D.C. 20234.
[2] Located at Boulder, Colorado 80302.

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Corrosion and Protection of Steel Piles in a Natural Seawater Environment

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W.F. Gerhold, B.T. Sanderson,
and R.L. Alumbaugh

Institute for Materials Research
National Bureau of Standards
Washington, D.C. 20234

(Supersedes NBSIR 76-1104)

Sponsored by:

American Iron and Steel Institute
1000 16th Street, N. W.
Washington, D. C. 20036

U.S. DEPARTMENT OF COMMERCE, Juanita M. Kreps, Secretary

Dr. Sidney Harman, Under Secretary

Jordan J. Baruch, Assistant Secretary for Science and Technology

NATIONAL BUREAU OF STANDARDS, Ernest Ambler, Acting Director

Issued June 1977

59

Library of Congress Cataloging in Publication Data

Main entry under title:
Corrosion and protection of steel piles in a natural seawater environment.
(National Bureau of Standards monograph ; 158)
"Supersedes NBSIR 76-1104."
Includes bibliographical references and index.
Supt. of Docs. no.: C13.44:158
1. Steel piling—Corrosion. 2. Sea-water—Corrosion.
I. Escalante, E. II. Series: United States. National Bureau of Standards. Monograph ; 158.
QC100.U556 no. 158 [TA786] 602'.1s [624'.154]
76-608410

National Bureau of Standards Monograph 158

Nat. Bur. Stand. (U.S.), Mongr. 158, 42 pages (June 1977)
CODEN: NBSMA6

U.S. GOVERNMENT PRINTING OFFICE
WASHINGTON: 1977

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402

Stock No. 003-003-01789-4

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Corrosion and Protection of Steel Piles in a Natural Seawater Environment

E. Escalante, W. P. Iverson, W. F. Gerhold, B. T. Sanderson, and R. L. Alumbaugh *

This report describes the first eight years of a long term program in which twenty-three coating systems and five cathodic protection systems are evaluated on their ability to protect steel piles in offshore conditions. These systems are made up of nonmetallic coatings, metallic pigmented coatings, nonmetallic coatings on metal filled coatings, nonmetallic coatings on metallic coatings, metallic coatings, and cathodic protection on bare and coated piles.

It includes a description of the annual on site electrochemical coating evaluation and a description of the final physical evaluation made on the piles after removal. The results of these electrochemical and physical evaluations are presented graphically and in tabular form.

Key words: Cathodic protection, coating systems; corrosion protection; offshore corrosion; sand erosion; seawater corr sion; splash zone corrosion.

1. Introduction

The corrosion of steel piles in seawater is presently being studied by several groups of investigators. Some of these groups have channeled their activities toward laboratory studies [1, 2, 3][1]. These studies are of interest in that insight into the corrosion problem can often be obtained by testing under controlled conditions. The very act of controlling conditions, however, can bias the data in subtle and undesirable ways. Other groups have used field tests that expose materials to harbor or bay waters [4, 5, 6, 7]. Under this exposure, the effect of the tide on corrosion can be closely observed. Corrosion studies in hydrospace are also reported in the literature [8, 9]. Such work involves the corrosion of materials in very deep water, often a mile or more below the surface.

These studies by various groups produce valuable information on the corrosion of materials under different types of exposure. However, very little work has been reported on the corrosion of steel exposed to actual offshore conditions [10, 11, 12]. Such work is of particular interest now because of the increased need for offshore structures. These structures must withstand all conditions of exposure, and in particular the incessant action of the waves found in open water. In addition, as structures are placed closer to the beach, their exposure to surf action increases. Accompanying this surf is a strong current of water returning to the ocean at the mud line. This under current picks up sand and debris which impinges upon any object in its path. This abrasive action exposes materials to their severest test.

This paper describes some results of the first eight years of a fifteen year program in which a variety of coating and cathodic protection systems are evaluated on their ability to protect steel piles in offshore conditions at Dam Neck, Virginia. It includes a description of the methods used in the evaluation and the results found on these systems.

2. Materials and Environment

To withstand the vigorous wave action experienced at the offshore test site, 8 × 8 in (0.20 m × 0.20 m) mild steel H-piles (ASTM A36) weighing 48 lb per ft (71 kg/m) were chosen for exposure. Several 8-in (0.20 m) diameter pile pipes (ASTM A252) were included to determine the effect of geometry on the deterioration of the coating. Nine mariner steel 8 × 8 in (0.20 m × 0.20 m) H-piles (ASTM A690) were also exposed. All piles were 35 ft long (10.7 m).

There are twenty-three protective coating systems used on the piles. Two of the twenty-three are cathodically protected. In addition, three systems of bare piles are protected with anodes. The systems exposed are listed and described in table 1.

* Civil Engineering Laboratory, NCBC, Port Hueneme, California.

[1] Figures in brackets indicate the literature references at the end of this paper.

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Table 1

Description of Steel Pile Systems Exposed to the Atlantic Ocean at Dam Neck, Virginia[a]

Piling System Number	Description	Number of Coats	Average Coating Thickness on Each Pile[b] (mils)	Coating Thickness Range[b] Minimum-Maximum (mils)	Remarks
1	BARE CARBON STEEL	-	-	-	
2	BARE CARBON STEEL WITH ZINC ANODES	-	-	-	Protected beneath waterline with two Zinc anodes[c]
3	BARE CARBON STEEL WITH ALUMINUM ANODES	-	-	-	Protected beneath waterline with two Aluminum anodes[c]
4	POLYAMIDE CURED COAL TAR EPOXY	2	A-16 B-16 C-15	A=11-20 B=10-22 C=10-22	
5	POLYAMIDE CURED COAL TAR EPOXY	2	A-20 B-20 C-19	A=13-30 B=12-30 C=11-27	Protected beneath waterline with two Zinc anodes[c]
6	POLYAMIME CURED COAL TAR EPOXY	2	A-15 B-15 C-13	A=12-20 B=10-28 C=7-20	
7	POLYAMIDE CURED COAL TAR EPOXY Coal Tar Epoxy and Aluminum Oxide	2 1	A-15(33)[d] B-23(38) C-21(36)	A=7-32(20-40)[d] B=17-30(40+) C=16-30(25-40)	Third coat and Aluminum Oxide applied between 16' and 22' from bottom of piles only
8	ALUMINUM PIGMENTED COAL TAR EPOXY Amine Cured, Red-Lead Pigmented, Coal Tar Epoxy Primer Amine Cured Coal Tar Epoxy Intermediate Amine Cured, Aluminum Pigmented, Coal Tar Epoxy Finish	1 1 1	A-27 B-25 C-28	A=17-35 B=14-40 C=15-40	
9	ALUMINUM PIGMENTED COAL TAR EPOXY Epoxy Primer Amine Cured Coal Tar Epoxy Intermediate Amine Cured, Aluminum Pigmented, Coal Tar Epoxy Finish	1 1 1	A-19 B-18 C-18	A=12-35 B=12-25 C=13-27	
10	HOT DIPPED ZINC (GALVANIZED)	1	A-9 B-8 C-8	A=5-13 B=5-15 C=5-14	
11	HOT DIPPED ZINC (GALVANIZED)	1	A-7 B-9 C-7	A=4-12 B=5-15 C=3-18	Protected beneath waterline with two Zinc anodes[c]
12	POLYVINYLIDENE CHLORIDE Formula 113/54, MIL-L-18389 (Alternate Orange and White Coats)	7	A-7 B-5 C-7	A=5-13 B=3-12 C=3-11	

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Table 1 (Con't)

Piling System Number	Description	Number of Coats	Average Coating Thickness on Each Pile[b] (mils)	Coating Thickness Range[b] Minimum-Maximum (mils)	Remarks
13	SEALED FLAMESPRAYED ALUMINUM Flamesprayed Aluminum Wire Wash Prime, Formula 117, Mil-P-15328B Clear Vinyl Sealcoat	 1 1 2	 A-10 B-9 C-9	 A=4-15 B=6-14 C=5-15	Aluminum preceded with a flamesprayed steel wire flash bonding coat one mil thick
14	FLAMESPRAYED ALUMINUM WIRE	1	A-9 B-9 C-9	A=6-16 B=5-15 C=6-18	Aluminum preceded with a flamesprayed steel wire flash bonding coat one mil thick
15	COATED FLAMESPRAYED ZINC Flamesprayed Zinc Wire Polyvinylidene Chloride, Formula 113/54, Mil-L-18389 (Alternate Orange and White Coats)	 1 7	 A-12 B-12 C-13	 A=7-20 B=5-18 C=9-25	
16	COATED FLAMESPRAYED ZINC Flamesprayed Zinc Wire Vinyl Red Lead Primer, Formula A119 Mil-P-15929	 1 5	 A-8 B-6 C-6	 A=4-15 B=2-15 C=2-14	
17	PHENOLIC MASTIC Amine Cured, Red Lead Pigmented, Phenolic Mastic Primer (with Mica Filler) Amine Cured Phenolic Mastic Finish	 1 1	 A-13 B-18 C-14	 A=6-22 B=10-25 C=7-28	
18	COATED ZINC RICH EPOXY Zinc Rich Epoxy Primer Polyamide Cured Coal Tar Epoxy Finish	 1 2	 A-19 B-21 C-22	 A=10-35 B=13-30 C=15-40	
19	COATED ZINC INORGANIC SILICATE Zinc Inorganic Silicate Primer High Build Vinyl Finish	 1 1	 A-12 B-10 C-12	 A=8-25 B=6-20 C=7-18	
20.	COATED ZINC INORGANIC SILICATE Zinc Inorganic Silicate Primer (Self Cured) Polyamide Cured High Build Epoxy Finish	 1 2	 A-10 B-14 C-12	 A=8-15 B=6-35 C=6-18	
21	COATED ZINC INORGANIC SILICATE Zinc Inorganic Silicate Primer (Self Cured) Amine Cured Coal Tar Epoxy Finish	 1 1	 A-21 B-22 C-19	 A=10-40 B=11-40 C=14-28	

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Table 1 (Con't)

Piling System Number	Description	Number of Coats	Average Coating Thickness on Each Pile[b] (mils)	Coating Thickness Range[b] Minimum-Maximum (mils)	Remarks
22	COATED ZINC INORGANIC SILICATE Zinc Inorganic Silicate Primer (Post Cured) Strontium-Chromate, Iron-Oxide Vinyl Phenolic Primer Vinyl Mastic Finish	 1 1 1	A-10 B-8 C-13	A=7-16 B=4-17 C=7-38	
23	BARE MARINER STEEL	-	-	-	Low Alloy Steel H-piles
24	BARE MARINER STEEL WITH ZINC ANODES	-	-	-	Protected beneath waterline with two Zinc anodes[c]
25	POLYAMIDE CURED COAL TAR EPOXY	2	A-17 B-16 C-17	A=6-40 B=8-28 C=10-30	Low Alloy Steel H-piles
26	BARE CARBON STEEL	-	-	-	Carbon Steel Pipe Piles
27	POLYAMIDE CURED COAL TAR EPOXY	2	A-20 B-17 C-24	A=15-28 B=15-24 C=17-30	Carbon Steel Pipe Piles
28	POLYAMIDE CURED COAL TAR EPOXY Coal Tar Epoxy and Aluminum Oxide	2	A-21(40+)[d] B-21(32) C-16(40+)	A=13-30(40)[d] B=12-30(30-40) C=16(40+)	Carbon Steel Pipe Piles Third coat and aluminum oxide applied between 16' and 22' from bottom of piles only
29	FLAKEGLASS FILLED POLYESTER	1	A-32 B-30 C-34	A=18-40 B=17-40 C=15-40	
30	BARE CARBON STEEL	-	-	-	
31	BARE CARBON STEEL	-	-	-	

(a) All piles were carbon steel "H" piles unless noted otherwise.

(b) Piles in each system were coated as follows:
A-Piles - Completely coated except for six 1" x 6" bare windows located at intervals along the outside face of the ocean flange of piles.
B-Piles - Completely coated.
C-Piles - Top 23 feet completely coated; bottom 12 feet left uncoated.

(c) Anodes on A and C-piles located in water below MLW; Anodes on B-piles located in the sand.

(d) Values in parenthesis indicate total thickness after application of third coat of Coal Tar Epoxy and Aluminum Oxide between 16 and 22 feet from bottom of piles.

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Figure 1 illustrates the various zones encountered by the pilings. The imbedded zone is the most stable area of exposure since conditions here remain fairly constant with time. It also is generally the least aggressive from the standpoint of corrosion. Immediately above the imbedded zone is the erosion zone which exposes the protective systems to their severest test. Here, the continual motion of the water due to surf and cross currents lifts the particles of sand from the floor which abrade the surface of the pile. The rate of deterioration of a pile in this zone is generally high. The fouling zone which includes the splash area develops a profusion of plant and animal life. The most corrosive portion of this zone is the splash area. Above the waterline is the atmospheric zone. Wave action is so variable that this zone is not clearly defined. In fact, in unusually heavy wave action during high tide, the atmospheric zone of the pile may momentarily be under water. The corrosiveness of this zone is high.

Characterization data of the ocean water by the U.S. Coast and Geodetic Survey Station at Virginia Beach, Virginia [13] show a mean salinity of 26.8 parts per thousand and a mean temperature of 57.9 °F (14.4 °C). The salinity has ranged from 18.2 to 37.5 parts per thousand and the water temperature has varied from 33.8 °F (1.0 °C) to 82.4 °F (28 °C) over a seven year period.

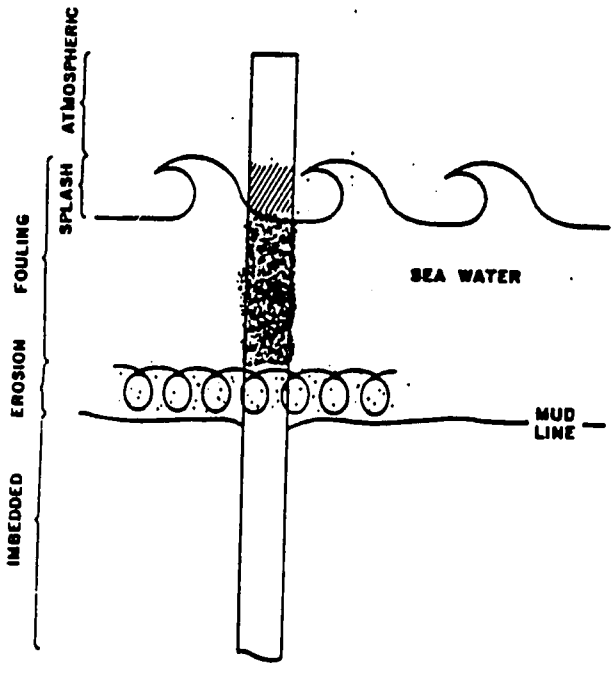

FIGURE 1

Borings made near the low water line fronting the site indicate that the bottom material consists primarily of fine sand. A thin strata of blue-grey clay and silt, less than 3 ft thick (0.9 m), exists near the surface. The median diameter of sand particles on the bottom as sampled in 1967 was 0.15 mm (0.006 in). This small particle size sand is easily carried into suspension by the motion of the water. The amount of suspended material in the immediate vicinity of a pile is even higher due to the increased water velocity resulting from eddy currents the pile generates. In addition to this local sand action, winter storms, hurricanes, and long summer-swells tend to move large volumes of sand causing the bottom elevation to change. Thus, the sand line and the erosion zone changed with time in a nonregular way as illustrated in figure 2.

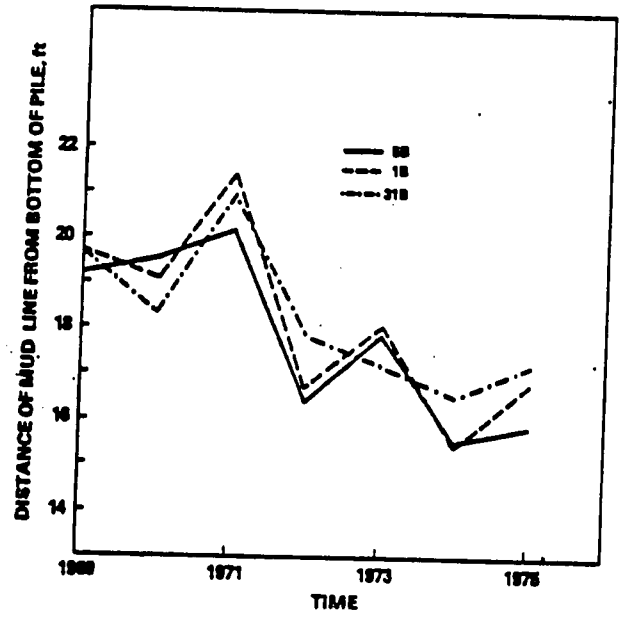

FIGURE 2

3. Experimental Procedure

Specimen Preparation—A set of three pile specimens, labeled A, B, and C, was prepared for each system. The A-piles are completely coated except for six windows located along the length of the pile as illustrated in figure 3. A window is a small area 1 × 6 in (2.5 cm by 15 cm) which is free of any coating material. Its purpose is to allow evaluation of the undercutting resistance of the protective coating. The B-piles are completely coated. The bottom 12 ft

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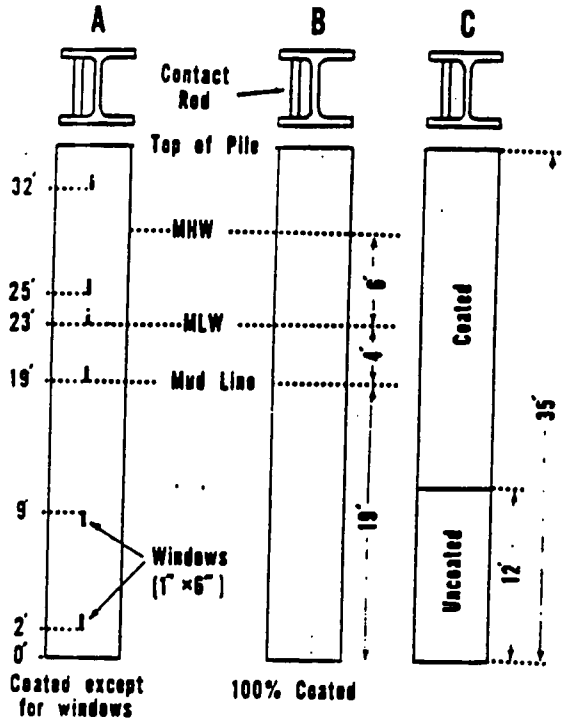

FIGURE 3. *Preparation of coated piling specimens.*

(3.6 m) of the C-piles are uncoated. All coatings were applied in accordance to manufacturer's specifications which included sandblasting to a near white finish prior to coating application. Two Type 316 stainless steel bars were welded between the flanges of each of the H-piles. They are located in such a way that one is approximately 2 ft (0.6 m) above mean high water and the other 2 ft (0.6 m) below mean high water. Stainless steel bars were butt-welded to the surface of the pipe piles. These bars are contact points used during electrochemical measurements. The pipe piles had a cone-shaped tip welded to the bottom end to facilitate installation. Each of the fifteen cathodically protected piles has two anodes located either in the water or below the mud line.

At the test site, the piles are positioned in three rows as indicated in figure 4. The distance from shore to the piles is approximately 100 yards (90 m). In June of 1967 the piles were water-jetted into position with 19 ft (5.7 m) buried in the sand to ensure adequate stability. Jetting reduces the likelihood of mechanical damage since the pile settles into position from its own weight and the turbulent action of the sand caused by the water jet on the bottom end of the pile. Once in place the jetting pipe is withdrawn.

Electrical Measurements—The steel piles are inspected annually by electrochemical and visual methods. The on-site electrochemical evaluation of the coatings on the piles, is limited to that portion of the pile below the waterline. Above the waterline, coating evaluation is in the form of visual inspection and photography. This annual data is then correlated with the information obtained on the evaluation after the piles are removed from the site. The after removal data is in the form of physical measurements and photographs. Extensive notes are kept on visual observations made during this final inspection.

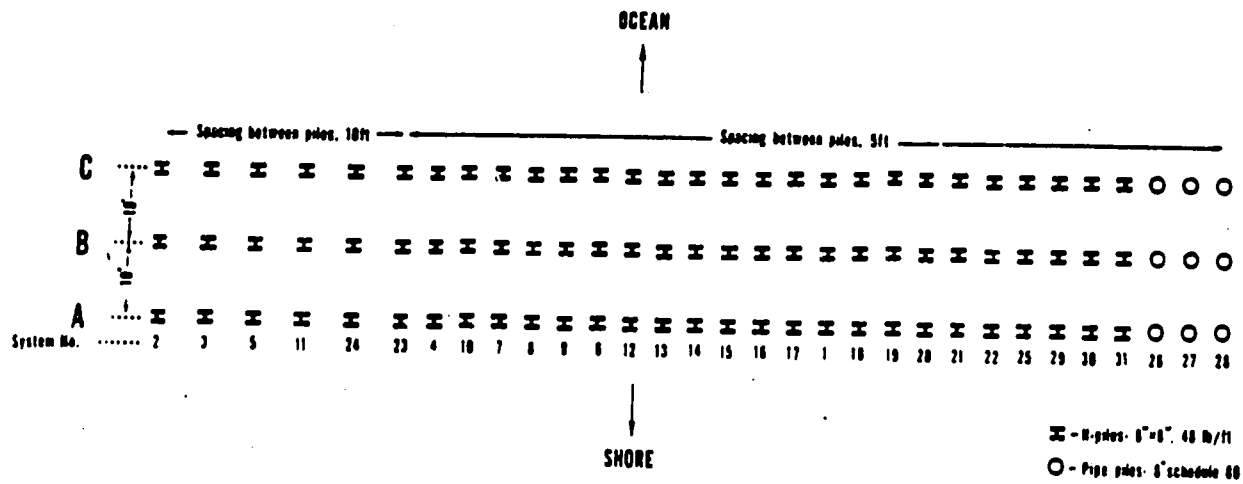

FIGURE 4. *Test pile installation, Dam Neck, Virginia.*

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On-site electrical measurements are obtained by having a steel cable suspended above the water between a centrally located pile and a winch on a vehicle parked on the beach. On this cable are hung two insulated 3 conductor electrical cables with vise grips on the ends. Electrical contact is made to the individual piles by clamping a vise grip on the stainless steel bar welded to the piling. The beach ends of the electrical conductor are connected to electronic instrumentation. The strong ocean currents and surf action have made the over-water suspension of the cables necessary.

Two types of electrochemical measurements are made in evaluating the condition of the coatings. The first type, coating index, is primarily a coating resistance measurement for a given change in potential after a five minute period. The potential of the piles with nonmetallic coatings is changed from open-circuit potential (zero applied current) to -0.850 V versus $Cu-CuSO_4$. In the case of metallic coatings a fixed overpotential is applied. For flame sprayed aluminum the overpotential is -0.120 V and for flame sprayed zinc the overpotential is -0.150 V. The coating index, $\Delta V/\Delta I$, is calculated and compared from year to year giving a measure of the degree of coating deterioration. The coating resistance measurement is also expressed in terms of relative coating effectiveness |12|. This approach compares the coating resistance of each pile to an arbitrary scale which has the bare piles at zero (0) relative coating effectiveness and the best coated pile (7B in 1967) as 100. The value of relative coating effectiveness between 0 and 100 is based on the relation (not shown) between the corrosion currents and the coating indices for the piles. The second type of measurement is for determining the rate of corrosion of bare piles and piles with metallic coatings. Both the Stern-Geary approach |14| and the polarization break method |15| are used in this case. Since the resistivity of seawater is so low, IR error compensation has been found to be unnecessary.

Potential measurements of the cathodically protected piles were made with a potentiometer using both a Ag-AgCl half-cell and a $Cu-CuSO_4$ half-cell. The $Cu-CuSO_4$ half-cell was the most convenient to use. It was positioned in the damp sand on the beach and covered to prevent light and heat effects. The Ag-AgCl half-cell, submerged in the water, served as a second reference electrode. The protective current on the cathodically protected piles is determined from the cathodic polarization curve [16] as well as the Stern-Geary technique.

The corrosion rate of a pile can be determined by polarization which requires knowledge of the area of the pile. This area is determined by measuring the length of the pile below the waterline at the time polarization measurements are made. Two piles are polarized at a time; one is anodically polarized while the other is cathodically polarized. Electrochemical readings are taken on both piles simultaneously. Power is supplied by a 12 volt storage battery.

Physical Measurements—The first removal for inspection of the piles was made in April 1973, after six years of exposure. Almost one third of the piles were extracted for final inspection. This extraction was done by a 100 ton floating crane that pulled the A-series piles out one at a time. During initial trials an attempt was made at removing two piles at a time, but this was abandoned because of the damage that resulted to the coating and the piles. The piles were then brought to shore for initial cursory inspection and photography. An extensive build-up of vegetable and animal life has developed on the piles. Wide steel spatulas were used to remove this build-up for preliminary inspection. Following this, the piles were shipped to Bethlehem Steel Company where the final intensive inspection took place. Here the coatings on the piles were cleaned and examined for extent of deterioration. The "windows," or intentional interruptions in the coatings described earlier, were examined for development of undercutting (separation of coating from substrate). During this entire process of examination photographs were taken to visually capture the appearance of the coatings. Upon completion of this process the piles were sandblasted to remove the coatings in preparation for the physical measurements that followed. These measurements, consisting of flange thicknesses, pit depth, and pit densities, were made in the following way. Each pile was marked with chalk at 1 ft (30 cm) intervals. Using an outside caliper micrometer, flange thickness measurements were made at every foot mark 1 in (2.5 cm) in from the flange's edge. Finally the deepest pit at every foot of each face (there are eight faces) was found and measured with a micrometer pit depth gauge.

4. Results and Discussion

The results will be discussed in seven interrelated parts. First, the corrosion of the bare steel piles will be described. This will be followed by a discussion of the five major coating systems studied (i.e., nonmetallic coatings, metal pigmented coatings, nonmetallic coatings on metal filled coatings, nonmetallic coatings on metallic coatings, and metallic coatings). Finally, the results of the cathodically protected systems will be presented.

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Bare Piles—After six years of exposure to the ocean, the corrosion of the bare piles has been extensive compared to that observed on the protected piles. These control specimens serve as a reference against which all protected piles are compared. Thus, they are important not only in their own right, but as standards of reference. The electrochemical measurements (fig. 5) indicate that their rate of corrosion has been fairly constant with time.

The last measurements of the A-piles were made in 1972 a few months before their removal for visual and physical inspection. Figure 5 shows that the corrosion rate of specimens 1A, 23A, and 30A was virtually identical in the four years the measurements were made. Specimen 23A is of special interest because it is a low alloy mariner steel. Their corrosion rate ranges from 1 to 2 mils per year (5 to 10 mdd[2]) for the entire area of the piles below the waterline. Electrochemical measurements were not made on 26A (pipe pile), or 31A.

The actual observed corrosion as determined from the flange thickness measurements made after cleaning for pile 1A is illustrated in figure 6. The average flange thickness of the pile is plotted for the entire length of the pile. The dashed line indicates the location of the original surface. This thickness measurement reflects the corrosion on *both surfaces* of the flange. One can see from the diagram that a large part of the corrosion occurs above the high water line. The average corrosion rate in this region is on the order of 8 to 12 mils per year (45 to 65 mdd). The region below the high water mark has a relatively low corrosion rate. However, the corrosion damage increases as the erosion zone is approached. The corrosion rate between the high water mark and the mud line ranges from 4 to 8 mils per year (20 to 45 mdd) on the average. Within the erosion zone the observed corrosion is also high. Note that the changing mud line has caused deterioration between 14 and 21 ft (4.3 to 6.4 m) from the bottom of the pile. This effect will be seen on all piles. In this narrow band the average corrosion rate for pile 1A is approximately 9 mils per year (50 mdd).

Specimen 30A is practically identical in behavior to 1A as illustrated in figure 7. This figure also displays data on the deepest pits found along the length of the pile. This data indicates that a perforation of the pile developed at about the thirty-two foot level within the six years of exposure. This perforation occurred in the web which is the portion of the pile between the two outer flanges. Pitting tendency decreases markedly below the mud line.

Figure 8 illustrates the corrosion deterioration observed on Specimen 31A. The bare carbon steel H-pile has developed more metal loss below the mud line than either 1A or 30A, and is of the order of 2 to 3 miles per year (10 to 15 mdd). Its pitting characteristics are very similar to those of 30A even to the perforation.

All three of the uncoated carbon steel H-piles developed at least one perforation through the web in the splash zone. Specimen 23A, the low alloy steel H-pile, was not removed from the site and, therefore, physical measurements could not be made to verify the electrochemical measurements which indicate that its corrosion rate is essentially identical to that of 1A and 30A as shown in figure 5.

The bare pipe pile, 26A, developed pitting very similar to that found in the bare H-piles with the exception that pitting did not develop below the mud line (fig. 9). Electrochemical measurements were not made on this pile. However, measurements made on 26B indicate that the corrosion rate on the bare pipe piles is slightly higher (25%) than that of the H-piles. Because of the geometry of the pipe pile, thickness measurements could not be made.

A flange thickness measurement survey of the bare piles revealed that the corrosion at any given depth was not uniform. The greatest corrosion observed was approximately 1 to 2 in (2.5 to 5 cm) from the edge of the flange. Since the flange thickness measurements reported here were made in this region of higher than average metal loss, the figures based on these measurements reflect this. Fortunately the survey also revealed that the bias was constant. Thus, all average flange thickness measurements reported for the four bare piles are high by 22 percent ± 5 percent. The corrosion rates mentioned in the text take this into account.

Nonmetallic Coatings—The nonmetallic coatings will be discussed in two parts. First, the coal tar epoxies will be described, and then similar data on coatings of the same generic type will be presented.

As a group, the coal tar epoxy paints have not performed as well as anticipated in the environment of this program. The electrochemical measurements made on the A-piles in the first five years are presented in figure 10. In this figure the coating index (electrical coating resistance) versus time is plotted. Thus, as the coating deteriorates more of the metallic substrate is exposed and the overall coating index drops. Similarly the relative coating effectiveness of the system drops. System 6, the polyamide cured coal tar epoxy, appears to have deteriorated the most of the coal tar epoxies, but

[2] For iron: mils per year × 5.48 = milligrams per square decimeter per day.

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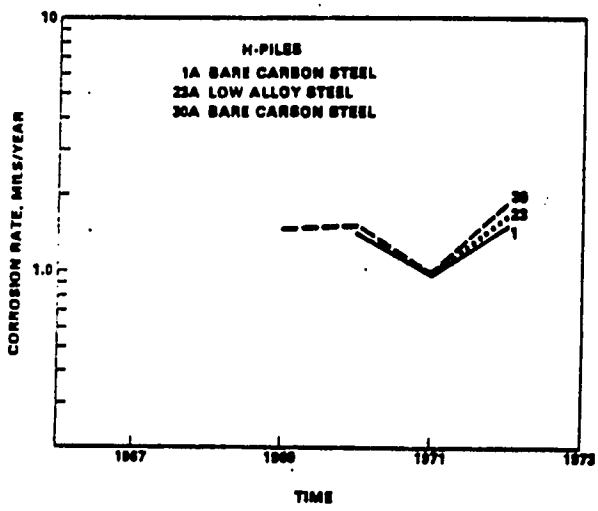

FIGURE 5

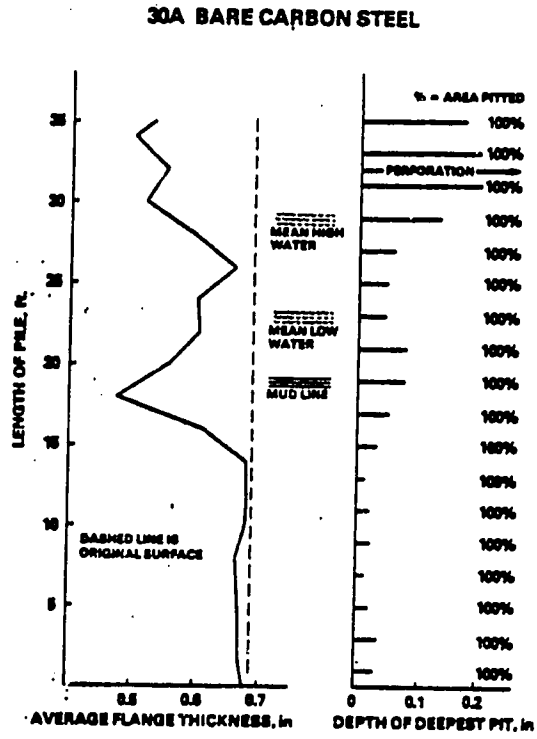

FIGURE 7

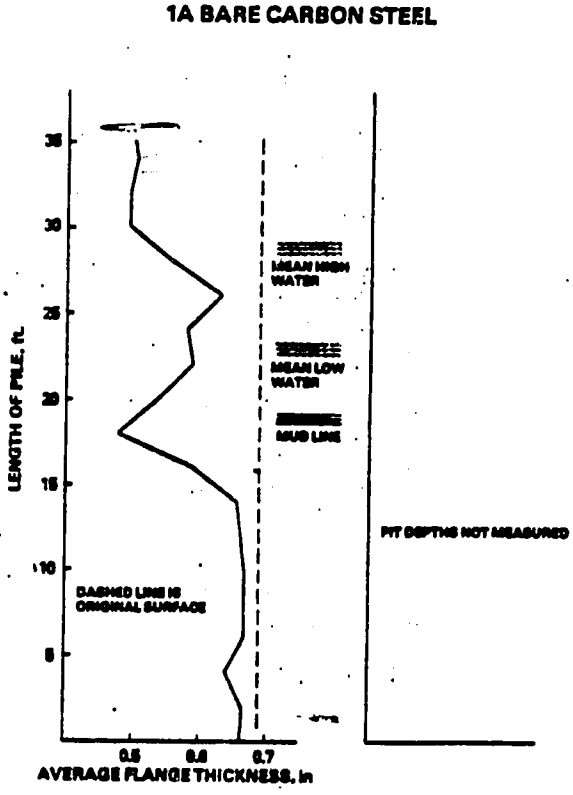

FIGURE 6

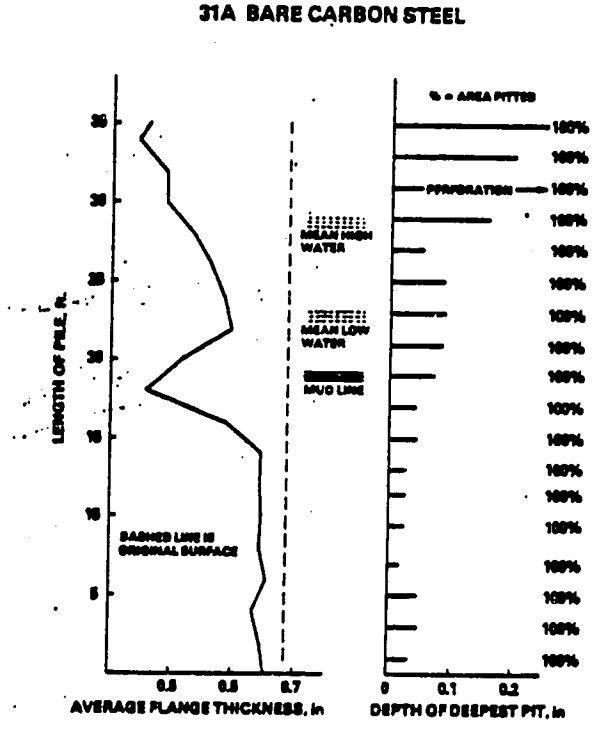

FIGURE 8

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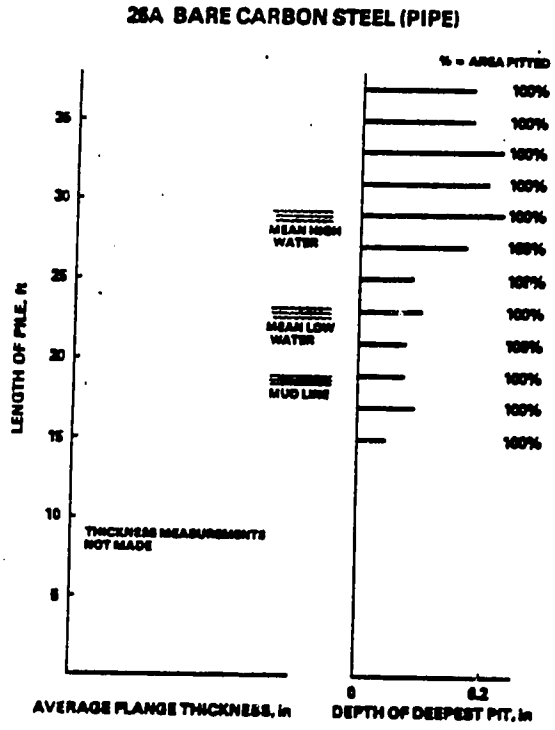

FIGURE 9

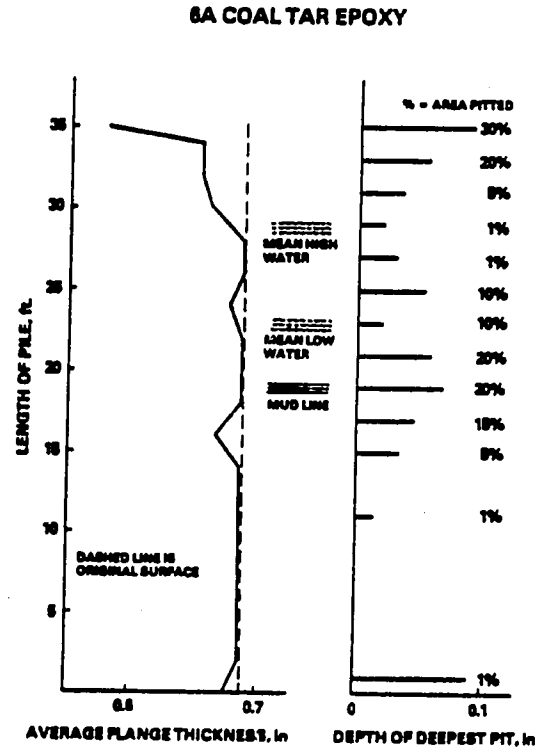

FIGURE 11

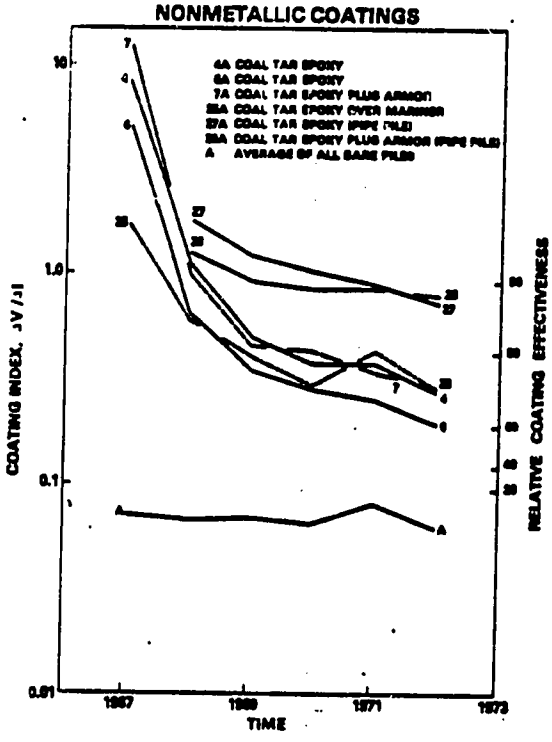

FIGURE 10

still has a coating effectiveness of 60 after five years of exposure. Figure 11 displays the average flange thickness of pile 6A with accompanying pitting. Specimen 6A is typical of the coal tar epoxies in that the greatest attack occurred above the high water line. The deepest pit in this region was less than 0.1 in (0.2 cm). Below the waterline, sand impingment in the erosion zone caused severe damage to the coating. In the atmospheric zone, undercutting of the windows in the coating system is difficult to appraise on this pile because of the extensive general failure of the coating as shown in figure 12. In the tidal zone, undercutting resistance is much improved, but general attack is still apparent (fig. 13). Below the mud line undercutting of the coating is minor. Mechanical damage to the coating during installation of the pile has caused most of the damage seen in figure 14.

The polyamide cured coal tar epoxy Systems 4, 7, and 25 are somewhat better than 6A and have a relative coating effectiveness of 70 in the same period of time as shown in figure 10. It is of interest to note that System 7, which has the aluminum oxide armor in the erosion zone, initially provided the highest degree of protection to the steel as indicated by the elec-

FIGURE 12

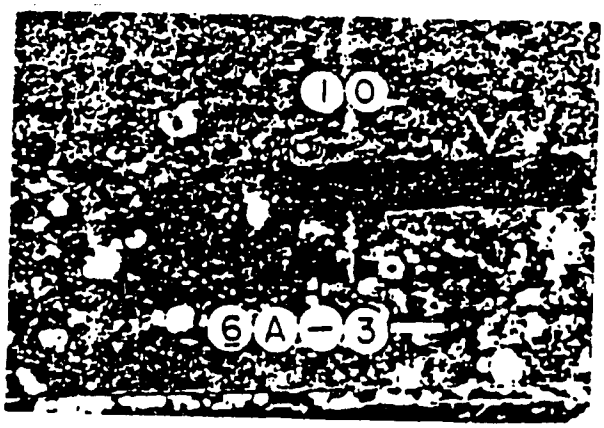

FIGURE 13

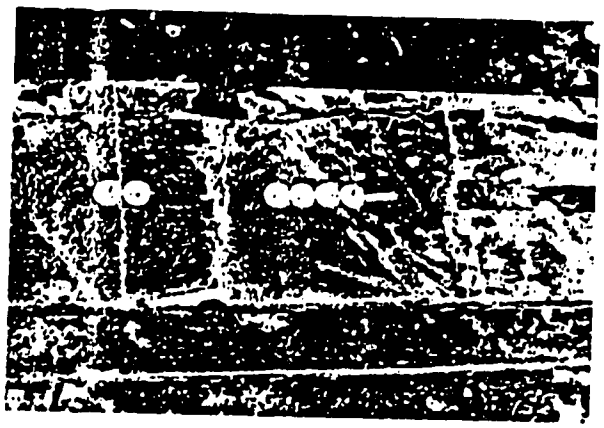

FIGURE 14

POLYAMINE
[redacted]e cured coal tar epoxy

trochemical measurements. The physical measurements of these three piles are illustrated in figures 15, 16, and 17. The poor resistance of the coal tar epoxy coatings in the atmospheric and splash zones is well indicated in these drawings. Below the waterline, however, they have performed well. Pile 7A shown in figure 16 indicated that the armor coat did reduce the rate of coating deterioration in the erosion zone. Figure 18 is a photograph of the window in the atmospheric zone of pile 7A. Note the severe undercutting extending half the width of the pile. The window in the tidal zone, that zone between mean high water and mean low water, reveals only a slight amount of undercutting that extends 0.25 in (0.7 cm) as shown in figure 19. Pitting due to coating failure is evident. Below the mud line undercutting resistance is even better as shown in figure 20. Generally the coal tar epoxy looks good in this region.

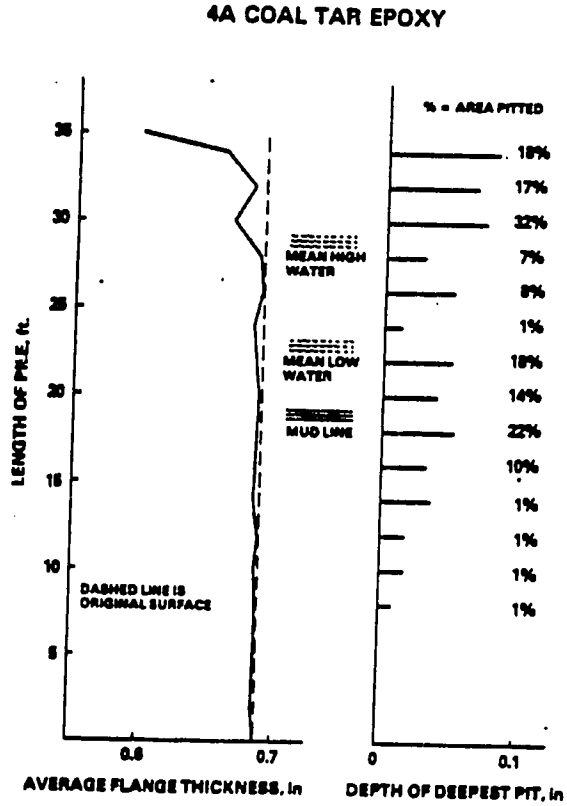

FIGURE 15

Pile 4A shown in figure 21 lacks the armor protection and has developed greater deterioration of the coating in the erosion zone as compared to pile 7A. The appearance of the window

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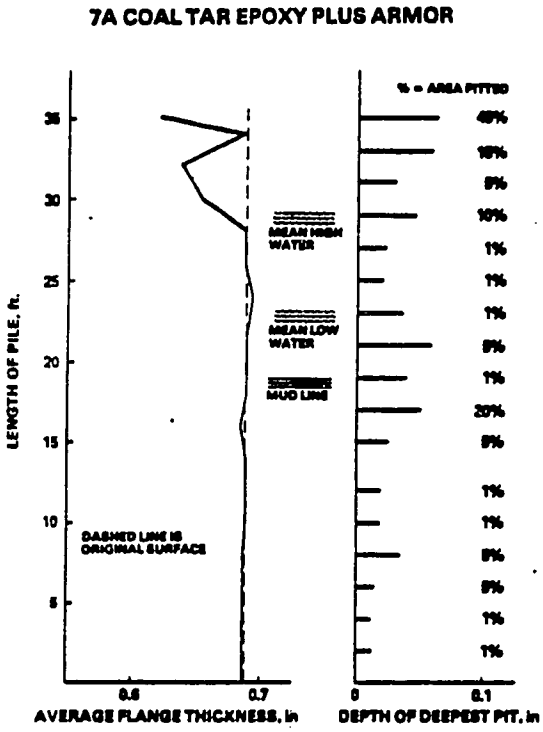

FIGURE 16

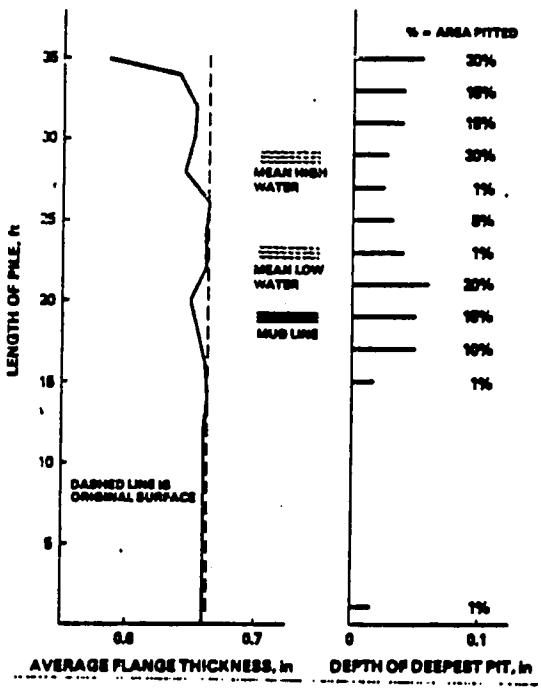

FIGURE 17

FIGURE 18

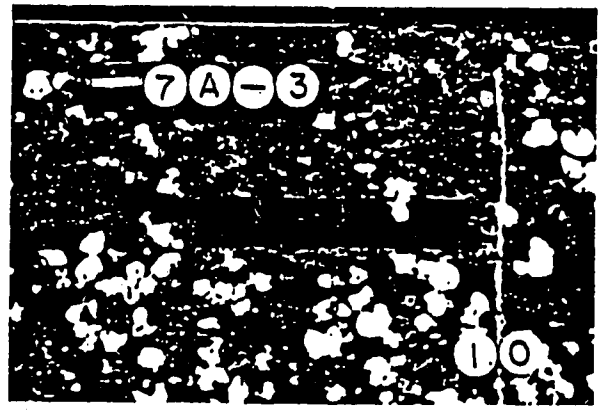

FIGURE 19

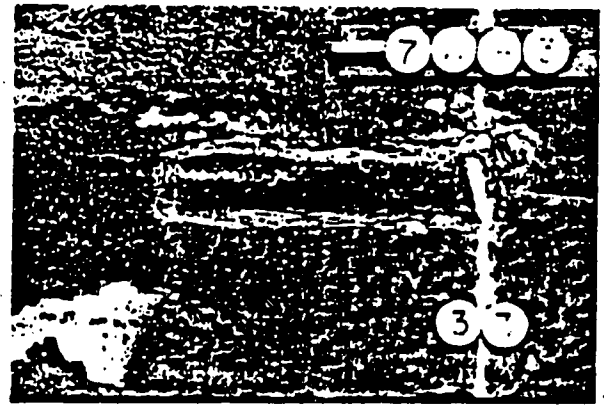

FIGURE 20

Polyamide cured coal tar epoxy

13

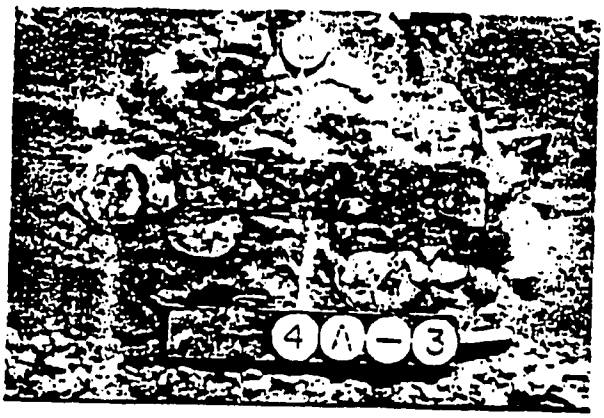

FIGURE 21

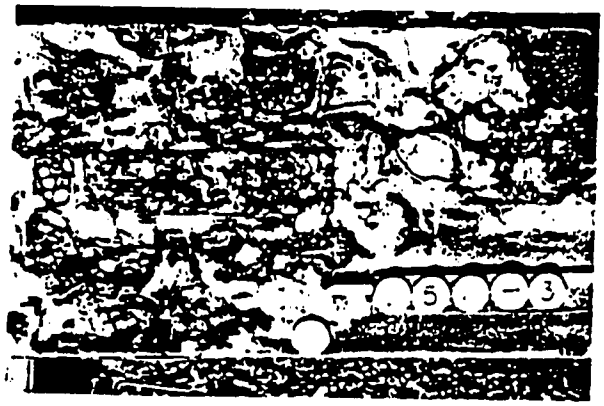

FIGURE 24

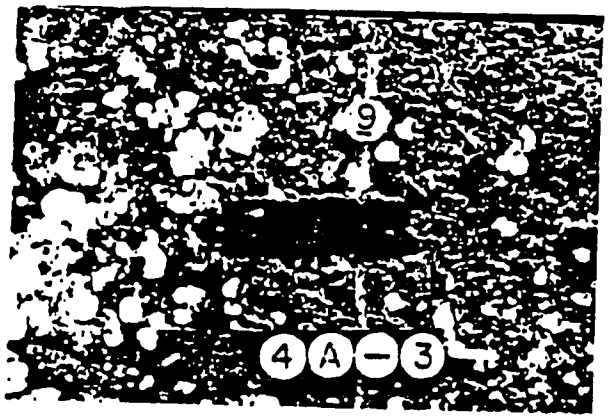

FIGURE 22

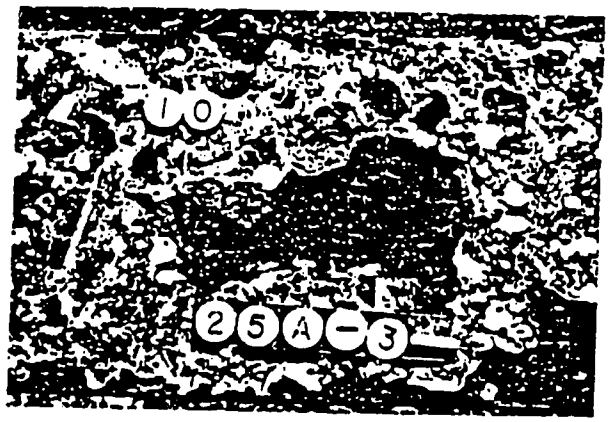

FIGURE 23

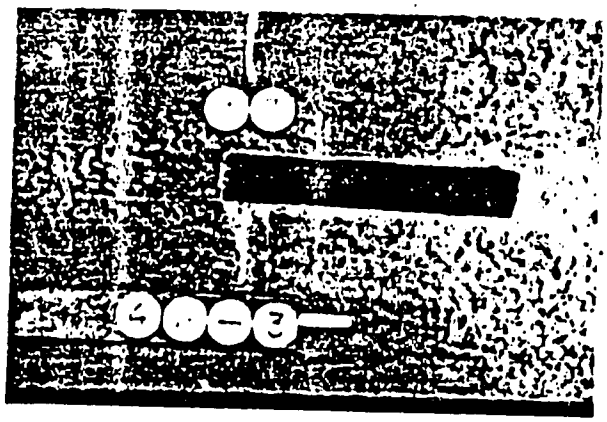

FIGURE 25

Polyamide cured coal tar epoxy

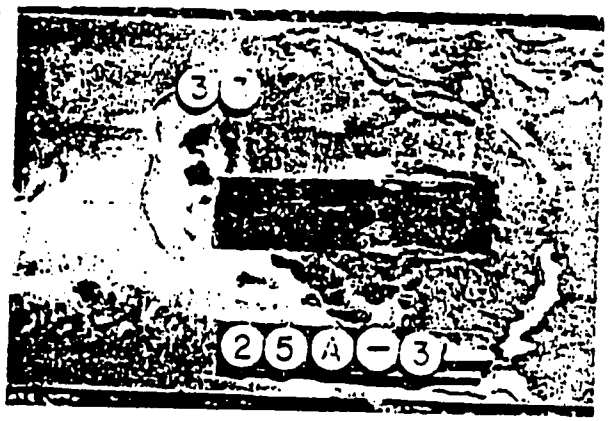

FIGURE 26

Polyamide cured coal tar epoxy

27A COAL TAR EPOXY (PIPE)

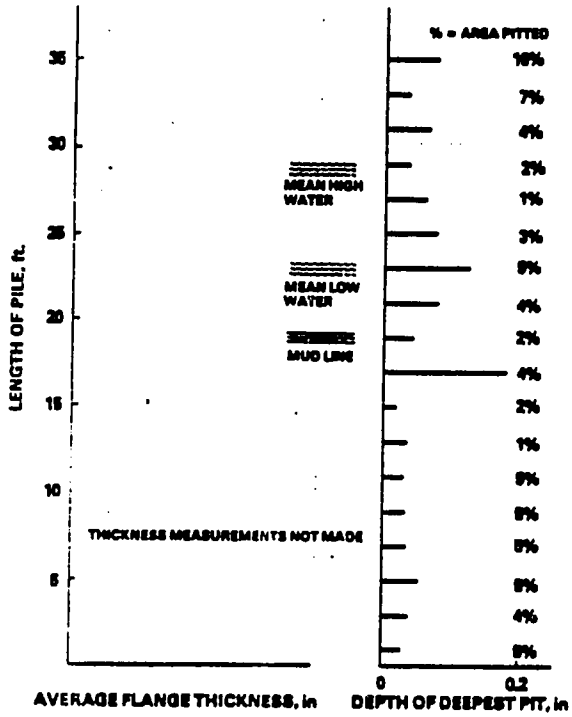

FIGURE 27

28A COAL TAR EPOXY WITH ARMOR (PIPE)

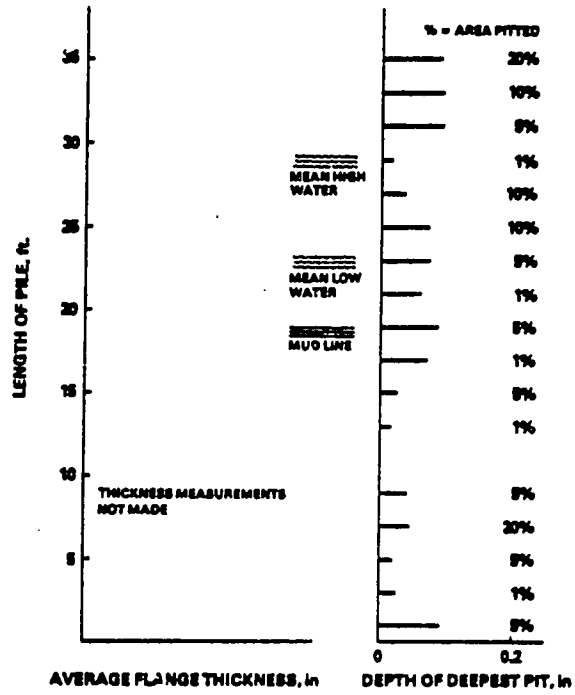

FIGURE 28

in the atmospheric zone of pile 4A is similar to that of 7A after six years of exposure as figure 21 shows. In the tidal zone, however, the window on 4A has undergone considerable damage not readily seen in figure 22. Undercutting in this area extends almost 1 in (2.5 cm) beneath the coating. General damage to the coating in the surrounding area is also apparent. Below the mud line the coating is in excellent condition with practically no undercutting as shown in figure 23.

In the erosion zone, the coal tar epoxy on mariner steel, System 25, has not fared as well as the same coating on carbon steel (System 4A). Figure 17 indicates loss of metal at the flange in this area. Its pitting resistance below the mud line, however, is far better than any of the other similarly coated piles. Undercutting of the coating in the atmospheric zone is severe as illustrated in figure 24. Coating damage in the tidal zone is also very extensive (fig. 25). Below the mud line, however, figure 26 illustrates that the coal tar epoxy on mariner steel has not been undercut.

In general, the coal tar epoxies on the H-piles have deteriorated considerably in the atmospheric zone with resulting metal losses averaging 2.3 mils per year (13 mdd). Below the water line metal loss has been minimal and on the order of 0.25 mils per year (1.4 mdd). Undercutting at windows ranged from severe in the atmospheric zone to insignificant below the mudline. From an electromechanical standpoint, the coal tar epoxy coated pipe piles look very good as illustrated in figure 10. Their rate of deterioration has been low, and after five years they have a coating effectiveness above 85.

The physical measurements on the pipe piles consists only of pit depth measurements (figs. 27 and 28) as meaningful wall thickness measurements were not practical. These observations indicate that though there were fewer coating failures on the pipe piles, (% area pitted) as compared to the H-piles, the resulting pits were deeper on the pipe piles. The deepest pit in the erosion zone of 27A was almost 0.2 in (0.5 cm) deep. Undercutting of the coating on pile 27A extends about 2 in (5 cm) beyond the edge of the window as shown in figure 29, and is considered severe. In the tidal zone undercutting resistance is improved. Undercutting extends 0.5 in (1 cm) at the most (fig. 30). Figure 31 illustrates that below the

FIGURE 29

FIGURE 30

FIGURE 31

Polyamine cured coal tar epoxy

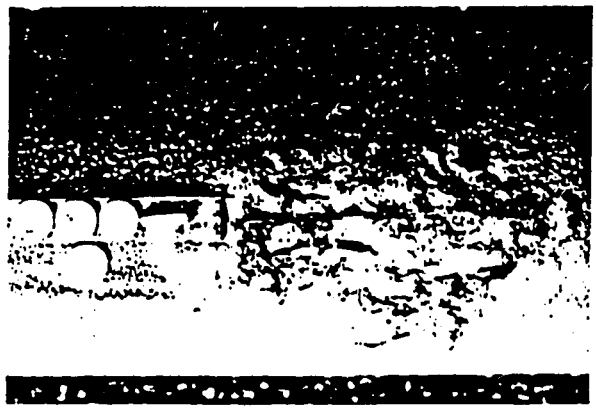

FIGURE 32

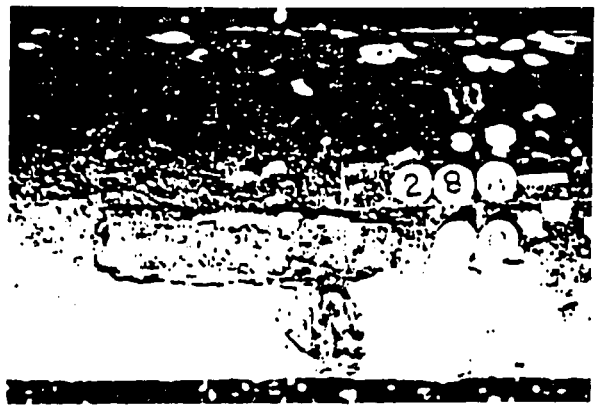

FIGURE 33

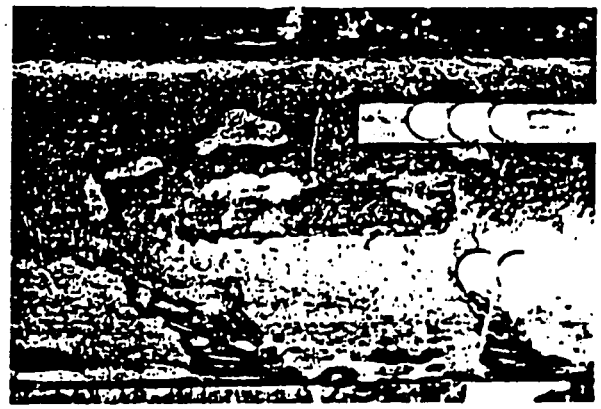

FIGURE 34

Polyamide cured coal tar epoxy

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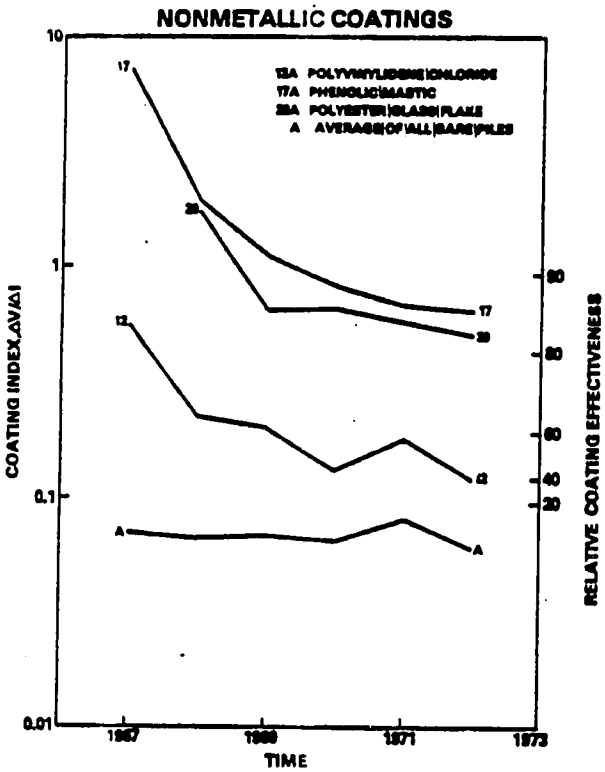

FIGURE 35

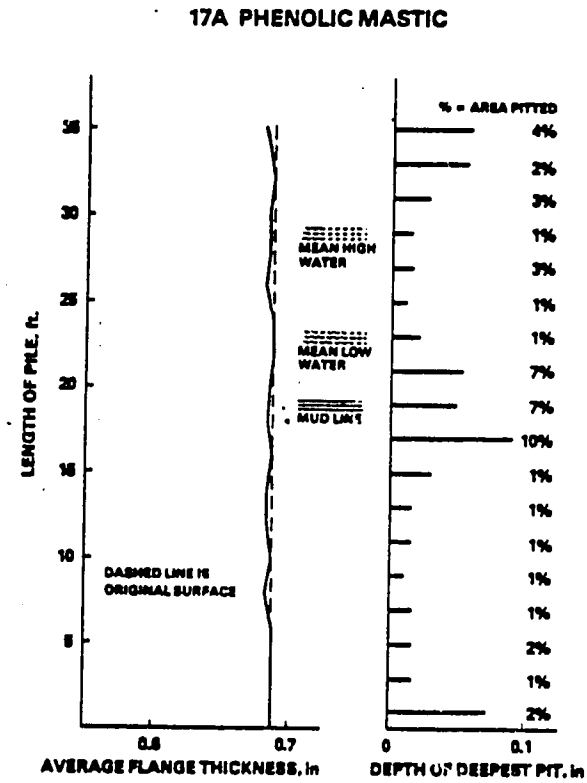

FIGURE 36

mud line, undercutting of the coating has progressed almost 1 in (2.5 cm) from the edge of the window. Coating delamination is also visible in this photograph. The windows in the coating on pile 28A are almost identical in appearance to those on 27A. In the atmospheric zone deterioration is extensive (fig. 32). In the tidal zone undercutting of the coating is moderate (fig. 33) with some mechanical damage visible. Below the mud line undercutting has progressed at least 1 in (2.5 cm) from the edge of the window (fig. 34).

The second group of nonmetallic coatings in the program are Systems 12 (Polyvinylidene Chloride), 17 (Phenolic Mastic), and 29 (Polyester Glass Flake). The electrochemical measurements on these piles are given in figure 35. This data reveals the good resistance to deterioration of Specimen 17A. Specimen 29A is almost as good, and both have a coating effectiveness above 80. The physical measurements for pile 17A are illustrated in figure 36. The resistance to deterioration of the phenolic mastic has been very good over the entire surface of the pile in the six years of exposure. Even in the erosion zone the amount of pitting was low with maximum pit depths less than 0.1 in (0.2 cm). The maximum degree of corrosion observed on this system was just below the mean high water line with a rate of 0.15 mils per year (0.8 mdd). In the atmospheric zone, the window in the coating suffered only moderate undercutting as shown in figure 37 with a maximum penetration of 1 in (2.5 cm) or less. The same figure shows that the coating in the vicinity of the window is still in excellent condition. Most of the rusty color is surface staining of the coating. In the tidal zone (fig. 38) undercutting extends less than 0.25 in (0.6 cm) beyond the window. Some coating failure at the edge of the flange is visible in this photograph. Below the mud line undercutting was practically nonexistent as shown in figure 39. The dark globular material on the window is an adhering mud and sand mixture that apparently does not affect the phenolic mastic.

The polyester glass flake, System 29, has an average coating thickness of 32 mils (0.8 mm). This system has displayed very good resistance to deterioration. Figure 40 is a plot of the physical measurements made on this coating. It is apparent from this data that the degree of pitting is minor. Flange thickness measurements were not made for two reasons. First, coating breakdown was so minimal that little

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would be gained by removing the coating for examination. Secondly, and equally important, it was very difficult to remove the polyester glass flake by sandblasting. The severest deterioration of the coating, which was minor, occurred at the edges of the flange in the erosion zone. Beyond that there was little deterioration of the coating. Even in the atmospheric or the splash zones little damage developed. The tendency to undercut as indicated at a window in the atmospheric zone is shown in figure 41. Undercutting extends at most 1 in (2.5 cm) from the original edge of the window. The coating was chipped away from the edge of the damaged area to reveal the degree of undercutting. In the tidal zone the degree of undercutting was minor as seen in figure 42. Not visible in this photography is damage at the edge of the flange. The coating was also removed from around the window below the mud line. The photograph of this window, figure 43, indicates that undercutting extends 0.5 in (1.2 cm) under the coating. In general, the polyester glass flake coating, System 29, performed exceptionally well, developing only a few scattered pits over its surface. Though physical measurements were not complete, from its appearance one can estimate the total corrosion rate to be less than 0.1 mil per year (0.5 mdd) over the six years of exposure.

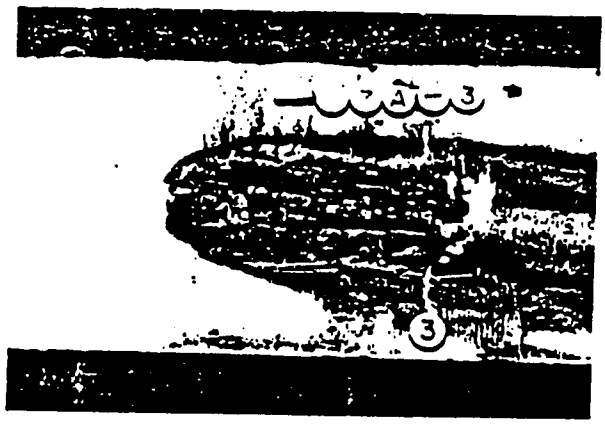

FIGURE 37

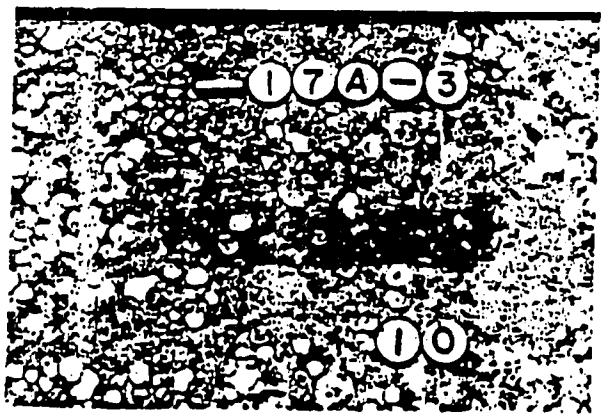

FIGURE 38

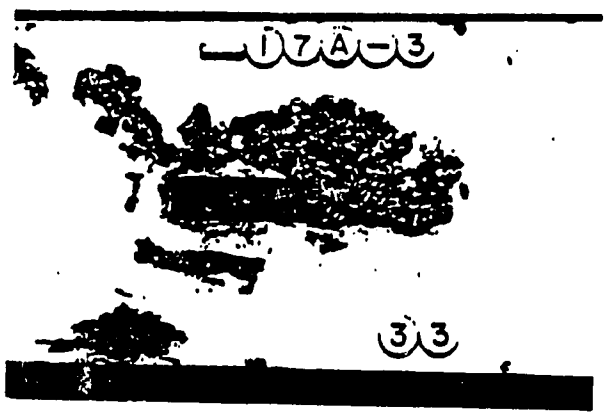

FIGURE 39

Phenolic mastic

Figure 35 illustrates the degree of deterioration of polyvinylidene chloride, System 12, as measured by electrochemical means. Without question, this system has given the least amount of protection to the steel. Initially it had a coating effectiveness of slightly more than 80. After five years the effectiveness of the coating dropped to 40. Figure 44 illustrates the data taken from the physical measurements. It is apparent from this figure that while the resulting corrosion of the pile is nowhere near that observed on the bare piles, it is considerably more than that seen on any of the piles protected by other types of nonmetallic coatings. The worst area of attack is in the erosion zone with a corrosion rate of 5 mils per year (27 mdd) in this narrow region. The average corrosion rate over the entire pile surface is calculated to be 2.4 mils per year (13 mdd). The deepest pits developed between mean low water and the mud line as shown in the same figure. Photographs taken of the window in the atmospheric zone show considerable deterioration of the polyvinylidene chloride not only in the area immediately adjacent to the window, but also in other surrounding areas. Figure 45 is an example of this observation. The least amount of undercutting is observed in the tidal zone where damage extends 0.3 in (0.8 cm) beyond the window as shown in figure 46. Below the mud line, the

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29A POLYESTER GLASS FLAKE

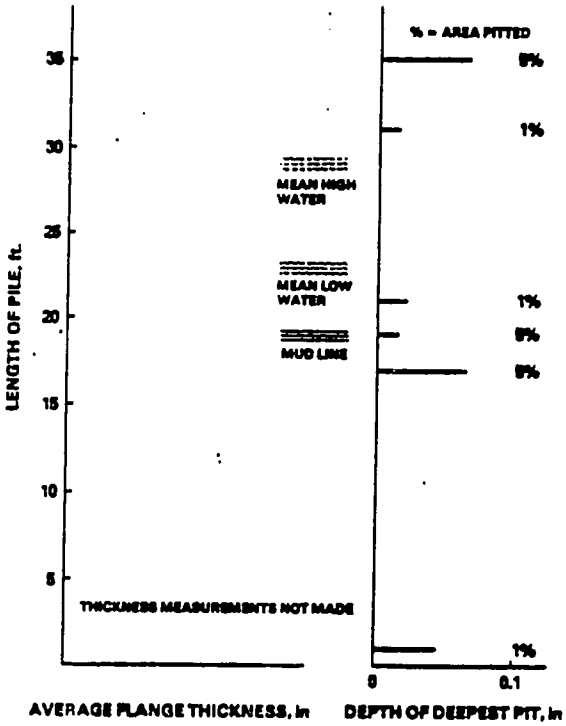

FIGURE 40

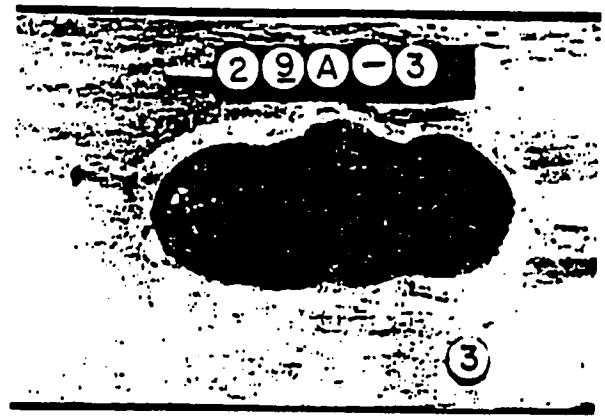

FIGURE 41

FIGURE 42

FIGURE 43

Flakeglass filled polyester

coating has been undercut almost two inches (5 cm) beyond the original edge of the window as shown in figure 47.

Metal Pigmented Coatings—Two aluminum pigmented coal tar epoxy coating systems (Systems 8 and 9) were included in the investigation. The electrochemical measurements on these two piles are illustrated in figure 48. From this figure one can see that the coating system on 8A has a relative coating effectiveness of over 70 while system 9A has slightly more than 60. The electrical resistivity of these two metal filled coatings is so high, that for all practical purposes they are nonconducting in the voltage ranges of our experiments. This is an important consideration as any conductivity through the film will affect the electrochemical measurements as will be pointed out later. The flange thickness measurements for pile 8A are illustrated in figure 49. This figure reveals that very little deterioration of the coating has taken place in the six years of exposure Most of the damage to the coating has occurred in the erosion zone. The corrosion rate in this region has averaged less than 0.1 mil per year (0.5 mdd). The degree of pitting damage is

79

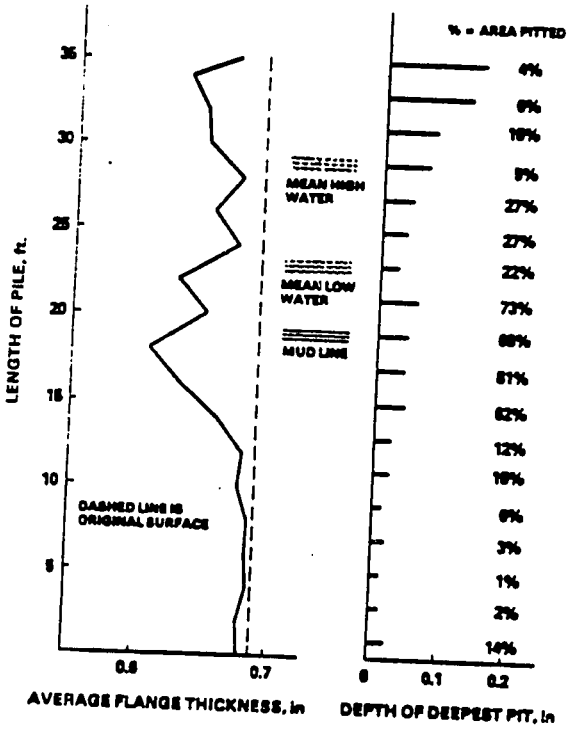

FIGURE 44

FIGURE 45

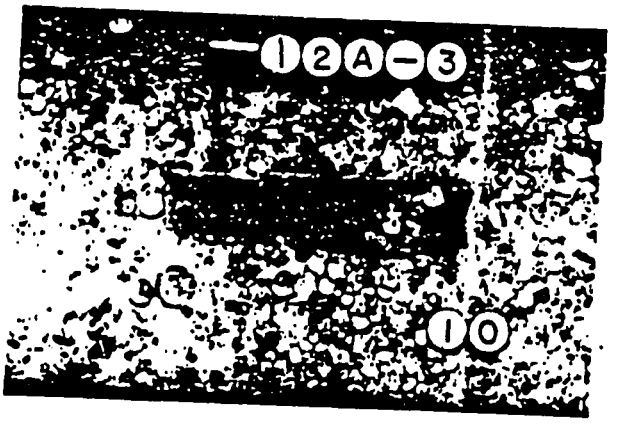

FIGURE 46

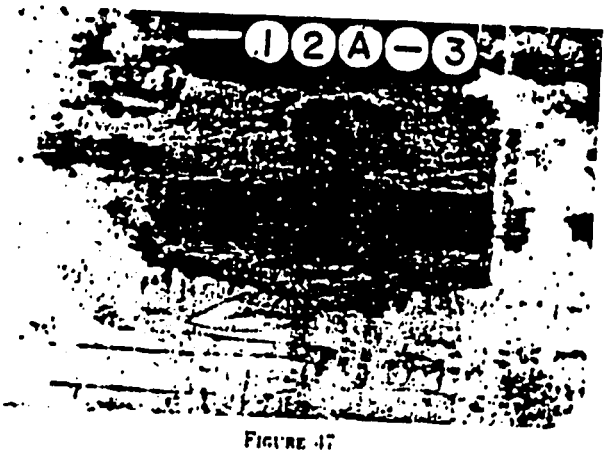

FIGURE 47

Polyvinylidene chloride

minor over most of the pile. In the atmospheric zone, undercutting of the coating extends less than 1.2 in (3 cm) beyond the original edge of the window as shown in figure 50. The same figure shows the otherwise excellent condition of the coating in the surrounding area. Most of the apparent damage is rust staining. In the tidal zone the coating at the edge of the window is in fairly good condition with only 0.1 in (0.2 cm) of undercutting as seen in figure 51. Some coating damage is visible in the surrounding area. Figure 52 is a similar window below the mud line which displays essentially no undercutting and no coating deterioration in the visible area.

The second system of aluminum pigmented coal tar epoxy, System 9, has a film thickness that is 30 percent thinner than System 8. Specimen 9A has undergone more damage as the physical measurements illustrate in figure 53. Incomplete sandblasting of the surface during the cleaning process has caused the flange of specimen 9A in figure 53 to appear thicker in the erosion zone than it really is. The coating 1 in (2.5 cm) from the edge where the flange thickness measurements are made is in

80

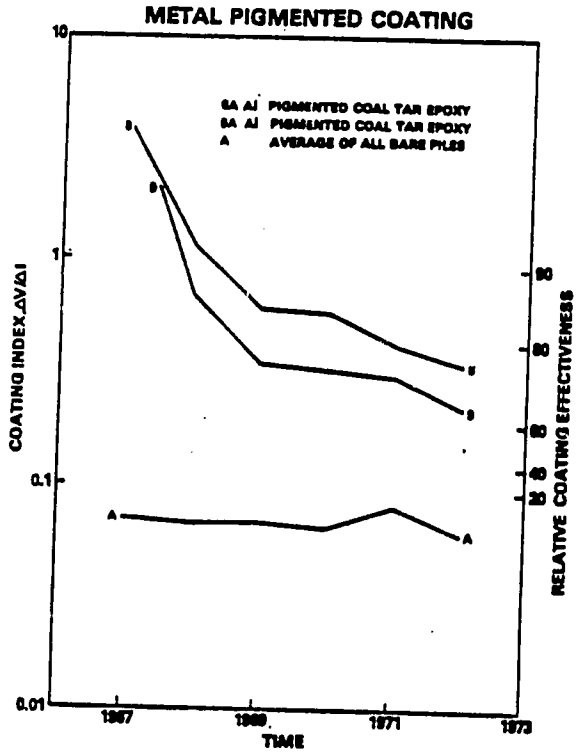

FIGURE 48

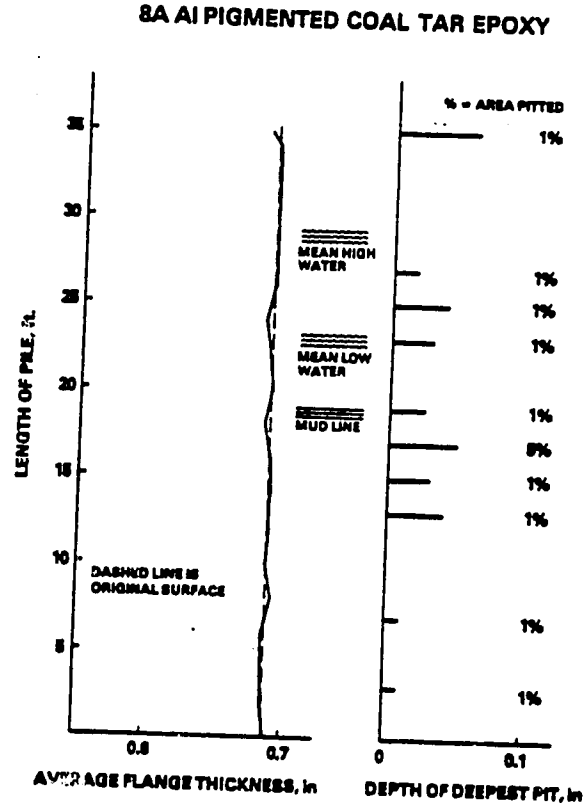

FIGURE 49

good condition, but two or three inches (5 to 7 cm) from the edge, the coating had deteriorated as indicated by the pitting data in the same figure. The average corrosion rate over the entire surface of the pile is calculated to be sligthly less than 0.2 mils per year (1 mdd). In the atmospheric zone, the coating window has produced undercutting extending about 1.5 inches (4 cm) under the coat as seen in figure 54. In the tidal zone, coating damage at the window is minor as can be seen in figure 55. Below the mud line undercutting has extended as much as 2 in (5 cm) under the paint system as shown in figure 56. Coating breakdown at the edge of the flange is also visible in this photograph. In general, both aluminum pigmented coal tar epoxy substrates have performed fairly well, although the thicker film, System 8A, has performed somewhat better in the six years of exposure.

Nonmetallic Coatings on Metal Filled Coatings—Metallic Zinc powder has been used in the metal filled undercoats of the five 2-coat systems discussed here. Whereas all of the topcoats are electrically isulating, three of the five metal filled undercoatings are electrically conducting. These three, Systems 18, 20, and 21 will be considered separately from the rest Figure 57 is a plot of the electrochemical data of these coatings. System 18, coal tar epoxy over zinc rich organic primer, is maintaining a relative coating effectiveness of 85. At the same time System 20, epoxy polyamide over zinc rich inorganic primer, has a relative coating effectiveness of 80. The coal tar epoxy over zinc rich inorganic primer, System 21, also has a relative coating effectiveness of 85. The relative coating effectiveness of these three systems may actually be slightly better than indicated by the electrochemical data. The reason being that as the overcoat erodes away or fails from some other cause, the electrically conducting metal filled undercoat is exposed. This undercoat may be protecting the steel very well, but because of its low electrical resistance it displays a lower coating effectiveness (coating index) than it really has.

The physical measurements on System 18A are illustrated in figure 58. The deterioration of the steel pile has been slight. The coating system has performed well in all of the zones of exposure. Average corrosion rate for the pile has been less than 0.2 mils per year (1 mdd). In the atmospheric zone, damage of the coating at the window has been severe as shown in figure 59. Undercutting of the coating extends almost 2 in (5 cm) beyond the window. Undercutting of the coating in the tidal zone has been

minor as shown in figure 60. Below the mud line the effect is negligible as seen in figure 61. Some of the coating damage visible in this photograph is mechanical abrasion due to removal and shipping.

System 20A has also shown good resistance to the ocean exposure as illustrated by the physical measurements of figure 62. In this case some deterioration has occurred at the erosion zone, but with insignificant attack below the mud line. The coating was not completely removed in some areas which accounts for the flange appearing thicker than it was originally. This certainly indicates that the coat was still protecting in these areas. The average corrosion rate for this pile was considerably less than 0.1 mil per year (0.5 mdd). Undercutting resistance has been very good in all zones. The window located in the atmospheric zone developed less than 0.5 inches (1.2 cm) of undercutting as shown in figure 63. General pitting can be seen in the surrounding coating. Figure 64 illustrates the excellent appearance of the coating in the tidal zone. Below the mud line undercutting resistance is also very good, however, some blistering is visible in the coating in the adjacent areas (fig. 65).

System 21 has displayed unusually good resistance to deterioration in the offshore exposure as shown in the physical measurements of figure 66. Incomplete sandblasting has led to the data showing the flange to be thicker than it was originally. As mentioned before, this clearly indicates that there was no metal loss in these areas. Thus, pile 21A is in excellent condition after six years of exposure. The amount of pitting is minor as the same figure shows. Undercutting of the coating in the atmospheric zone has been moderate with damage extending about 0.6 in (1.5 cm) beyond the window as seen in figure 67. The coating in the surrounding area is in excellent condition. In the tidal zone undercutting is of minor consequence and extends less than 0.1 in (0.2 cm) as illustrated in figure 68. Below the mud line there was no measurable undercutting of the coating as shown in figure 69. Mechanical damage to the edge has removed some of the coating.

Attention is again directed to figure 57 which illustrates the electrochemical data for the nonmetallic coatings on metal filled coatings. Systems 18, 20, and 21 have been described. The remaining systems in this category are piles 19A (vinyl over zinc rich inorganic primer), and 22A (vinyl mastic over zinc rich inorganic primer).

The electrochemical data indicate that Systems 19 and 22 are very similar in their deterioration and degree of protection as figure 57 illustrates. The relative coating effectiveness

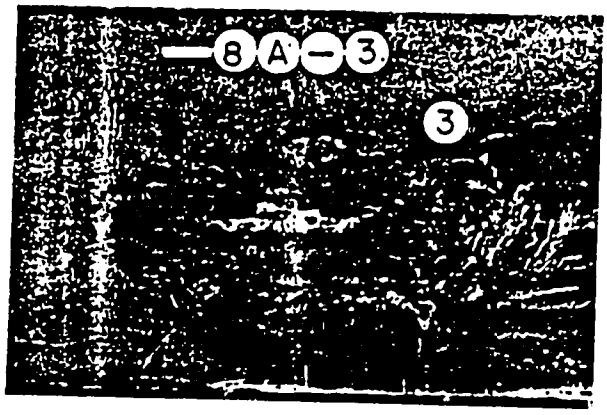

FIGURE 50

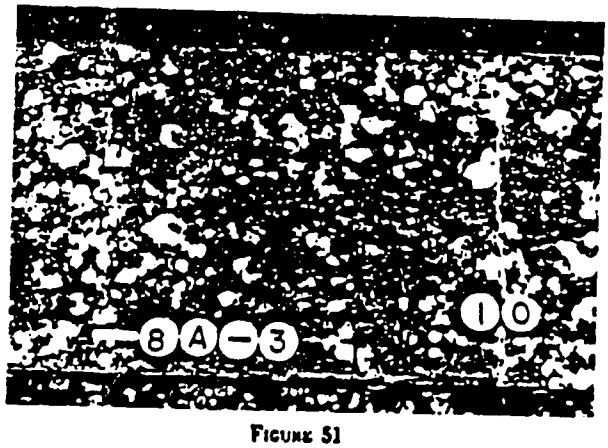

FIGURE 51

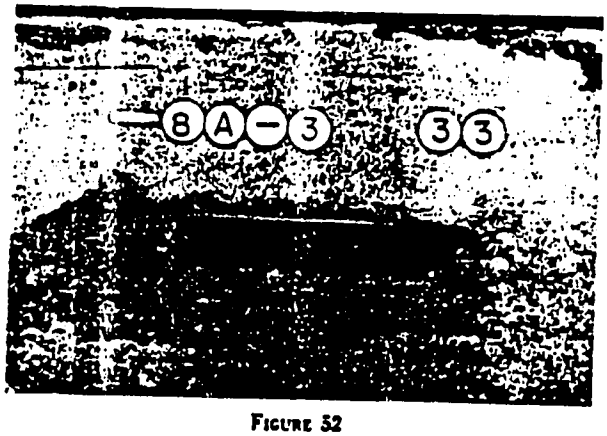

FIGURE 52

Aluminum pigmented coal tar epoxy

42

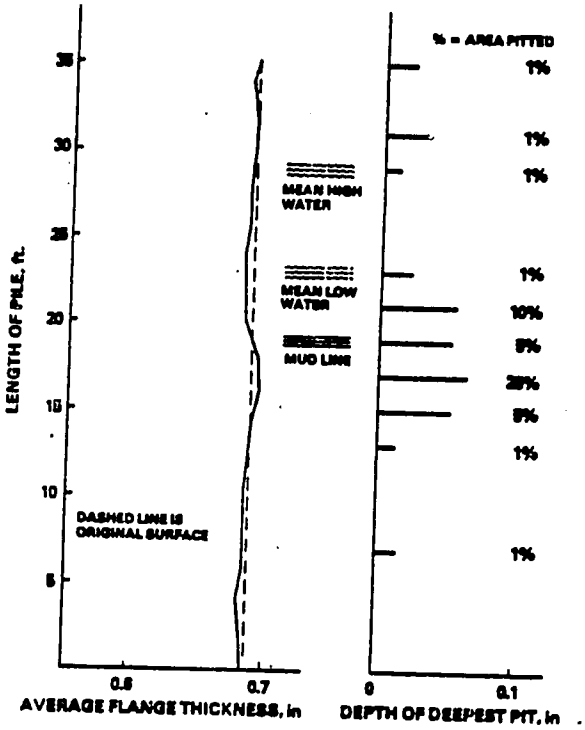

Figure 53

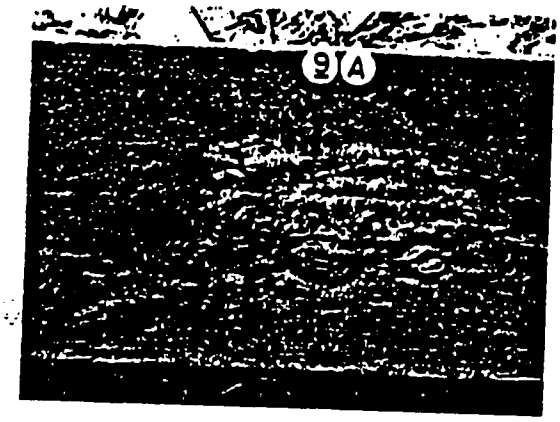

Figure 54

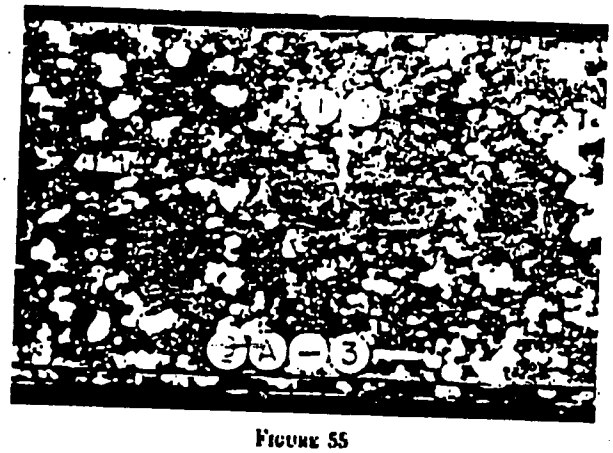

Figure 55

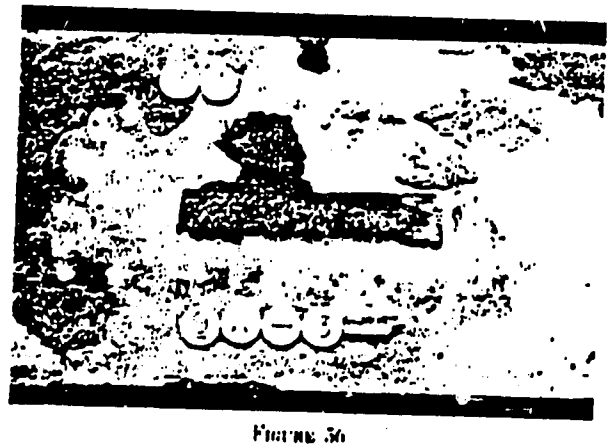

Figure 56

Aluminum pigmented coal tar epoxy

of both is slightly over 60. The physical measurement data for pile 19A is plotted in figure 70. Attack of the pile has been general over its length. However, there was more attack in the erosion zone than this data, taken 1 in (2.5 cm) from the edge, indicates. The corrosion extended from the 15-ft mark to the 20-ft mark on the inner surface of the flanges and 2 to 3 in from the edge. This attack is indicated by the pit depth measurements of figure 70. Its average corrosion rate is about 0.2 mils per year (1 mdd). Undercutting in the atmospheric zone shown in figure 71 extends less than 0.5 in (1.2 cm) beyond the window with some edge deterioration evident. General deterioration has been extensive in the tidal zone. Figure 72 is a photograph of the window in this region that reveals less than 0.1 in (0.2 cm) undercutting. Below the mud line undercutting was also less than 0.1 inches (0.2 cm) as shown in figure 73. The coating was damaged mechanically, but no undercutting was found under the surrounding encrustation.

Pile 22A, vinyl mastic over inorganic zinc rich, has a relative coating effectiveness slightly above 60 after six years. The flange thickness measurements are illustrated in figure 74.

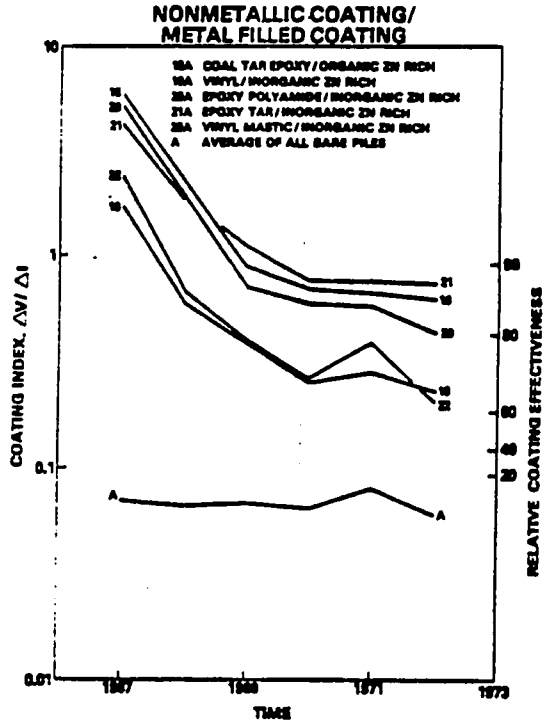

FIGURE 57

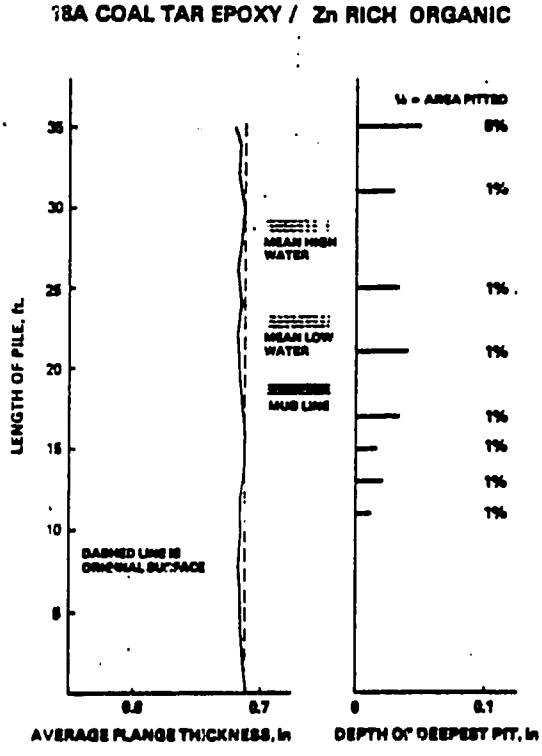

FIGURE 58

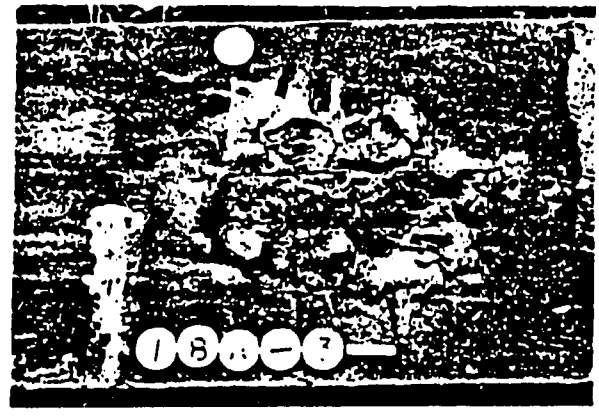

FIGURE 59

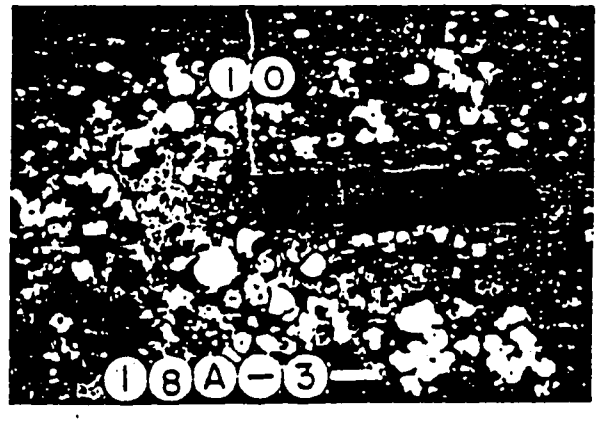

FIGURE 60

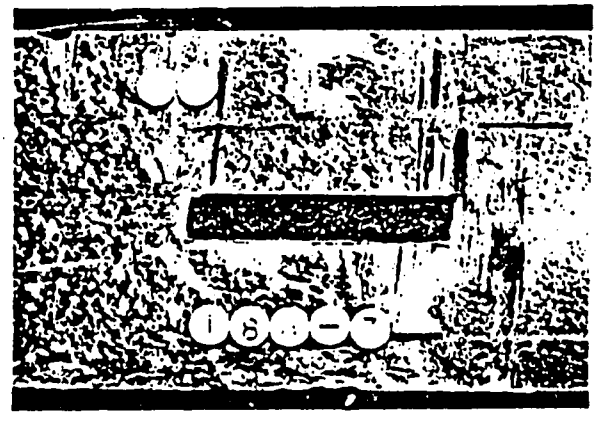

FIGURE 61

Coated zinc rich epoxy

64

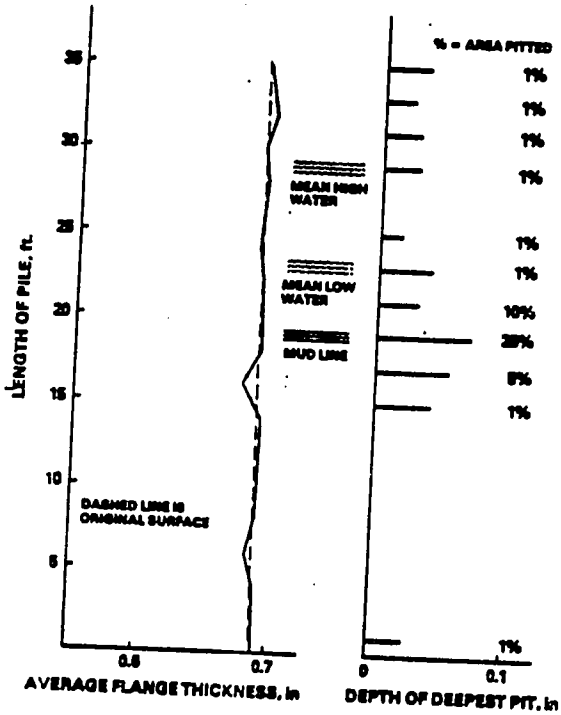

FIGURE 62

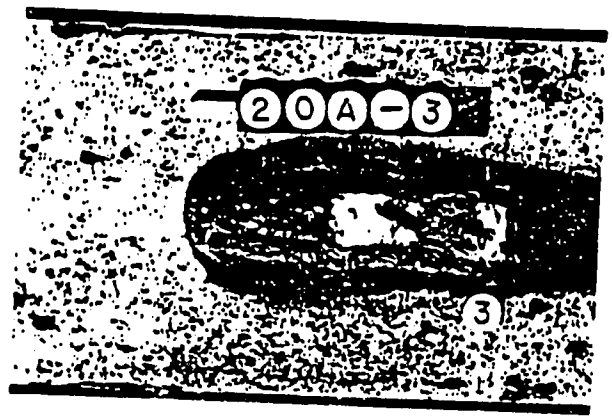

FIGURE 63

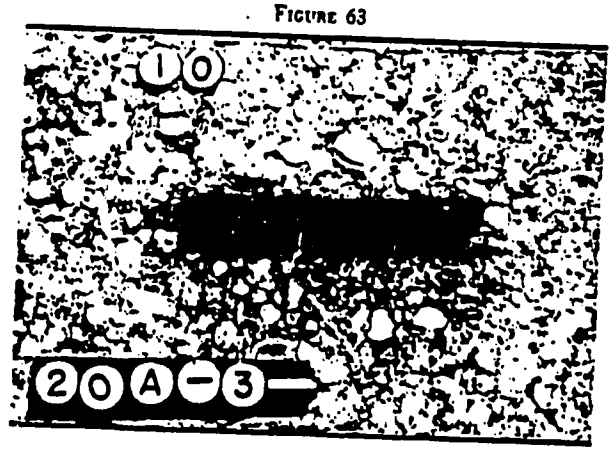

FIGURE 64

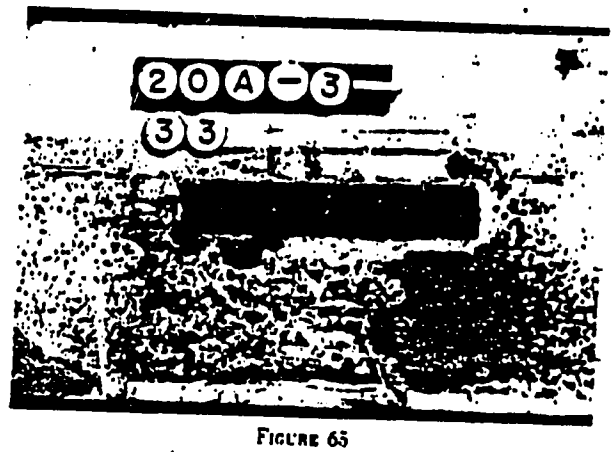

FIGURE 65

Coated zinc inorganic silicate

There is very little attack in the atmospheric zone. Undercutting in this area is less than 0.1 in (0.2 cm) as shown in figure 75. In the tidal zone general deterioration of the coating has taken place, but with very little actual metal loss. This is illustrated in figure 76. Undercutting here is also less than 0.1 in (0.2 cm). Below the mud line undercutting extends about 0.2 in (0.5 cm) beyond the window as figure 77 shows. Notice the blistering of the coating in the surrounding area. The overall average corrosion rate for pile 22A is less than 0.25 mils per year (1.4 mdd).

In general, these two-coat systems, nonmetallic coatings over metal filled coatings, have performed very well with overall corrosion rates, averaging less than 0.2 mil per year (1 mdd). The coal tar epoxy over inorganic zinc rich, 21A, has shown above average resistance to the ocean environment in the six years of exposure.

Nonmetallic Coating on Metallic Coatings—This group of coatings is made up of three systems: 13A, Vinyl sealer over flame sprayed aluminum, 15A, Polyvinylidene Chloride over flame sprayed zinc, and 16A, Vinyl-red lead over flame sprayed zinc. With these systems, as

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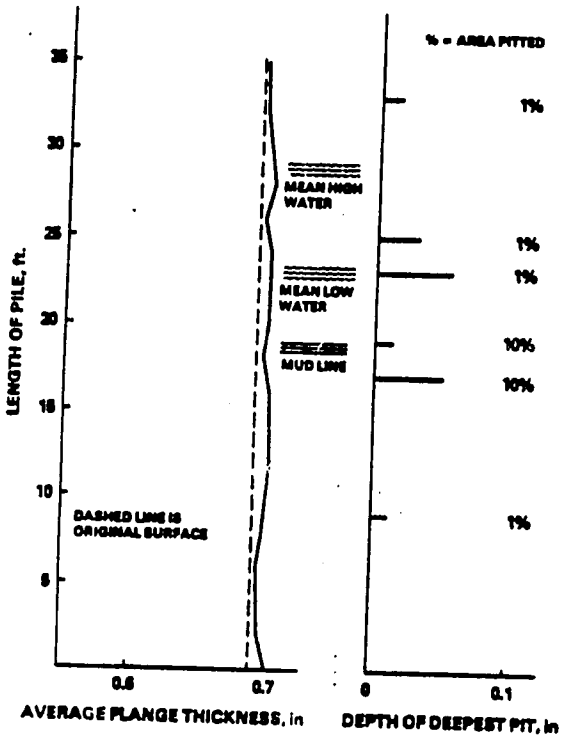

FIGURE 66

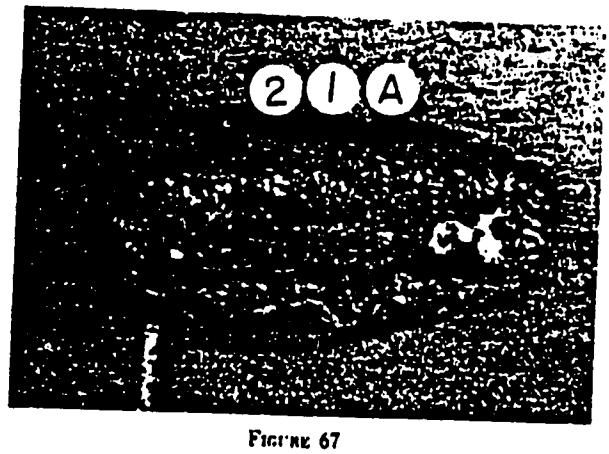

FIGURE 67

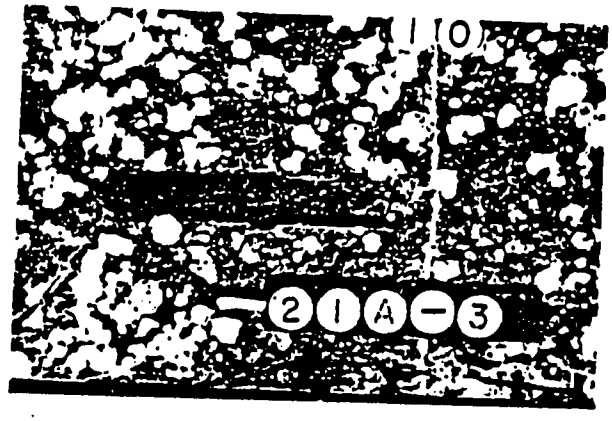

FIGURE 68

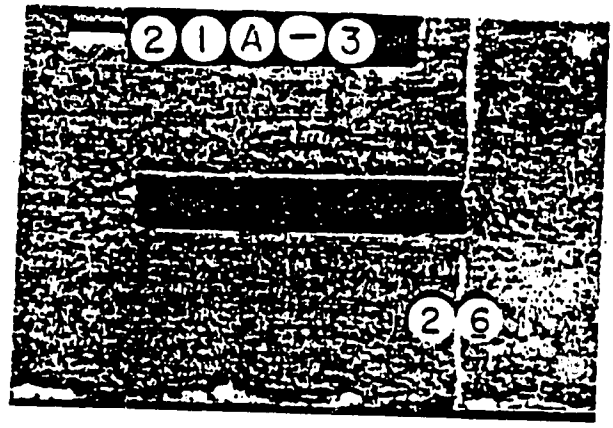

FIGURE 69

Coated zinc inorganic silicate

with some of the electrically conducting metal filled coatings, the coating index (relative coating effectiveness) measurements are more complex. The electrochemical data still gives an excellent indication of the protective ability of the nonconducting top coat. Furthermore, as the top coat deteriorates the same data reflects the changes occurring on the metallic base coat. Figure 78 illustrates the electrochemical data gathered for the systems indicated. The vinyl sealer over flame sprayed aluminum system, pile 13A, now has a relative coating effectiveness above 60. It is imporant to point out that the vinyl seals the pores of the flame sprayed aluminum and is not intended to form a continuous film over the surface of the aluminum. The flame sprayed aluminum coating, however, is still providing mechanical and electrochemical protection to the steel piling with the relative coating effectiveness being much better than that indicated by figure 78. Figure 79 illustrates the data on the physical measurements of this piling. Only a small amount of metal has been lost in the area of the erosion zone. The amount of pitting is practically insignificant. The average corrosion rate of 13A has

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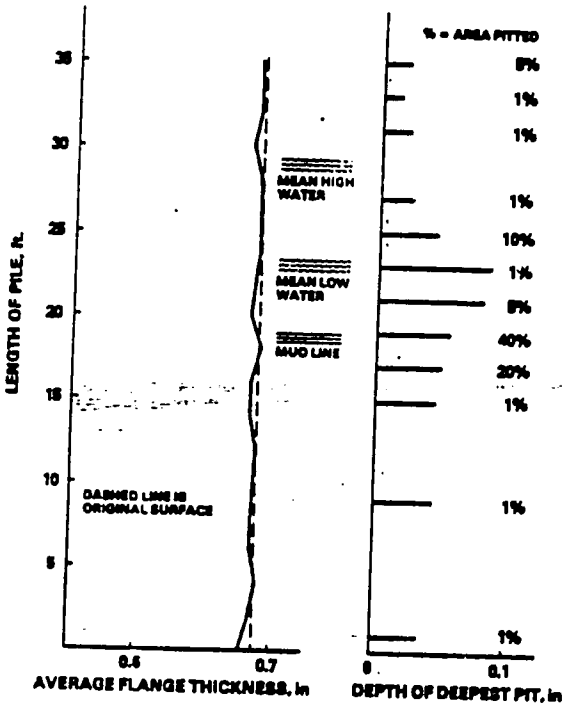

FIGURE 70

FIGURE 71

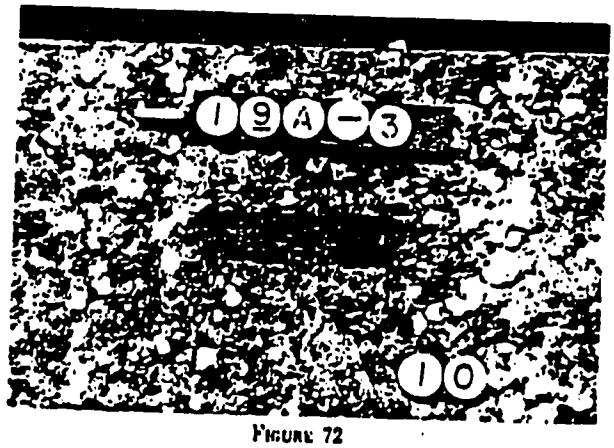

FIGURE 72

FIGURE 73

Coated zinc inorganic silicate

been less than 0.05 mils per year (0.3 mdd) for the six years of exposure.. In the atmospheric zone, the coating is in excellent condition. Corrosion damage extends slightly less than 0.5 in (1.2 cm) from the edge of the window as shown in Figure 80. Undercutting of the coating at the window in the tidal zone is too slight to be measurable, however, general coating failure is visible as figure 81 shows. Though the coating has obviously deteriorated below the mud line (fig. 82), there has been little subsequent attack to the steel pile. Damage to the coating at the window extends about 0.1 in (0.2 cm).

Pile 15A, polyvinylidene chloride over zinc flame spray, is unusual in that the electrochemical readings indicate that initially its coating effectiveness decreased as the nonmetallic coating failed, but then the metallic zinc coating proceeded to provide protection. Consequently, the coating effectiveness of the system improved as illustrated in figure 78. Total coating effectiveness below the water line is well above 85. In general, the zinc seems to have developed some nonconducting film, probably an oxide, that has brought this improvement about. The average flange thickness measurements are plotted in figure 83. Total metal

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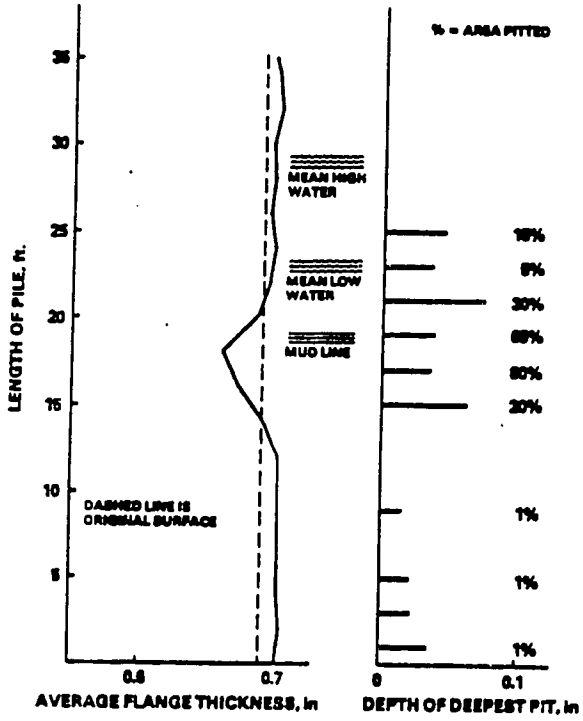

FIGURE 74

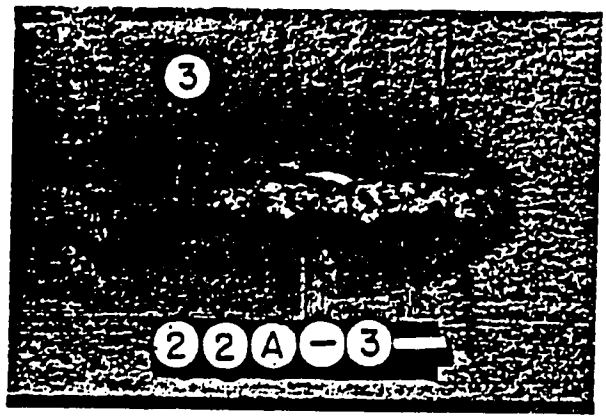

FIGURE 75

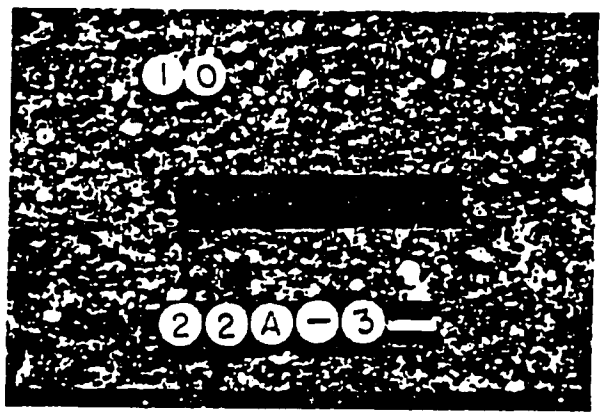

FIGURE 76

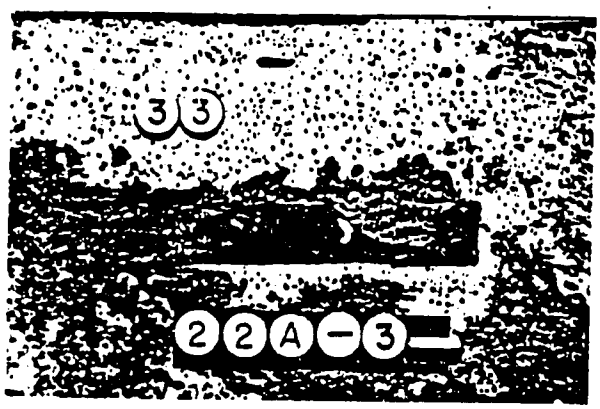

FIGURE 77

Coated zinc inorganic silicate

loss is small and uniform over the surface of the pile. Similarly, pitting is scattered and of minor consequence. The average corrosion rate for the entire pile is about 0.1 mil per year (0.5 mdd). There were no windows in the coating of this pile. The following photographs are included to display its appearance in areas similar to those seen for the other pilings. The coating in the atmosphere is in very good condition with only minor damage in a few areas. Unfortunately the photograph of this area is of such poor quality that it will not be shown. In the tidal zone the nonmetallic coating is badly blistered as figure 84 shows, but the piling is still being protected by the zinc. Top coat blistering extends into the area below the mud line as figure 85 illustrates, but corrosion damage to the pile is minor.

The vinyl over zinc flame spray system, pile 16A, has undergone the most deterioration of the topcoated metallic coating systems. The relative coating effectiveness of 16A is about 50 percent as figure 78 illustrates. After the top coat began to fail during the first year of exposure, the flame sprayed zinc protected the piling for a short period. Soon after, however, the system started to deteriorate steadily. It is of interest to note that the total coating thick-

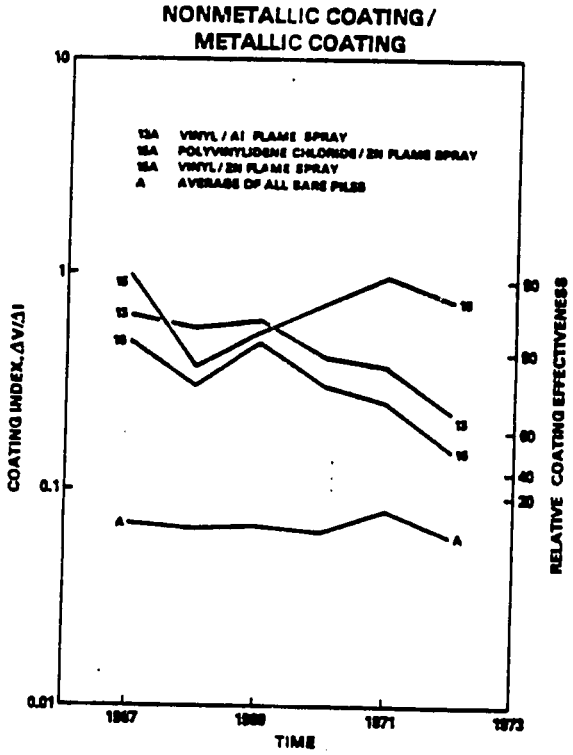

FIGURE 78

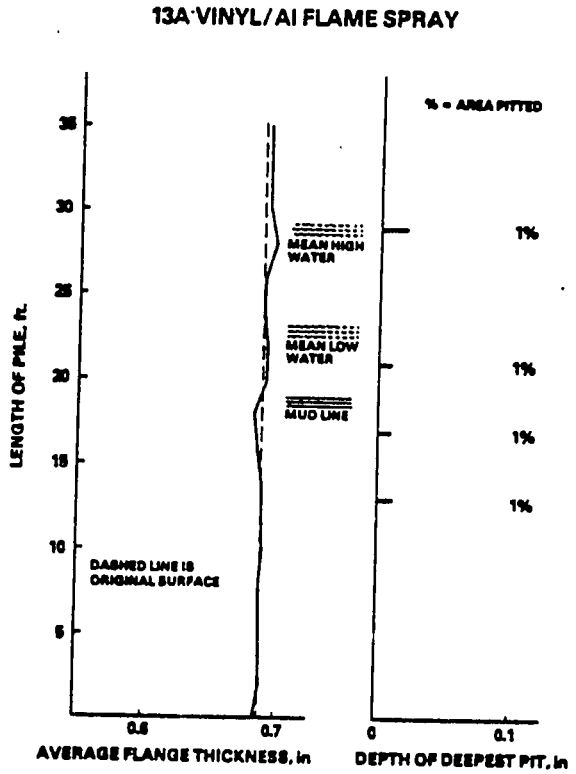

FIGURE 79

ness of this system is about 50 percent less than that of pile 15A. Corrosion damage to the steel pile in the form of general corrosion and pitting has been extensive as the plot of the physical measurements in Figure 86 illustrate. The average corrosion rate for the entire pile is about 1.5 mils per year (8 mdd). In the atmospheric zone coating failure was severe as figure 87 shows. The window in the coating is barely visible. In the tidal zone failure was also entensive as shown in figure 88. Figure 89 illustrates the condition of the piling below the mud line where it has fared somewhat better than in other zones. With such complete failure of the coating, evaluation of the undercutting is of no consequence and, therefore, is not attempted.

The nonmetallic coating on metallic coating systems have displayed a broad spectrum of coating response to the offshore exposure. With the exception of 16A, they have protected the steel piles well.

Metallic Coatings—Two metallic coating systems will be discussed. The first one, 10A, is a hot dipped galvanized steel piling. Pile 14A, the second one, was coated with a flame sprayed aluminum coating.

Corrosion rates for the nonferrous coatings cannot be calculated easily from the electrochemical data because it is not known with any degree of certainty what fraction of the total corrosion current measured is due to the corrosion of the steel substrate and what fraction is due to the nonferrous coating. Therefore, the corrosion current density shown in figure 90 is reported for these highly conducting coatings rather than the coating index used for the nonconducting coatings.

The results on the bare carbon steel piles are shown for reference as was done in all illustrations of electrochemical data. The corrosion current indicates that the bare steel corroded at a relatively uniform rate with time while the corrosion of the galvanized pile, 10A, has changed considerably in the same period. During the first three years, the corrosion current decreases by a factor of ten. Thereafter it increased steadily until now, eight years later, it is approaching the corrosion of the bare carbon steel pile. This data on the galvanized steel is made up of information from piles A, B, and C, two of which are still at the offshore site. Figure 91 illustrates the physical measurements on pile 10A. The pile shows some

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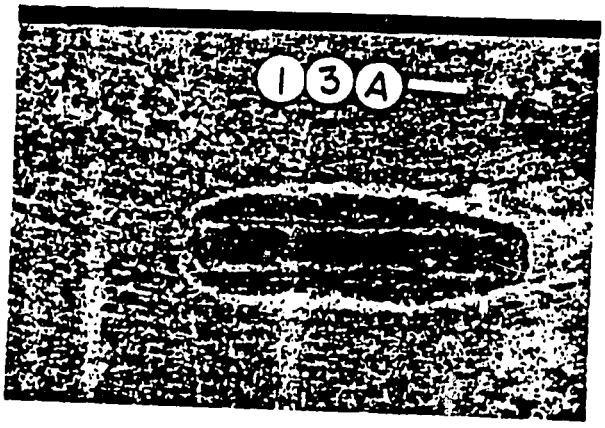

FIGURE 80

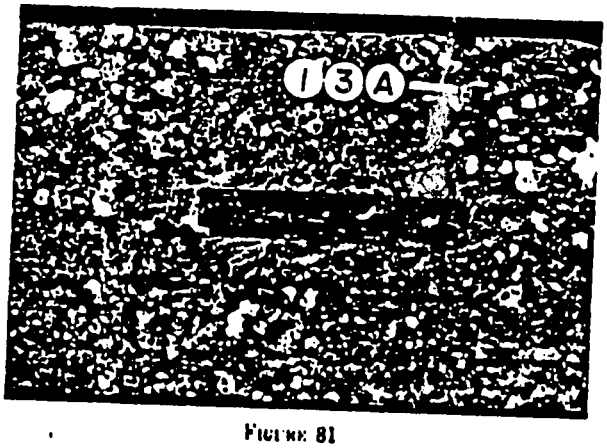

FIGURE 81

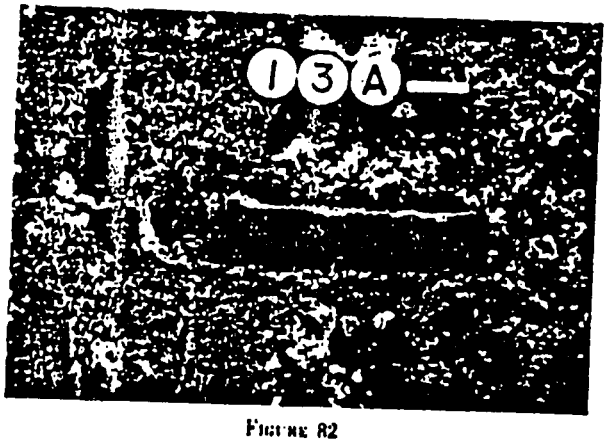

FIGURE 82

Flamesprayed aluminum wire

corrosion in the atmospheric zone and considerable corrosion in the abrasion zone. The average corrosion rate for the pile is less than 0.15 mils per year (0.8 mdd). There are no windows in this system, but photographs are included for information. Above the high water line, coating failure is in the form of pits as figure 92 illustrates. In the tidal zone pitting continues along with some undercutting of the coating. A small section of coating was easily separated from the substrate as figure 93 shows. Below the mud line the coating was very thin or altogether missing in some areas as figure 94 illustrates.

The flame sprayed aluminum system, pile 14A, is similar to pile 10A in its electrochemical behavior as indicated in figure 90. It too shows an increase in corrosion which is approaching that of bare steel as the aluminum deteriorates. The flange thickness measurements, figure 95, reveal some metal loss in the erosion zone, and practically no pitting anywhere. In the atmospheric zone the aluminum flame spray coating appears in excellent condition with the exception of the corrosion damage extending almost 1 in (2.5 cm) from the window shown in figure 96. In the tidal zone the coating is also in excellent condition (fig. 97) with minor damage extending from the window. From the mud line down, however, damage is more extensive. Figure 98 illustrates the window in this region with coating damage over most of the visible surface.

The metallic coatings began to show signs of deterioration after approximately five years of exposure. The steel piles that they protected are in excellent condition with minor damage in the abrasion zone.

Cathodically Protected Piles—The potentials of the cathodically protected piles over an eight year period are presented in table 2. Although the potentials of the steel piles versus a Ag-AgCl half-cell and a Cu-$CuSO_4$ half-cell were both measured, only the potentials versus Cu-$CuSO_4$ half-cell are indicated. In general, the potentials of the piles with anodes in the sand were less negative (more noble) during the eight year period than those piles with their anodes in the water. After one year, the potentials of the bare steel piles with aluminum and zinc anodes in the sand, roes to more negative values which then remained rather constant during the eight year period.

The average corrosion current densities of several bare steel piles and the average protective current densities of steel piles with zinc anodes are plotted in figure 99. The protective current density of the protected piles represent both the galvanic current as well as local action current on the anodes. The local action current was not directly determined but it has

90

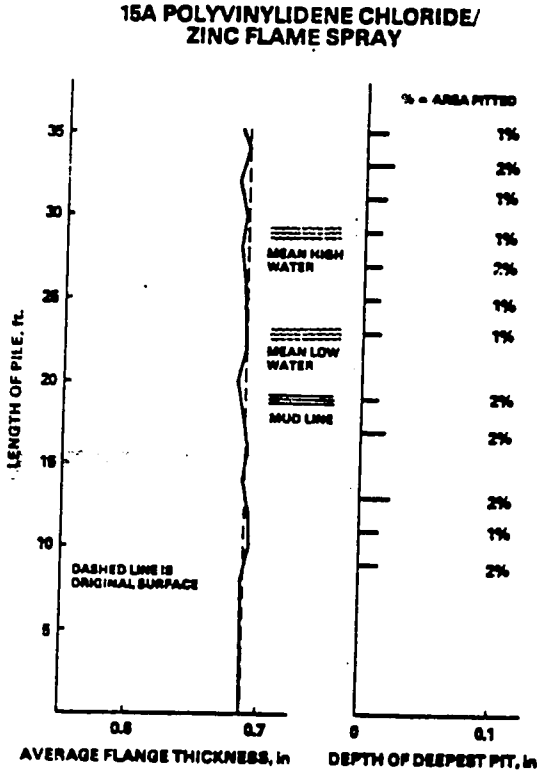

FIGURE 83

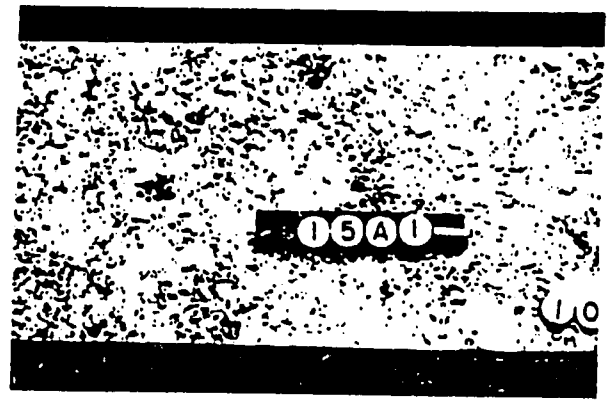

FIGURE 84

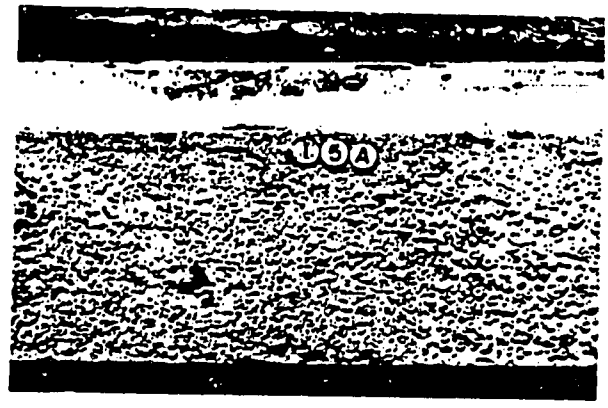

FIGURE 85

Coated flamesprayed zinc

been estimated to be about 10 percent of the total corrosion current density [12]. The current density calculations were based upon the total submerged area of the pile. The areas of the anodes (originally 5-10% of the total submerged pile area) were not included in the calculations. Their consideration would have made the total protection current densities for the piles with anodes slightly less. These considerations apply to all of the systems to be discussed.

As seen in figure 99, the [redacted] current densities of the zinc anode protected systems are less than those of the unprotected piles. It appears that there is not very much difference in the protective current densities provided by the anodes in the water and buried in the sand over the 6 year period (1970 to 1975). More time will be required to determine any real differences.

Aluminum anodes in the sand appear to be less effective than the anodes in water in protecting the steel (fig. 100).

In the case of mariner steel, however, the protection current density of the zinc anodes buried in the sand, over the 6 year period, is definitely less than the current density of the zinc anodes exposed to the water (fig. 101).

The coal tar epoxy coated piles, with zinc anodes in the sand appear to be more effective (from a galvanic current standpoint) than the coated piles without cathodic protection except for one year (1971). For the piles with windows (5A and 25A), there was little discernible differences for two years (1971, 1972) between the piles with anodes in the water and the piles without anodes (fig. 102).

A comparison of the galvanized pile, with zinc anodes (System 11) and without zinc anodes (System 10), is shown in figure 103. Only a portion of the curve for the protective current density of the galvanized pile is shown. From 1973 to 1975 the curve represents the averages on piles B and C. Initially (1967) the average corrosion current density on piles A, B, and C was quite high and then decreased to very low values for 1967-1971 (fig. 90). The protective current density is very low for the zinc anodes buried in the sand and appears to be steadily decreasing with the passage of time. The protective current density for the zinc anodes in the water is about 3 times higher and appears to be increasing with time.

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16A VINYL/ZN FLAME SPRAY

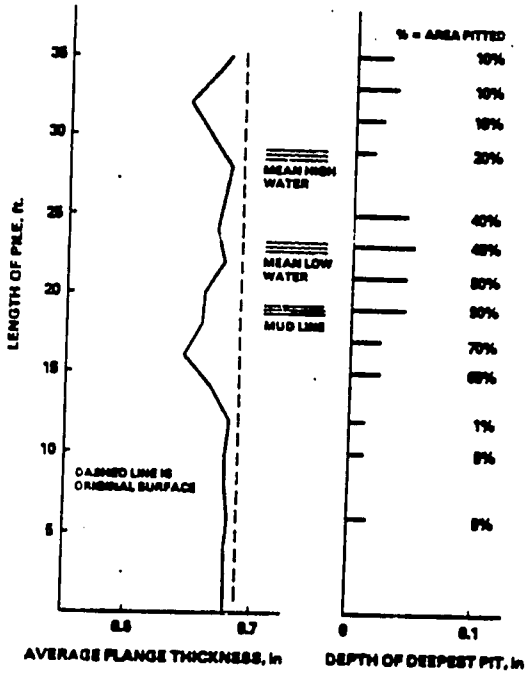

FIGURE 86

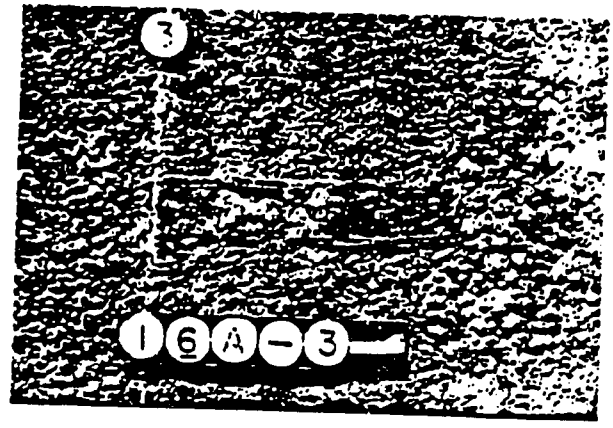

FIGURE 87

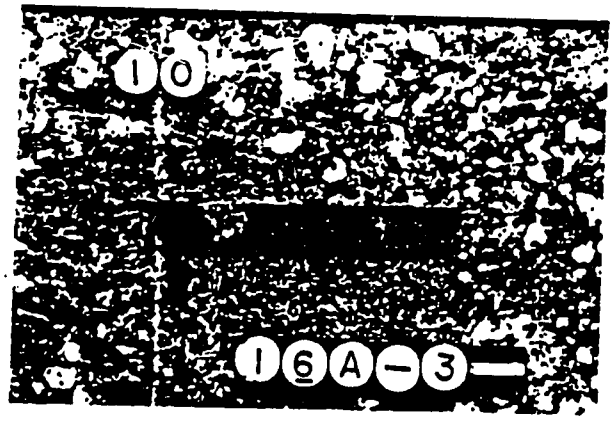

FIGURE 88

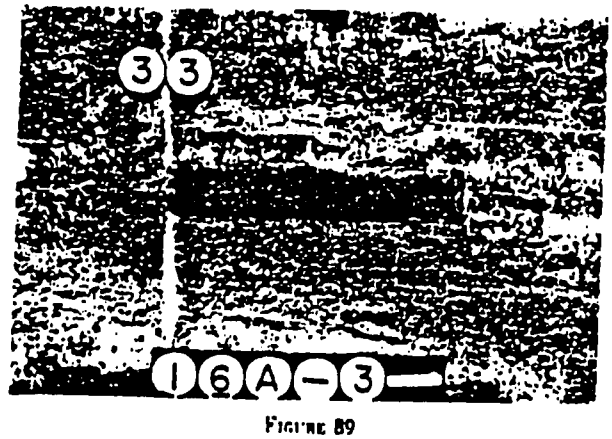

FIGURE 89

Coated flamesprayed zinc

5. Summary

Every coating system reduced the corrosion of the steel piling in seawater. In this respect they differed only in the degree of protection they afforded the steel. In the first six years of exposure some coatings reduced corrosion by a factor of 200 while others reduced corrosion by a factor of 2 as compared to the bare piles. In table 3, the coatings are listed in order of increasing degree of corrosion of the piling. It is apparent from this table that there is no group of coatings (i.e., nonmetallic, metal pigmented, etc.) that is entirely satisfactory.

An average corrosion rate of 0.1 mpy (0.5 mdd) or less was measured for six systems. Four of these six are two-coat systems. Generally the two-coat systems performed very well in this program. The other two systems with average corrosion rates <0.5 mpy (0.5 mdd) are an aluminum pigmented coating, and a glass flake filled coating. Both performed very well with the glass flake filled coating being particularly resistant to the abrasive action of the erosion zone.

92

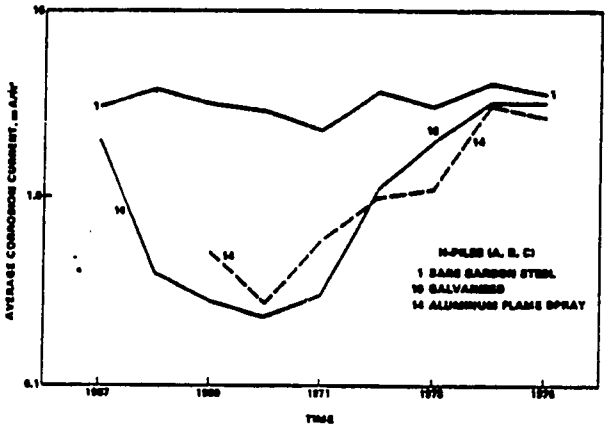

FIGURE 90

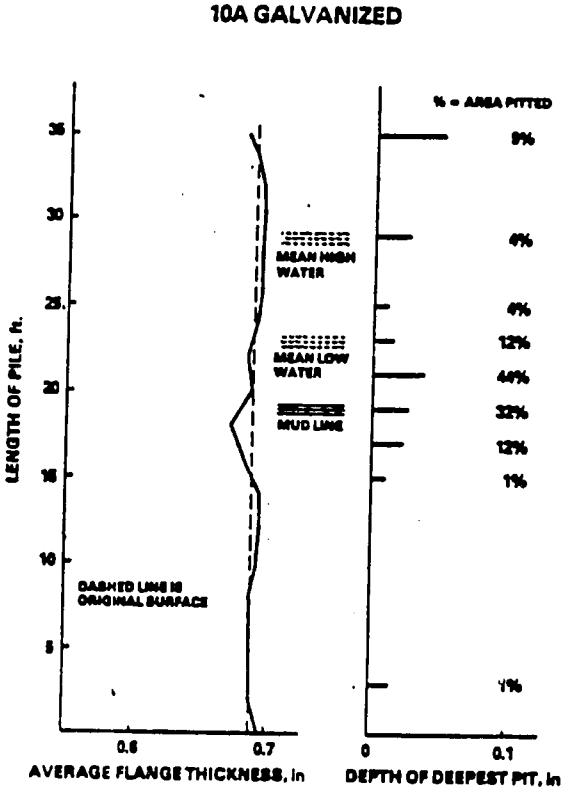

FIGURE 91

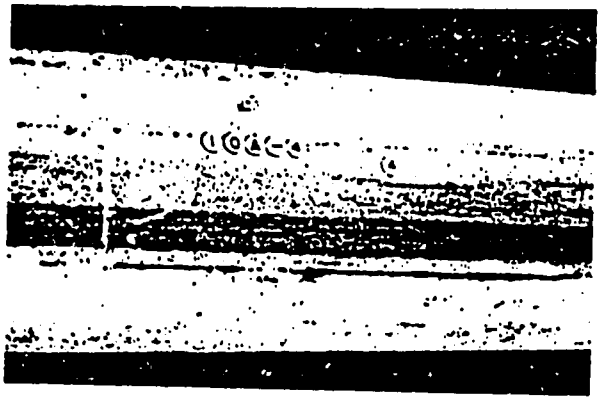

FIGURE 92

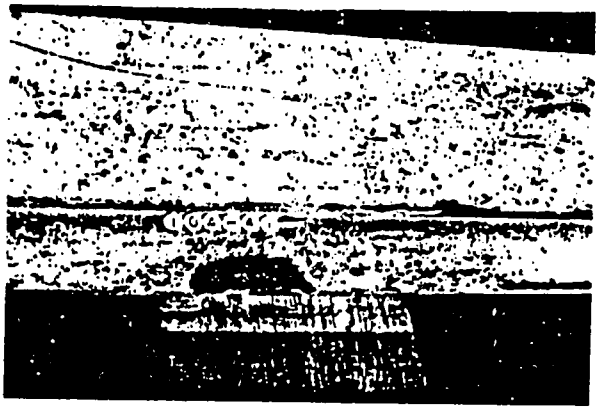

FIGURE 93

FIGURE 94

Hot dipped zinc (galvanized)

93

14A Al FLAME SPRAY

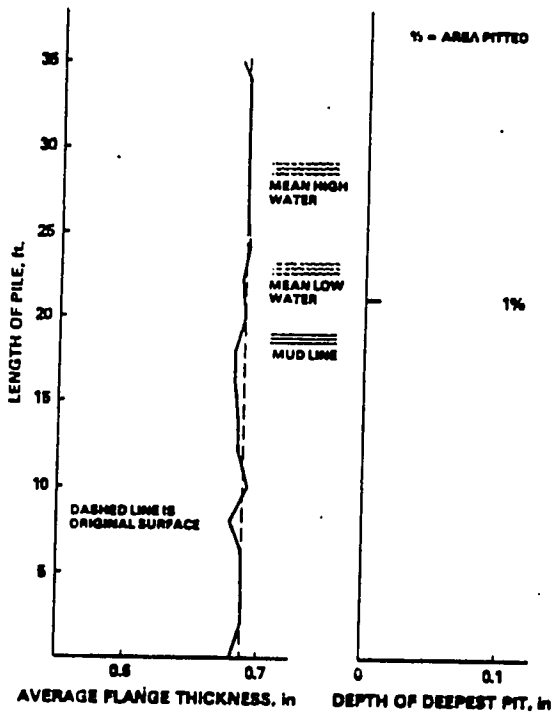

FIGURE 95

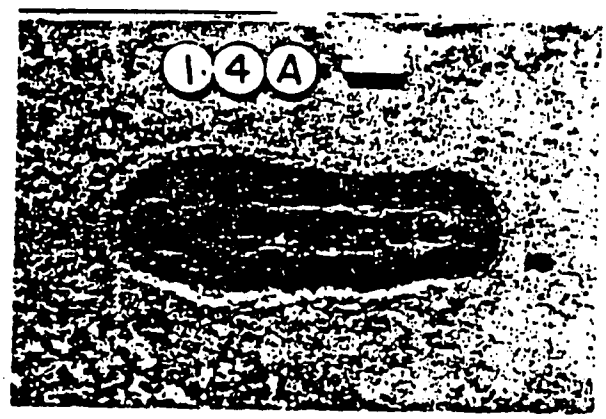

FIGURE 96

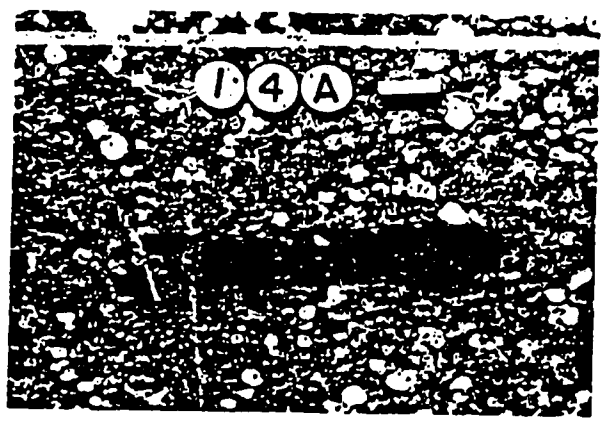

FIGURE 97

FIGURE 98

Sealed flamesprayed aluminum

Seven systems exhibited corrosion rates in the range of 0.14 mpy (0.8 mdd) to 0.24 mpy (1.3 mdd) as table 3 reveals. All seven of these coatings performed well. Two are metallic coatings that were distinctive in their ability to protect the piling uniformly including the corners of the flange. Most coatings first failed at the corners. System 22 suffered extensive breakdown in the erosion zone but unusually good resistance to attack in the atmospheric-splash zone.

The remaining six systems were the least protective with average corrosion rates on the steel greater than 0.53 mpy (3 mdd). Four of the six systems are coal tar epoxy coatings which were particularly poor in the atmospheric-splash zone leading to relatively high average corrosion for the steel. Of all the coatings, System 12 provided the least protection to the steel, even though it has been reported to perform well by other laboratories [7].

As expected, the electrochemical measurements of the cathodically protected systems clearly indicate that their corrosion rates are much lower than similar piles without protection. Furthermore, it is of interest to note that,

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Table 2 - Potentials of Cathodically Protected Steel Piles Over a Period of 8 Years of Exposure (Offshore) in the Atlantic Ocean at Dam Neck, Virginia.

Pile	Pile[1/] Description	Anode[2/] System	Potential of Pile, V-Ref-Cu-CuSO$_4$, Positioned Remote - On the Beach								
			1967[4/] Intermediate Tide	1968 Low Tide	1969 High Tide	1970 High Tide	1971 High Tide	1972 High Tide	1973 High Tide	1974 High Tide	1975 High Tide
2A	Bare Steel	Zn, in water	-1.04	-1.03	-1.08	-1.07	-1.08	-1.04	-1.06	-1.07	-1.03
2B	Bare Steel	Zn, in sand	-0.70	-0.73	-0.91	-0.83	-0.96	-0.93	-0.89	-0.97	-0.88
2C	Bare Steel	Zn, in water	-1.05	-1.05	-1.05	-1.04	-1.07	-1.06	-1.06	-1.06	-1.05
3A	Bare Steel	Al, in water	-1.04	-1.03	-1.04	-1.04	-1.05	-1.03	-1.06	-1.04	-1.03
3B	Bare Steel	Al, in sand	-0.71	-0.73	-0.92	-0.82	-0.94	-0.87	-0.96	-0.85	-0.92
3C	Bare Steel	Al, in water	-1.04	-1.04	-1.04	-1.03	-1.05	-1.04	-1.06	-1.03	-0.99
5A	[3/]Coated Steel	Zn, in water	-1.10	-1.07	-1.12	-1.09	-1.05	-1.07	-1.10	-1.12	-1.08
5B	Coated Steel	Zn, in sand	-1.09	-1.07	-1.10	-1.08	-1.03	-1.09	-1.09	-1.08	-1.07
5C	Coated Steel	Zn, in water	-1.09	-1.08	-1.11	-1.09	-1.04	-1.00	-1.08	-1.06	-1.04
11A	Galv. Steel	Zn, in water	-1.08	-1.06	-1.08	-1.08	-1.02	-1.03	-1.08	-1.07	-1.05
11B	Hot-Dipped	Zn, in sand	-1.05	-0.99	-1.01	-0.98	-0.98	-0.98	-1.03	-0.98	-0.96
11C	3 oz Coat	Zn, in water	-1.08	-1.06	-1.08	-1.07	-1.02	-1.06	-1.04	-1.06	-1.04
24A	Bare	Zn, in water	-1.07	-1.05	-1.07	-1.07	-1.01	-1.03	-1.06	-1.08	-1.04
24B	Low Alloy	Zn, in sand	-0.86	-0.93	-1.00	-0.92	-0.94	-1.00	-1.00	-0.96	-0.97
24C	Steel	Zn, in water	-1.05	-1.05	-1.07	-1.07	-1.01	-1.05	-1.04	-1.06	-1.03

1/ All piles, except system 24, are mild carbon steel, all are H-piles, 8 in. x 8 in. x 48 lbs/ft.-35 ft. long. In all cases, the sand line was from 19 to 21 ft. measured from the bottom of the pile, in general the row of C piles having the more sand. The length of a pile exposed to sand and water varied between 24 ft. and 28 ft., depending on the normal tide.

2/ Zinc anodes are 4 in. x 4 in. x 36 in. weighing 150 lbs. Aluminum anodes are 4 in. x 4 in. x 38 in. weighing 60 lbs. Each pile is protected by two anodes permanently mounted on opposite flanges at the same elevation. On the A and C piles, the anodes are mounted in the water zone between the sand line and the mean low water line. On the B piles, the anodes are mounted in the sand zone, the tops of the anodes being about 6 ft. below the sand line.

3/ Piles are coated with coal tar epoxy. Pile A has 5 windows (bare area, 1 in. x 6 in.). Pile B was completely coated, and pile C was completely coated except for the lower 12 ft. in the mud zone.

4/ Initial measurements - made in 1967, 4 months after installation.

Table 3. Corrosion Rates of H-Piles Based on Flange Thickness Measurements

SYSTEM	COATING DESCRIPTION	Overall Average Corrosion Rate mpy[a]	Average Corrosion Rate Within Zone, mpy[a]			
			Imbedded Zone 0 to 15 ft.[b]	Erosion Zone 15 to 21 ft.[b]	Immersed Zone 15 to 29 ft.[b]	Atmospheric Zone 29 to 35 ft.[b]
21	Coal Tar Epoxy/Zinc Rich Inorganic	<0.01	<0.01	<0.01	<0.01	<0.01
13	Vinyl/Flame Sprayed Aluminum	0.03	0.01	0.17	0.07	0
20	Epoxy Polyamide/Zinc Rich Inorganic	0.05	0.02	0.22	0.10	0
8	Aluminum Pigmented Coal Tar Epoxy	0.07	0.07	0.06	0.08	0.03
29	Polyester Glass Flake	<0.10	<0.10	<0.10	<0.10	<0.10
15	Polyvinylidene Chloride/Flame Sprayed Zinc	0.10	0	0.14	0.12	0.29
10	Galvanized	0.14	0	0.67	0.32	0.06
17	Phenolic Mastic	0.14	0.11	0.11	0.15	0.21
14	Flame Sprayed Aluminum	0.16	0.19	0.39	0.19	0.03
9	Aluminum Pigmented Coal Tar Epoxy	0.18	0.18	0.08	0.21	0.04
18	Coal Tar Epoxy/Zinc Rich Organic	0.19	0.17	0.15	0.21	0.24
19	Vinyl/Zinc Rich Inorganic	0.20	0.19	0.22	0.18	0.31
22	Vinyl Mastic/Zinc Rich Inorganic	0.24	0.02	1.4	0.61	0
4	Coal Tar Epoxy	0.53	0.17	0.21	0.27	2.1
25	Coal Tar Epoxy on Mariner Steel	0.53	0.18	0.44	0.45	1.6
7	Coal Tar Epoxy plus Armor	0.55	0.13	0.07	0.07	2.7
6	Coal Tar Epoxy	0.80	0.27	0.72	0.46	2.9
16	Vinyl-Red Lead/Flame Sprayed Zinc	1.4	0.08	3.2	1.8	2.3
12	Polyvinylidene Chloride	2.4	0.81	4.9	3.6	3.5
30	Bare Carbon Steel	4.9	0.9	8.9	6.7	10.5
1	Bare Carbon Steel	6.0	1.8	9.7	7.9	12.2
31	Bare Carbon Steel	7.3	2.8	10.5	9.0	13.9
26	Bare Carbon Steel	Pipe[c]	-	-	-	-
27	Coal Tar Epoxy	Pipe[c]	-	-	-	-
28	Coal Tar Epoxy plus Armor	Pipe[c]	-	-	-	-

[a] For Iron: mils per year x 5.48 = milligrams per square decimeter per day. [b] Distance from bottom of pile.
[c] Flange thickness measurements not made on pipe piles.

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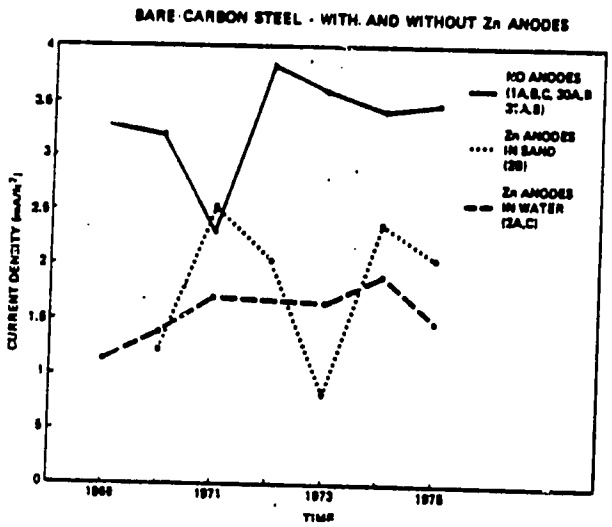

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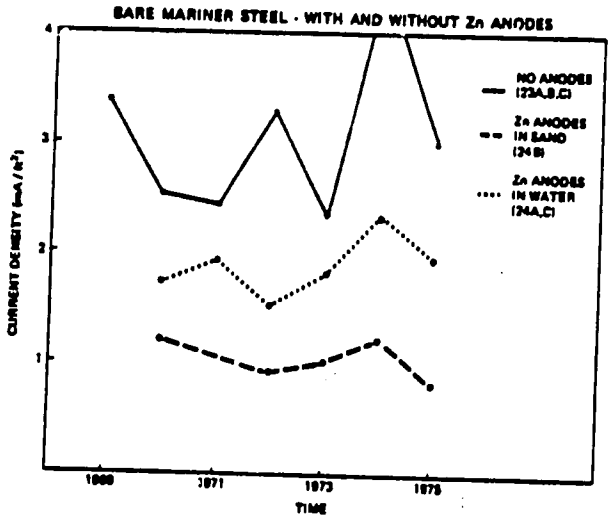

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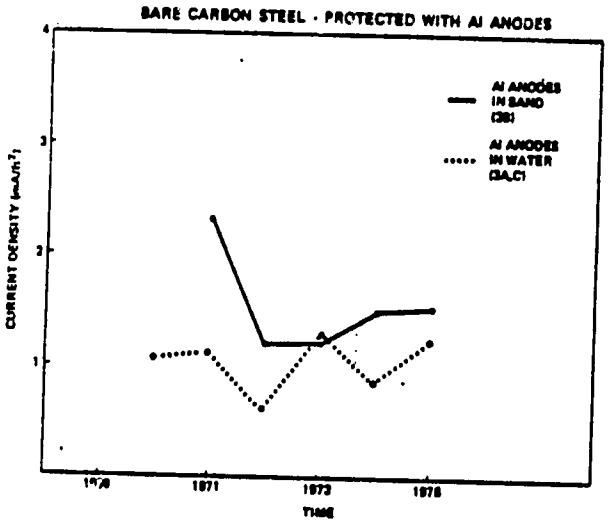

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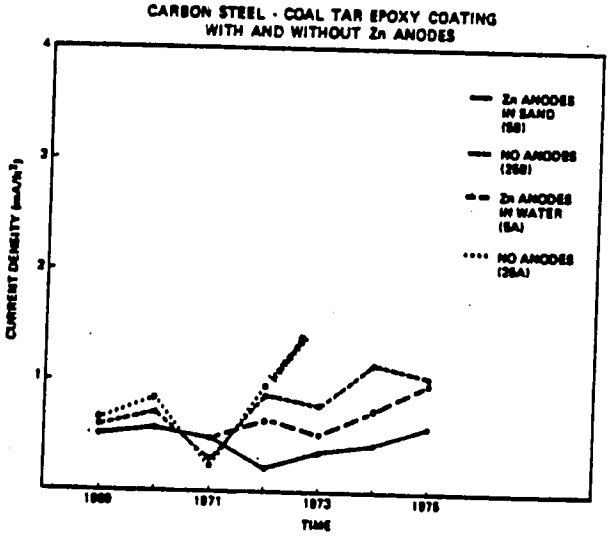

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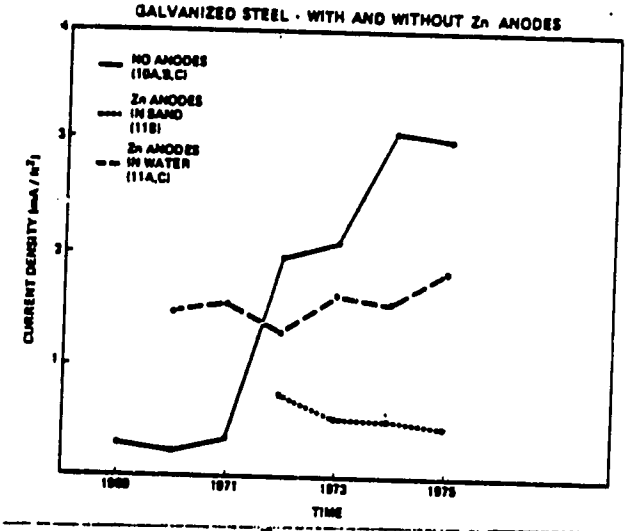

FIGURE 103

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with only one exception, the anodes located below the mud line are providing more protection than similar anodes above the mud line. These preliminary results on the cathodically protected systems must await verification pending their removal for physical examination.

The authors are grateful for the continuing cooperation and financial support of the American Iron and Steel Institute, and the funding aid from the U.S. Army Corp of Engineers at the initial phase of the program. In our own laboratory we wish to thank J. L. Fink and J. T. Hill for their valuable assistance in various phases of the work, and W. J. Schwerdtfeger (retired) for his many helpful discussions, suggestions, and participation at the start of the investigation. Appreciation is extended to the coating manufacturers who provided technical and material assistance, and the U.S. Navy Amphibious Construction Battalion No. 2 for installation and removal of the piles; to the U.S. Navy Fleet Combat Directions Systems Training Center for providing the site, and to the divers from the U.S. Navy Underwater Demolition Units for their aid in making electrical connections. This work is dedicated to the memory of Melvin Romanoff without whom the program would not have existed.

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NBS-114A (REV. 7-73)

U.S. DEPT. OF COMM. BIBLIOGRAPHIC DATA SHEET	1. PUBLICATION OR REPORT NO. NBS MN-158	2. Gov't Accession No.	3. Recipient's Accession No.
4. TITLE AND SUBTITLE Corrosion and Protection of Steel Piles in a Natural Seawater Environment			5. Publication Date June 1977
			6. Performing Organization Code
7. AUTHOR(S) E. Escalante, W.P. Iverson, W.F. Gerhold, B.T. Sanderson, R.L. Alumbaugh			8. Performing Organ. Report No.
9. PERFORMING ORGANIZATION NAME AND ADDRESS NATIONAL BUREAU OF STANDARDS DEPARTMENT OF COMMERCE WASHINGTON, D.C. 20234			10. Project/Task/Work Unit No. Progress Report 1967-1976
			11. Contract/Grant No.
12. Sponsoring Organization Name and Complete Address (Street, City, State, ZIP) American Iron and Steel Institute 1000 16th St. N.W. Washington, D.C. 20036			13. Type of Report & Period Covered Final
			14. Sponsoring Agency Code

15. SUPPLEMENTARY NOTES Originally printed for limited distribution to sponsor as NBSIR 76-1104. This document has gone through the editorial review. Library of Congress Catalog Card Number: 76-608410

16. ABSTRACT (A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)

This report describes the first eight years of a long term program in which twenty-three coating systems and five cathodic protection systems are evaluated on their ability to protect steel piles in offshore conditions. These systems are made up of nonmetallic coatings, metallic pigmented coatings, nonmetallic coatings on metal filled coatings, nonmetallic coatings on metallic coatings, metallic coatings, and cathodic protection on bare and coated piles.

It includes a description of the annual on site electrochemical coating evaluation and a description of the final physical evaluation made on the piles after removal. The results of these electrochemical and physical evaluations are presented graphically and in tabular form.

17. KEY WORDS (six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)
Cathodic protection; coating systems; corrosion protection; offshore corrosion; sand corrosion; seawater corrosion; splash zone corrosion.

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99.

CONTROL OF CORROSION OF FERROUS METALS

By Herbert J. Schmidt, Jr., P.E.

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V-D

CONTROL OF CORROSION OF FERROUS METALS

IT IS EASIER and cheaper to provide for prevention of corrosion before a structure or facility is constructed or during construction than to correct an existing problem. However, with the shortage of capital funds coupled with non-awareness of possible corrosion problems, corrosion prevention measures are ofttimes not properly employed.

There are several considerations which should be investigated prior to designing and constructing a new structure, an addition or modification of an existing structure or facility or maintaining or repairing an existing structure or facility.

How Metals Corrode.

Since steel is a commonly used material of construction, an understanding of why steel or other metals corrode would be most helpful in properly selecting a material of construction and then properly employing methods to reduce, insofar as possible, maintenance costs. The following is a brief statement on corrosion of ferrous metals—what it is, how it occurs, and what can be done to protect against it.

Elements of Corrosion. Corrosion, or dust, is an age-old reaction that has plagued man since the time metals were first refined into usable forms. The basic cause of corrosion is the instability of metals in their refined forms. In the case of iron, the action of oxygen and water, usually in the form of rain, mist or dew, causes rust. When we analyze rust, we find it is iron oxide. In rusting, the iron has reverted to its original native state.

Instability of Metals

Corrosion takes place in the presence of water and oxygen. If one is absent, corrosion usually does not occur. The same would be true in

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water where the free oxygen is removed. In addition, water having a high alkalinity content retards corrosion.

Nature shows us that metals tend to revert to their native state through the natural process of corrosion.

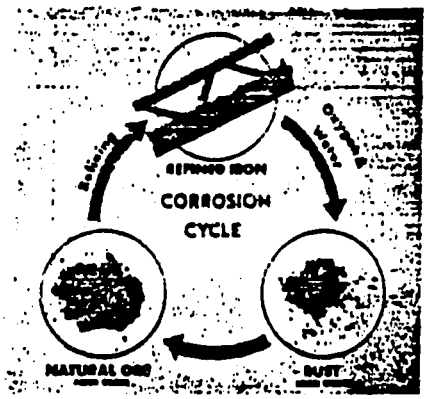

Figure 1. Corrosion Cycle.

Water an Electrolyte

Electro-Chemical Action. The basic requirements of corrosion, which is an electro-chemical condition, are always the same. There must be a flow of electricity between certain areas of a metal surface through a solution capable of conducting an electrical current. This solution is called an electrolyte. Water, and especially salt water, are excellent electrolytes.

In addition, we must have two distinct areas on a metal surface between which electricity can flow. Electricity flows from a negative area (the anode) via the electrolyte to a positive area, called the cathode. Thus, we have the three necessary requirements for corrosion: an electrolyte, a negative area, and a positive area on the metal surface.

(Courtesy of Tnemec Topics)

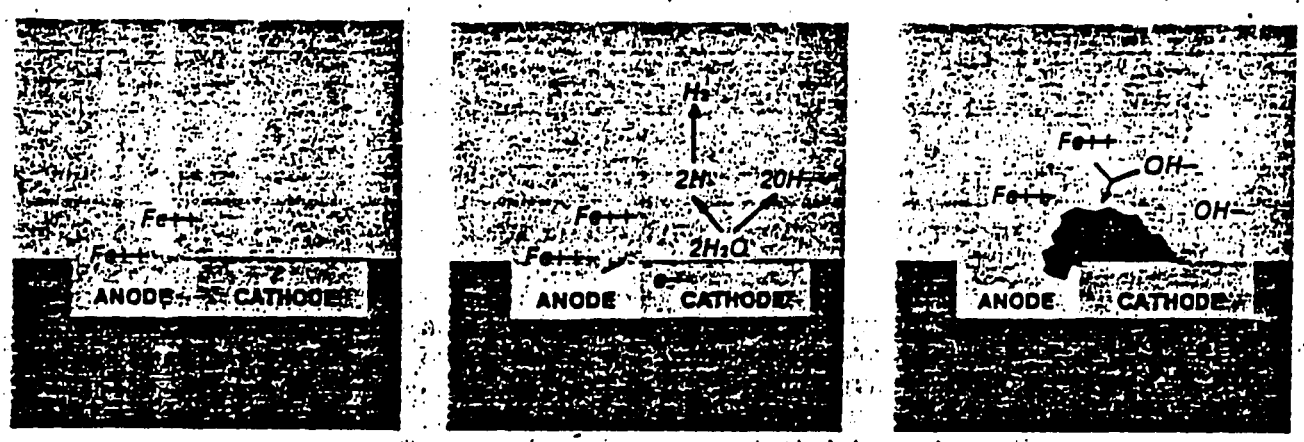

Figure 2. Electrochemical Corrosion.

The anode area gives off iron ions (Fe^{++}) while negatively charged electrons (e-) move toward the cathode area.

The negatively charged electrons (e-) pass through the metal to the cathode area and react with water (H_2O) to form hydrogen gas (H_2) and hydroxyl ions (2OH).

This leaves behind hydroxyl ions (OH−) which combine with the iron ions (Fe^{++}) to form ferrous hydroxide ($Fe(OH)_2$). The ferrous hydroxide reacts with free oxygen in the water to form ferric oxide (rust).

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Unprotected Metal Loss. The loss of metal results at the anode, whereas the metal that is protected from corrosion is at the cathode. The amount of loss varies with different metals. Some of the loss rates of common metals are as follows:

Iron or Steel	20 lbs/ampere year
Lead	74 lbs/ampere year
Copper (Cut)	45 lbs/ampere year
Zinc	23 lbs/ampere year
Aluminum	6.4 lbs/ampere year

Basically, this is the reaction that occurs when these three conditions are present: positively charged metal ions detach themselves from the cathode region, where they are neutralized by removing hydrogen ions from the water, forming hydrogen gas.

The hydroxyl ions left, being negatively charged, unite with the metal ions that pass into the solution and form ferrous or ferric hydroxide. This soon becomes oxidized with free oxygen in the water to form iron rust.

Aqueous Environment

This discussion of the mechanism of corrosion has referred particularly to corrosion in an aqueous environment, since this type is clearly explainable by electro-chemical principles. In the atmosphere, the same electro-chemical action may occur in pockets of water and on wet steel.

Alternate Grades of Steel.

General Purpose Carbon Steels. Construction grades, such as manufactured in accordance with A.S.T.M. Specifications A-36, A-328, etc.

Special Purpose Steels.

Chemical Properties

Corrosion-Resistant Steel. High strength, low alloy carbon steels, such as Mariner Grade, are used in steel sheet piling and H-bearing piles. Additional life is possible, primarily in alternately wet and dry situations or locations, when this type of steel is specified. Consideration should be given to insuring that all the chemical properties of the steel that should be present, are actually present in the steel ordered and delivered. Otherwise, additional money may be spent without obtaining any added protection or life.

Weathering Steel. This grade of steel is produced by various manufacturers with trade names such as "Corten" or "Mayari R" Weathering Steel. This grade of steel has found wide acceptance in use in structural steel for bridges and exposed steel framing members for buildings, among other uses. While it can be used in many locations for many purposes, it has been found in certain instances that this grade of steel affords no additional protection when placed in close proximity to salt water or salt air exposure. Uniform coloring of a dark reddish brown nature develops over a period of time. This can be, and is, often accelerated by sandblasting the steel before erection to remove the mill scale and present a uniform surface for uniform weathering to take place. However, in locations that are exposed to the public's touch, if the surface is written on or damaged and then the writing is removed or the damage is repaired, there will be found to be a considerable difference in the coloration of the steel for an extended period of time.

Analysis of Corrosion.

Scope and References. This section discusses in general terms corrosion or rusting, which is the deteriorating of metallic construction materials, such

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as steel sheet piling, bearing piles and utility lines, by reaction with elements of air, soil, or water. Preventive measures which may be employed to halt or reduce this deterioration also are covered. Obviously a complete discussion of corrosion and its control would neither be practical nor pertinent in this section. The reader is referred to "Corrosion Handbook" edited by Herbert H. Uhlig and published by John Wiley and Sons; "Corrosion and Corrosion Control" by Herbert H. Uhlig, published by John Wiley and Sons; "An Introduction to Metallic Corrosion" by U.R. Evans, published by Edward Arnold Ltd., and to "Underground Corrosion", published as Circular C-450, by the National Bureau of Standards. Current information on the subject may be obtained from the publications office of the National Association of Corrosion Engineers, Houston, Texas 77027.

Underground and Underwater Corrosion of Steel. Corrosion below the ground surface and underwater (exclusive of corrosion inside pipes) are substantially identical in cause, form, and remedy.

Corrosion Currents. The primary cause of underground corrosion is the flow of electric current from the structure to the soil in certain areas, where corrosion will be extremely rapid, and its return in other areas, where corrosion will proceed slowly or not at all.

Flow of Currents

Variations. Flow of these electric currents results in variations in corrosion rates which are determined by electrical rather than chemical factors although variations in composition of soils affect potential differences and thereby the rate of flow of electric current.

Galvanic Cells. Almost every person who has had experience in maintaining underground piping has observed corrosion of piping developing leaks under a paved road with piping on either side in good condition. This is a common example of a galvanic cell caused by difference in oxygen concentration, called a differential aeration cell. The effect of such cells is that corrosion occurs where oxygen content is the *least*.

Interaction of Metals. Also familiar is corrosion of steel pipe adjacent to bronze fittings. In this case the currents result from the different characteristics of the two metals. Electric currents resulting from combinations of two different metals in the same soil, or two different soils contacting the same metals are properly called galvanic currents and can be measured easily in a laboratory, and with some difficulty in the field.

In the following table, known as the "GALVANIC SERIES OF METALS", each metal is an anode to any metal under it in the table. and the lower metal is always the cathode. In the electrolyte, current will always

Galvanic Series of Metals

Magnesium	Copper, Brass
Aluminum	Silver, Silver Solder
Zinc	Graphite, Carbon
Steel, Iron	Platinum
Lead, Lead-Tin Solder	Gold

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flow from the metal higher on the list to any lower on the list when the two metals are in contact with an electrolyte and are in metallic contact with each other.

A similar relation of anode to cathode exists with iron and steel. Any type of ferrous metal on the following list is always anodic to the ones lower on the list:

New Steel Pipe	Old Wrought-Iron Pipe
Old Steel Pipe	New Cast Iron Pipe
New Wrought-Iron Pipe	Old Cast Iron Pipe

Corrosion currents will be produced on any metal where conditions create an anode and a cathode immersed in a moist electrolyte and connected by a metallic path. Some of these conditions are: different metals or a difference in the surface condition of a metal; stresses in a metal; different soils; stray direct current; and bacteria.

Coating or Reversing

Prevention. Underground corrosion can be stopped by preventing the flow of current between anode and cathode. This can be done by stopping the flow of current by coating or by reversing the flow of current leaving the anode by cathodic protection. Since it is not practical to provide a perfect coating without any holidays, a combination of coating supplemented by cathodic protection is usually the most economical effective corrosion control when the cathodic protection system can be properly maintained.

Galvanic Currents

Stray Currents. Similar corrosion effects may also be caused by electric currents originating in direct current electric distribution systems particularly direct current electrified railway systems and welding operations at piers or wharves. Currents originating from such outside sources are called stray currents, and were at one time a major cause of severe underground corrosion. There is a regrettably common tendency to attribute any unexpected underground corrosion failure to stray currents of mysterious origin, rather than to actual galvanic current causes. Galvanic currents inevitably exist in any buried structure of appreciable size, but their magnitude (and consequently the damage which may be done by them) is controlled by the resistance of the soil to the flow of electric current. The resistivity of different soils quite commonly varies over a range of 1000 to 1, and may vary also with season and rainfall.

Steel Piling.

Differential Aeration. In the case of steel sheet pile bulkheads or exposed steel H- or pipe pile substructures, it is often observed that scaling is heavy in a band in the splash zone just above the high tide level, and corrosion is also severe in a band at and just below the mean low water level. This aggravated corrosion just below the mean low water level results from a condition known as "differential aeration". In its simplest form, a differential aeration cell will result on a metal surface immersed in an electrolyte with one portion shielded from a free supply of oxygen while the remainder has a relatively abundant supply. Corrosion currents will then circulate between the two portions of the metal sample in such a direction as to cause corrosion of that portion receiving the least supply of oxygen.

Best Available Document

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Tidal Zone. On piling, the steel surfaces in the tidal zone between mean low water and mean high water receive a greater supply of oxygen than the continuously immersed surfaces at and just below mean low water. As a result, current discharge, resulting in corrosion, occurs in the area at and just below mean low water. Piling in the tidal zone normally is attacked at a relatively lower rate being partially protected at the expense of piling at and below mean low water.

Splash Zone. In the splash zone above the tidal range, piling surfaces are subject to frequent wetting and drying cycles. In this area, the wetting and drying pattern is erratic depending upon wind and wave action. Differential aeration cells within the splash zone are continually being formed, acting, and drying up as splashing action occurs. Contrasted to steel in the tidal zone, steel in the splash zone receives little protection at the expense of the continuously immersed steel below mean low water. This explains why a band of aggravated corrosion will normally be formed on uncoated steel piling above mean high water.

Factors Affecting Corrosion Rates.

Soil Resistivity. The influence of soil resistivity upon corrosion rates is important enough to warrant investigation prior to design of an important buried structure.

Four Electrode Method

Measuring Soil Resistivity. Determination of soil resistivity can be obtained from borings, and soil resistivity at various depths can be obtained, without making borings, by the "Four Electrode Method", which gives the average soil resistivity to any desired depth by varying the electrode spacing. As a rule, soils having a resistivity in the order of 1000 ohm-cm or less can be classified as severely corrosive. Sea water has a resistivity of about 20 ohm-cm as an example. Soils having resistivities ranging greater than 20,000 ohm-cm are usually classified as only slightly corrosive, but small deep pitting can occur in such solids. A steel structure passing through successive layers of different soils will suffer more attack than a structure in a uniform bed of soil with the same average resistivity as the layered soil.

Relation of Moisture Content. While soil resistivity varies with moisture content, well-drained surface soils in areas of heavy rainfall normally have relatively high resistivity even when saturated with water, because most of the soluble elements have been washed away. Cinders in soil cause deep rapid pitting of steel.

Preventive Measures

Two Approaches

The progress of electro-chemical corrosion can be minimized in two general ways: the application of protective coatings of various types, and the installation of cathodic protection systems of either the impressed-current or sacrificial-anode type. In addition, the bonding of all buried structural members will facilitate the application of cathodic protection, thus minimizing corrosion resulting from differing potentials of adjacent members. Consultation with a Certified Corrosion Engineer (by National Association of Corro-

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sion Engineers) is always advised whenever a corrosion problem manifests itself.

Protective Coatings.

Types. A number of types of coatings have emerged to date as suitable for the protection of exposed steel in water; coal-tar epoxies, inorganic and organic zinc primers with an epoxy or coal tar epoxy finish coats, and cold applied coal-tar coatings are the primary products now in use, with other types such as splash zone epoxies, underwater brush or roller applied modified polyesters, etc., constantly appearing on the market. Hot applied coal-tar enamel with bonded glass and felt outerwrape have been used successfully on round pipe piles in certain locations. The choice of a type for a given installation is normally made on the basis of adaptability to local exposure conditions, relative durability and cost.

V-D

Surface Preparation. All these coatings require preparation of the steel surfaces involving sandblasting, jet water blasting, or similar methods to insure proper adhesion. This factor cannot be overemphasized; improper surface preparation can completely negate the effectiveness of the coating. Because of the variations in chemical formulae within each type of coating, the manufacturer's specifications for application of each should be carefully followed.

Surface Preparation

Application. Coatings are most commonly employed on those portions of the steel which are in the splash zone and in the tidal range; in the submerged portions, coatings may be used in conjunction with, or alternative to, cathodic protection. Steel surfaces which are in continuous contact with undisturbed soils do not normally require protective coatings because of the lack of sufficient available oxygen to facilitate corrosion; however, local conditions must be investigated to determine whether or not a problem may exist. As indicated above, the decision as to the extent of application of any type of coating is normally based upon economic considerations involving the required service life of the structure.

Repairing Damage. When selecting a protective coating system, consideration should be given to how the coating can be repaired. Whether the protective coating is applied in a shop or in the field at the construction site, the protective coating may receive some damage due to handling. This damage must be repaired, either just prior to or after installation. Some of the coatings now in use cannot be repaired by utilizing the same coating materials under damp or submerged conditions. However, coatings such as underwater modified polyesters that are applied by brush or roller, can be utilized to make these repairs.

How to Specify Protecting Coatings. There are various points to consider before writing a coating specification and several inspections to be made during and after the application.

Qualities. A good specification has to be a compromise between practicality, cost and performance. An inadequate specification.

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such as one calling for a good painting system without sufficient surface preparation, is a waste of time and money. Similarly, a more than adequate specification, such as blasting to white metal or near white metal where a brush-off or commercial blast would be satisfactory, results in money spent unjustifiably.

Composition. A specification should be realistic, and the requirements should be within the realm of reasonable and practical performance by the applicator with accepted materials, methods, and equipment. To be complete, a specification must cover surface preparation, coating material, and application in detail and with sufficient clarity to avoid misinterpretation. Like a three-legged stool, inadequacy in any one of these renders the entire job essentially ineffective. In addition, a specification must outline and require inspection to insure that the quality of the job falls within defined limits.

Background Information. Before the preparation of a coating specification for any given job, it is necessary to obtain a certain background of information to outline the requirements and limitations.

Exposure and Service Conditions.

Specification Data

Is the exposure indoor or outdoor?
If it is an outdoor exposure, geographical location must be established since it can affect severity. For example, extremely hot or cold climates as well as seacoast locations can affect the choice of coating.
Is there exposure to chemicals and, if so, determine kind, concentration, and temperature as well as whether the exposure is immersion, splash and spill or fumes.
What is the service temperature range of the substrate, and is it continuous or cyclic? If cyclic, what is the frequency?
Are other special conditions such as abrasion, abuse, flexing, vibration, or impact involved?

Substrate Material and Condition.

The kind of substrate must be known such as carbon steel, galvanized steel, nonferrous metals, masonry, and wood.
With previously uncoated substrates encountered in new construction, the degree of weathering in regard to mill scale and rusting must be known.
With previously coated substrate encountered in maintenance work, the degree and type of deterioration of original coating and substrate must be known as well as the type of original coating and kind of extent of chemical contamination involved, if any.

Local Limitations.

Does potential contamination of product or equipment limit the cleaning or application methods that may be used?
Is there potential contamination of surfaces between cleaning, priming, and subsequent coats?

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Are there any time limitations for completion of the work?
Are there any unusual climatic conditions expected, such as extremes of temperature, humidity, or rain that must be considered?
Are there any special considerations that should be given to labor relations?
In addition to normal good safety practices, are any special considerations required due to local conditions? For example, do they eliminate the use of spark-producing cleaning methods or require unusual ventilation?

Size, Shape, Complexity, and Accessibility.

If tanks are involved, are they on the ground or elevated and is the interior, exterior, or both to be coated?
In the case of structural steel, are small complicated elements involved? Also, is accessibility difficult owing to congestion or over-all height?
In the case of piping, the same considerations apply as for structural steel.
Is the equipment of unusual shape or complexity and is accessibility limited or difficult?
Are there any unusual heights or depths involved in connection with walls, ceilings, or floors? Are there any other unusual architectural features or complexities that require special considerations?

Color Limitations. Is a wide choice of color permissible, is it limited to a narrow range, or is there no choice, a specific color being required?

Economics: Costs Versus Performance. As the first step in determining or analyzing the economics of any coating system, it is necessary to establish its objective. For example, is the primary function protection, decoration, elimination of product contamination, or a combination of these? Having established the objective, the economic goal then is to select, based on established performance data, the coating system that accomplishes the objective at the lowest cost per square foot per year, the only true cost index of a coating except in the case of surfaces that are permanently installed underwater after initial coating and when initial coating cannot be reapplied.

Primary Function

These seven factors are considered individually as questions, and answers are established as dictated by the specific coating problem. This process provides the basic data for a coating specification. Of course, the degree of analysis made is dependent on the magnitude of the job.

Writing A Specification—Considerations. There are two general systems for the writing of a job specification. One includes all the necessary details to make it self-sufficient without the need of any reference standards. The other system uses a brief job specification supported by references to Standard Cleaning and Coating Specifications.

Reference can be made to:

Steel Structures Painting Council Standard Specifications for Cleaning and Painting
American Water Works Association Cleaning and Coating Specifications
Federal Specifications
National Association of Corrosion Engineers Standard

Surface Preparation.

A. Materials.
B. Equipment.
C. Techniques.
D. Definitions of surface conditions before and after cleaning.

Coating Systems.

A. Materials by trade names or Standard Specifications.
B. Selection.
C. Film Thicknesses.

Description of Materials.

Specification Factors

Application.

A. Environmental Limitations.
B. Methods.
C. Equipment.

Inspection.

A. Requirements.
B. Equipment.
C. Techniques.

Safety Precautions.

Inspection Procedures. When there is a large volume of specification work, the system of using brief job specifications, supported by detailed standard specifications saved substantial time and money compared to the system of using detailed job specifications that are self-sufficient. It must be emphasized that a specification is not adequate unless provision is made to check the work to verify that it meets the specification. Such inspection must cover the following:

A. Surface preparation.
B. A periodic check during application.
C. The completed job.

Surface Preparation.

Techniques

A. Visual inspection for method is specified, degree of cleanliness and freedom from foreign matter, such as dirt, grease, oil and water with emphasis on "hard to get at" areas.
B. A check of profile on blast cleaned metal surfaces when specified by comparison with reference standards.

Periodic Check During Application.

Verification that specified materials are used and in the specified manner.
Visual check of each coat for adequate and acceptable workmanship.

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Spot checks of each coat for wet film thickness, having previously established the ratio of wet to dry film thickness, to insure that the specified dry film thickness is obtained.
Visual check for freedom of contamination between coats.
Verify that drying time limitations are met.
Verify that surface is primed when prescribed.
Verify that painting is not done during adverse weather conditions, such as extreme temperatures and humidities.

The Completed Job.

Visual check of overall workmanship.
Measurement of total dry film thickness.
When specified, check for coating defects using a pin-hole detector.

For Coal Tar Epoxy

Typical Protective Coating Specification. Following is a typical specification for shop cleaning and coating steel sheet piling and accessories with coal tar epoxy prior to its use in construction of a bulkhead. Similar specifications can be prepared utilizing various other types of paints and coatings for other structures. This typical specification has been found to be practical in its scope and has achieved the desired results.

Coal Tar Epoxy Coating for Steel Sheet Piling

Scope:

a. The work shall consist of providing all materials, supervision, labor, equipment, tools and supplies necessary to provide a protective coal tar epoxy coating system for steel sheet piling and accessories.

b. The coating shall be applied to all surfaces of the sheet piling, with the exception of the interior-contacting surfaces of the interlocks. The steel "H" Piles, the entire wale assembly, the tie rods, turnbuckles and all bolts shall be coated in their entirety, except for the threads and nuts which shall be coated in the field after assembly.

Coating Materials:

a. The coating shall be self-curing, consisting of two components. The material used shall meet all requirements of the Federal Specification for Coal Tar Epoxy MIL-P-23236 Type I, Class 2, and/or the Corps of Engineers' Formula C-200, and/or Steel Structures Painting Council Specification SSPC-Paint, No. 16, Coal Tar Epoxy-polyamide Black Paint.

b. All coatings shall be so processed and packaged as to insure that within a period of one (1) year from date of manufacture, they will not gel, liver or thicken deleteriously, or form gas in the closed container.

Packaging and Labeling: Coatings and vehicles shall be packaged in standard containers not larger than 5 gallons in size, with removable friction or lug-type covers. Each container of separately packaged component shall be clearly and durably labeled to indicate the purchaser's order number, date of manufacture, manufacturer's batch number, quantity, color, component

identification, and the designated name and formula or specification number of the coating together with special instructions.

Certifications:

a. In addition to meeting the other qualifications, the coating manufacturer shall certify that:

(1) He has been a producer of coatings of this class for a period of at least two years.
(2) The coating being offered under this specification is the same formulation which has been manufactured and distributed by him during this two year period.
(3) The coating being offered under this specification has been successfully used in sea water, immersion service for at least two years.

Surface Preparation:

a. All surfaces shall be thoroughly prepared for coating application in strict accordance with the coating manufacturer's recommendation. All cleaning and coating work must be performed in a heated building. Preceding grit blasting, steel must be heated to at least 100°F to eliminate possibility of moisture on the surfaces to be cleaned and coated.
b. Grit blasting shall be to clean grey metal, at least equivalent to a White Blast as defined by SSPC Specification SP-5-63. All work blasted in one day must be coated on that day.
c. Any areas of the surface which show traces of oil, grease or other organic matter shall be removed prior to coating. The contamination shall be removed by using either a solvent or spot blasting.
d. All surfaces to be coated must be completely dry, free of moisture, soil, dust and grit at the time the coating is applied.
e. The finished coating shall be post-cured under cover at a temperature of approximately 125°F, whenever the ambient average temperature falls below 70°F.

Specifications Continued

Application of Coating: All coatings shall be applied by brush or spray using commercially available spray equipment. The coatings shall exhibit reasonable leveling without excessive sagging when applied at the required film thickness. Proper adhesion between coats shall be insured, depending on method of coating application, with out undue restrictions concerning timing, temperature or other conditions associated with application. Coating manufacturer's recommendations shall be adhered to.

Progress of Coating Work: Where coating on any type of surface has commenced, the complete coating operation, including priming and finishing coats when multiple coats are used on that portion of the work, shall be completed as soon as practicable, without prolonged delays. Where necessary, sufficient time shall elapse between successive coats to permit them to dry properly for recoating and this period shall be modified as necessary to suit shop conditions.

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Coating Thickness

a. A minimum thickness (not average) of 16 mils dry film is required on all surfaces to be coated.
b. Where two coats are required to achieve the recommended film build, the interval between coats should be as short as possible. To ensure maximum intercoat adhesion, it is recommended that: (1) The next coat be applied as soon as possible after the previous coat is firm. (2) If the previous coat has cured for more than the recoat time specified by the manufacturer, wash with fresh water, then brush blast to provide an adequate mechanical bond before recoating.

Final Curing Time: Coated surfaces shall be permitted as long a drying time as practicable but in any event the folllowing minimum requirements shall be met. The steel coated with the coal tar epoxy system shall not be driven until the finished coating has cured at least 7 days at 77°F, or been postcured at higher temperatures for a shorter time period in accordance with the coating manufacturers recommendations.

Thinning: Whenever possible the material shall be applied without thinning to a minimum dry film thickness of 8 to 20 mils dry film per coat without running, curtaining or sagging. Where thinning must be done, it shall be limited to one pint of solvent as recommended by the coating manufacturer per gallon of coating material. If the material is thinned, it may be necessary to apply more than the standard 1 or 2 coats to attain the required minimum dry film thickness of 16 mils.

Inspection

a. Satisfactory performance will be based upon acceptance of the completed work by the Engineer. All work will be subject to inspection by the Engineer. The grit blasting is to be approved before the start of the coating application.
b. Inspection of the completed coating will be based upon a Nordson Mikrotest or other magnetic detector readings. Detection of inadequately coated sections will be indicated by circling with chalk the areas to be recoated.

Appearance of Finished Coating

a. The finished coating shall be generally smooth and free of sharp protuberances which could be removed by abrasion. A minor amount of sags, dimpling, or curtaining which does not exceed 2 to 3 percent of the surface will not be considered cause for rejection unless they present sharp edges which might be removed by abrasion.
b. Sharp protuberances shall be cut off using a sharp wood chisel laid flat against the surface. The areas from which material has been removed shall be recoated to smooth the surface.

Protection of Coated Steel: The Contractor shall exercise extreme care in the handling of all coated steel so as not to damage the coated surfaces. Any damage to the coating due to handling or construction operations shall be repaired by the Contractor at no additional expense.

Safety

a. The coating shall be sprayed in enclosed spaces with an *adequate ventilation system.* The system shall be capable of positively exchanging the air in the enclosed space for fresh air at the rate of not less than 5,000 cubic feet per minute for each spray gun in operation, and all parts of the space shall be swept by moving air. The ventilating system shall be operated during the entire application period and shall be continued after spraying has halted until the applied film is no longer giving off appreciable solvent vapors. The air in the enclosed painting space shall be safe at all times from fire and explosion hazards as determined by an Explosimeter, manufactured by the Mine Safety Appliance Company. Where spraying is being carried on in enclosed or other spaces not freely swept by natural wind currents, workmen shall wear respirators fed by fresh air. Grit blast nozzle operators shall wear fresh-air-fed helmets under all circumstances.

b. In addition to normal safety precautions, workmen shall take extra care to avoid inhaling fumes or atomized particles of the coating and to avoid contact of the paint with the skin.

Measurement: Coal tar epoxy coating shall extend from the top of the in-place sheets and special sections down to – feet, on the piling. Allowance shall be made for trimming the top of the sheets. This item will not be measured as coating.

Payment: Payment for coal tar epoxy coating as described under – will be included in the unit price per ton for items – on the Proposal Sheet.

Cathodic Protection

External Source

Impressed-Current Systems. The development of impressed-current systems has progressed to a point where this type of protection is widely used. The basic principle involved is the creation of an external source of direct current (a rectifier), thus providing a difference of electrical potential which causes a flow of electrical current from an anode, through the electrolyte (water or damp earth) to the metal which is to be protected, thus overcoming the electrolytic current. This condition is analogous to the process of electroplating. The externally created potential defference causes oxidation at the positive terminal (the anode) and the formation of a film of hydrogen on the surface of the protected metal (the cathode). The requirements as to the extent of the installation and the necessary electric power are specific considerations for each construction site and must be determined individually.

Normally operation of a cathodic protection system will cause a minimal deposit of calcareous or siliceous material to form on the steel surface, thus creating a protective barrier against corrosion. Such a coating has the further effect of diminishing the power required for the operation of the system.

Sacrificial Anode Systems. Sacrificial systems involve the placing of suitably-sized pieces of metals (anodes) of more negative potential than the steel, in close proximity to the members which are to be protected. The difference in potential between the sacrificial metal and the steel must be sufficient to generate a flow of current through the electrolyte which is great enough to overcome the electrolytic current, thus producing the same effect

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as that of an impressed-current system. However, proper placement and size of the anodes is of utmost importance. Economic comparisons and practical considerations of a sacrificial system versus an impressed-current system should be made.

The more common metals used for this purpose are magnesium, aluminum, and zinc, or alloys of these metals and others, as indicated by their position on the Galvanic Series of Metals.

The operation of a sacrificial system is much less susceptible to accurate control because the amount of sacrificial metal available to protect a structure diminishes constantly, and replacement of that metal as well as frequent inspection of the protected steel becomes much more critical for effective protection.

Stray Currents

Causes. Stray currents are produced by direct currents carried by metallic conductors which are in contact with the earth. Such current may often be identified as to source by periodic fluctuations or other such characteristics. The entry of stray current into a structure, and its eventual departure, results in corrosion of the steel elements at the points of discharge of the current into the electrolyte or the earth.

Periodic Fluctuations

Preventive Measures. The control of corrosion due to stray currents can be accomplished by adequate bonding and grounding of the structure to be protected, thus providing a path for the controlled discharge of such currents.

Economic Considerations.

The necessity for providing protective measures in the form of coatings or cathodic protection systems or a combination of both, should be determined on the basis of the required service life of the structure and the local corrosion condition. As outlined, the rate of corrosion is affected by many variables, and an advance prediction of the corrosion rate at a given site is extremely difficult to make, because of the possibility of change among those variables. It is generally true that the progress of corrosion is not constant; the rate of corrosion in the submerged or buried portions generally becomes lower with the passage of time.

Many Variables

In order to cope with a situation of such indeterminate nature, it is recommended that two basic steps be followed before a decision is reached as to the desirability of installing a cathodic protection system. First, investigation should be made as to the condition of any adjacent structures of similar construction, as an indication of what may be expected; second, it is recommended that a series of test installations be provided to permit a periodic check of the progress of corrosion at the specific site. These installations could consist of a number of steel plates of suitable dimensions, placed at representative locations within the structure. At given intervals, such as one, two, four and eight years after construction, the plates can be extracted, cleaned of any surface dirt, growths or products of corrosion, and checked for pitting and weight loss, thus giving any accurate picture of the actual progress of corrosion at the site. At such time as the severity of the corrosion can be accurately determined, the necessity for providing a protective system can be analyzed, with the required service life of the structure as the guiding criteria.

Because of the difficulty of installing a properly designed cathodic protection system on a completed structure which has no provisions for such an

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installation, it is further recommended that certain basic items of work be included in the original construction to facilitate installation of the necessary electric cable and equipment at a later date, if required. These basic steps involve primarily the electrical bonding of the steel elements, usually by means of welded steel bars, the inclusion of suitable sleeves for passage of cable through structural elements, and certain other minimal measures. The expense involved in providing these measures is generally very minor in relation to the total cost of the structure. A preliminary design for a cathodic system must be made to locate the necessary conduit sleeves, etc.

Corrosion of Underground Utility Lines

Causes. Corrosion of buried metallic pipelines, etc., is caused by electrolysis and by stray currents, as outlined above for steel elements in water. Again, the severity of the corrosion is a function of several variables, as follows:

Variables

- Amount of available oxygen present in the soil.
- Amount of water present in the soil.
- Type of soil surrounding the line.
- Dissimilarities in the soil surround the pipe-mineral content, etc.
- Segregation of the different metals in the alloy used in steel pipe.
- Impurities in the metal, such as slag in steel.
- Temperature of the soil.
- Surface conditions of the pipe (presence of scale or applied coatings).

Preventive Measures. Corrosion of utility lines may be minimized or prevented by the application of protective coatings or by the adoption of a cathodic protection system, or a combination of both. In addition, all metallic elements in the buried system should be bonded.

Protective Coatings. The types of coatings generally used for pipeline protection are:

- Coal-tar enamels with glass and/or felt wraps.
- Organic resins; fused and air dried.
- Polyethelene tapes with and without protective tape wraps.
- Extruded polyethelene coverings.
- Polyvinyl chloride tapes.

Adequate Bond

Proper surface preparation is essential to provide adequate bond, and the manufacturers' requirements should be carefully followed. The choice of method is normally governed by the service conditions and by economic factors. Here again, other types of coatings are continually appearing on the market.

Cathodic Protection. Cathodic protection of either the impressed-current or sacrificial types may be employed as a protective measure. The purpose of the system is to create a potential difference, causing a flow of electric current which overcomes the electrolytic or stray-current flow.

Economic Considerations. In order to establish the need for protective measures in a given locality, investigation should be made of existing facilities, wherever possible, by visual inspection. Soil tests should also be made to

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determine the nature and condition of the subgrade material, as well as that of the back-fill material. Moisture content, soil resistivity and permeability are important considerations in that regard. A check should also be made for the possible presence of stray current from nearby electrical equipment.

In the event that the subsurface condition is conducive to corrosion, it is recommended that a suitable coating be applied and a cathodic protection system be adopted if the required service life of the utility line so warrants.

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APPENDIX C

CATHODIC PROTECTION

Report
References

Recommended Practices - Control of External Corrosion on Underground or Submerged Metallic Piping Systems

Marine Corrosion Engineers
Marine and Industrial Agents

Wilson Walton International Inc.
66 Hudson Street, PO Box M-890, Hoboken, New Jersey 07030, USA
Tel. (212) 227-6657, (201) 795-2044 Telex 1-25919 Cable: Wazedens

Port of Kismayo
USAID/Somali Democratic Republic
Berths 1-4 Rehabilitation
Cathodic Protection Design
January 6, 1984

PRELIMINARY

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No. CR182
CORROSION
STATE OF CALIFORNIA

1.0.0. Design Area Parameters

1.1.0 Bulkhead will be steel sheet piles (PZ-38) shop coated with a high quality coating system on the water side topped by an overhanging concrete cap.

1.1.1 The port facility will be "L" shaped and consist of 4 berths having a total overall length of 2140 ft. The dredged water depth will be 31 ft.

1.1.2 The total submerged surface area is calculated as follows:

2140' x 1.67 x 31' = 110,788 sq. ft.

1.2.0 Mooring Dolphins (2) will be 50 ton bollards mounted on a concrete cap supported by 4 W-14 x 73 H piles. These piles will be coated similarly to the bulkhead piles.

1.2.1 The total submerged surface area of each dolphin is as follows:

4 x 7' x 40' = 1120 sq. ft.

1.3.0 Fender Piles (179) will be ~~W-12x30~~ HP 10 x 112 H piles, uncoated and recovered from the existing facility.

1.3.1 The submerged surface area of each pile is as follows:

- Continued -

1.0.0 Design Area Parameters

1.3.1 (Continued)

6' x 31' = 186 sq. ft.

1.4.0 Tie Rods will be 3¼" Dia. for the bulkhead piles and 3" dia. for the 50 ton bollards. The rods will be approximately 90' long and will be coated with a high quality coating system.

1.4.1 The buried surface area of the rods is calculated as follows:

3¼" ÷ 12 x π x 90' = 77 sq. ft/rod

3" ÷ 12 x π x 90' = 71 sq. ft/rod

1.4.2 The quantity of rods is calculated based on 2 rods/bollard and bulkhead rods on 4'6" centers:

2140' ÷ 4'6" = 476 Rods (3¼" dia.)

24 Bollards x 2 = 48 Rods (3" dia.)

1.5.0 Piplines serving the port will be welded steel lines coated with a high quality coating system as follows:

Molasses Line - 15" dia ÷ 12xπx500'=1964 sq.ft.

Cold Water Line-4" dia ÷ 12xπx2100'=2199 sq.ft.

- Continued -

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1.0.0 Design Area Parameters

1.5.0 (Continued)

Fire Line - 6" dia + 12xΠx2100'=3299 sq.ft.

Gasoline Line - 8"dia + 12xΠx330'=691 sq.ft.

Fuel Oil Line - 8"dia + 12xΠx330'=691 sq.ft.

1.5.1 All lines will be fitted with suitable isolating gaskets installed above ground to isolate them from each other and any other buried steel structures.

2.0.0 Cathodic Protection Design Criteria

2.1.0 Water Conditions:

Salinity - 20-25 OHM-CM.

Temperature - 70°- 90°F.

Tide Range - 3' - 4'

2.2.0 Maximum coating failure and/or damage during first ten years - 25% submerged areas - 10% buried areas.

2.3.0 Anode efficiency factor allows for 15% of anode material still remaining at end of projected design life of system - 1.15.

2.4.0 Anode materials specified for these applications are sacrificial types as follows:

- Continued -

2.0.0 Cathodic Protection Design Criteria

2.4.0 (Continued)

Water side - High efficiency aluminum/zinc/ induim alloy.

Land side - High efficiency magnesium/zinc/ aluminum alloy.

2.4.1 These materials have been selected because of their proven cost effectiveness, availability, ease of installation and reliability.

3.0.0 Cathodic Protection Designs

3.1.0 Bulkhead

110,788 sq.ft.x0.25x15 ma/sq.ft.=415 Amps.req'd.

3.1.1 10 Year System

415 Amps x 1.15 x 10 yrs. x7.6 lbs/A-Yr.=36,310 lbs. Using an aluminum alloy anode having a net wt. of 102 lbs. gives: 36,310 ÷ 102=356 pcs. req'd.

3.1.2 Estimated cost for this system is calculated as follows:

Anodes -	$60,000
Freight-	8,000
Labor/Mat'l.	80,000
Total	$148,000
Cost/Year	$ 14,800

- Continued -

3.0.0 Cathodic Protection Designs

3.2.0 20 Year System

415 Amps x 1.15 x 20 yrs. x 7.6 lbs/a-yr.=72,620 lbs.

Using an aluminum alloy anode having a net wt. of 205 lbs. gives: 72,620 ÷ 205 = 356 pcs. req'd.

3.2.1 Estimated cost for this system is calculated as follows:

Anodes	-	$120,000
Freight	-	16,000
Labor/Materials	-	130,000
Total		$266,000
Cost/Year		$ 13,300

3.3.0 Mooring Dolphin (2)

3.3.1 10 Year System

1120 sq.ft. x .25 x 15 ma/sq.ft. = 4.2 Amps req'd.

4.2 Amps x 1.15 x 10 yrs. x 7.6 lbs/a-yr.=368 lbs.

Using an aluminum alloy anode having a net wt. of 102 lbs. gives:

368 ÷ 102 = 4 pcs. req'd./Dolphin

Total = 8 pcs. Req'd.

3.3.2 Estimated cost for this system is as follows:

- Continued -

3.3.0 Mooring Dolphin (2)

3.3.2 (Continued)

Anodes	-	$1,500.00
Freight	-	200.00
Labor/Mat'l.	-	1,800.00
Total	-	$3,500.00
Cost/Year	-	$ 350.00

3.4.0 Fender Piles (179)

3.4.1 10 Year System

186 sq.ft. x 15 ma/sq.ft. = 2.8 Amps.

2.8 x 10 yrs. x 7.6 lbs/a-yr.=212 lbs.

212 ÷ 102 = 2 pcs. req'd./pile

2 x 179 = 358 pcs. req'd.

3.4.2 Estimated cost for this system is as follows:

Anodes	-	$60,000
Freight	-	8,000
Labor/Mat'l.	-	80,000
Total	-	$148,000
Cost/Year	-	$ 14,800

3.5.0 Tie Rods

3.5.1 20 Year System

77 sq.ft. x .10 x 2 ma/sq.ft.=.0154 x 476=7.3 amps.

71 sq.ft. x .10 x 2 ma/sq.ft.=.0142 x 48= 0.7 amps.

- Continued -

3.5.0 Tie Rods (Continued)

3.5.2 Magnesium alloy anodes come in standard sizes. For a 20 year life system a 17 lb. anode is required. The anticipated output of 15 ma/anode is reasonable in 3000-8000 ohm-cm soil and will fulfill the 20 year design life. Therefore one anode can be installed for each tie rod giving a total of 524 pcs.

3.5.3 Estimated cost for this system is as follows:

Anodes	-	$32,000
Freight	-	5,000
Labor/Mat'l.	-	20,000
Total	-	$57,000
Cost/Year	-	$ 2,850

3.6.0 Pipelines

3.6.1 Total protective current required for all five lines for 20 year system is as follows:

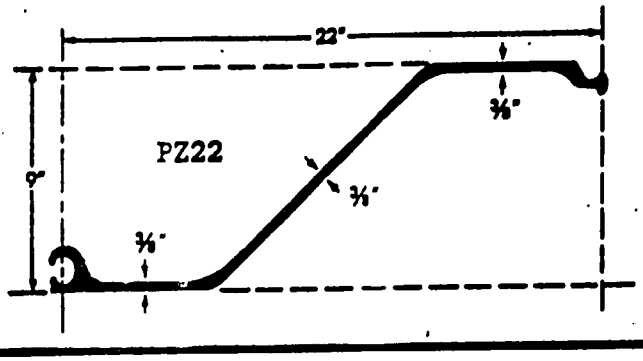
8844 sq.ft. x .10 x 2 ma/sq.ft. = 1.77 Amps.

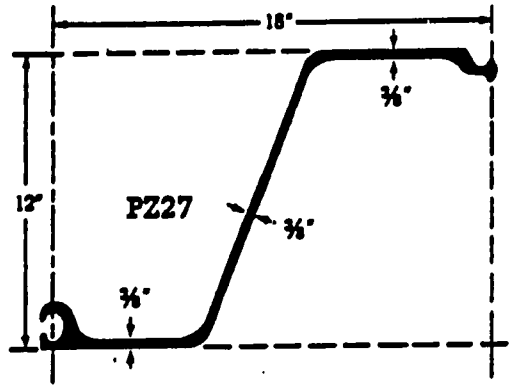
1.77 ÷ 0.020 ma. = 89 pcs. of 17 lb. Mag. Anodes

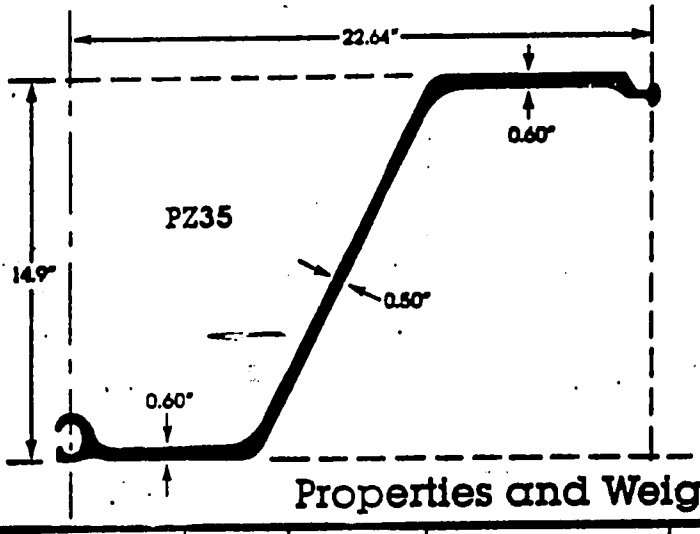
3.6.2 Estimated cost for this system is as follows:

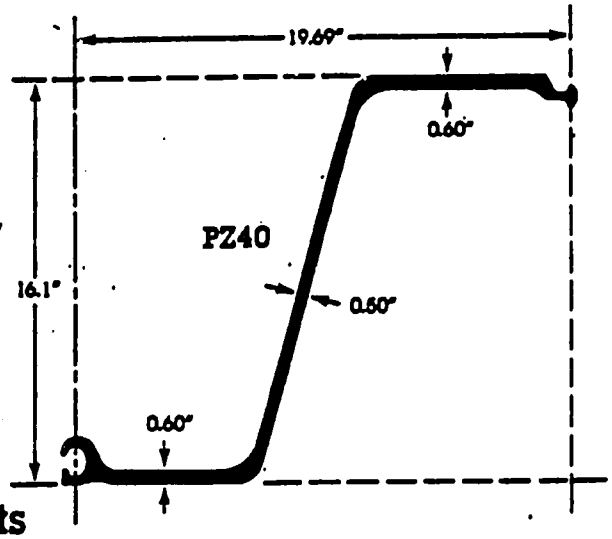
Anodes	-	$5,500.00
Freight	-	1,000.00
Labor/Mat'l.	-	4,500.00
Total	-	$11,000.00

Now...
4 sheet piling sections from Bethlehem Steel









Properties and Weights

Section Designation	Area, sq in.	Nominal Width, in.	Weight in Pounds: Per lin ft of bar*	Weight in Pounds: Per sq ft of wall	Moment of Inertia, in.⁴	Section Modulus, in.³: Single Section	Section Modulus, in.³: Per lin ft of wall	Surface Area, sq ft per lin ft of bar: Total Area	Surface Area, sq ft per lin ft of bar: Nominal Coating Area*
PZ22	11.86	22	40.3	22.0	154.7	33.1	18.1	4.94	4.48
PZ27	11.91	18	40.5	27.0	276.3	45.3	30.2	4.94	4.48
PZ35	19.41	22.64	66.0	35.0	681.5	91.4	48.5	5.83	5.37
PZ40	19.30	19.69	65.6	40.0	805.4	99.6	60.7	5.83	5.37

Note: All sections interlock with one another.

*Excludes bowl and ball of interlock.

For more information, call your nearest Bethlehem sales office. Or write Construction Products Sales, Bethlehem Steel Corporation, Bethlehem, PA 18016.

Bethlehem

Descriptive Sheet 3814
Printed in U.S.A.

Data current as of May 1983

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3.6.0 Pipelines (Continued)

3.6.2 Cost/Year - $550.00

4.0.0 Cost Summary	Est. Cost Installed
Bulkhead (10 year system)	$148,000.00
Bulkhead (20 year system)	$266,000.00
Mooring Dolphins (10 year system)	$ 3,500.00
Fender Piles (10 year system)	$148,000.00
Tie Rods (20 year system)	$ 57,000.00
Pipelines (20 year system)	$ 11,000.00

4.1.0 All prices and cost estimates are based on current U.S. material and labor costs without any escalation factor.

4.2.0 All materials to be specified in final design will be of best U.S. quality readily available from at least three firms experienced in the manufacture and/or assembly of this type equipment.

4.3.0 Prospective suppliers of sacrificial anodes are as follows:

Wilson, Walton International, Inc.
66 Hudson Street
Hoboken, New Jersey 07030

- Continued -

4.3.0 Prospective suppliers (Continued)

Cathodic Technology, Inc.
P. O. Box 9188
Houston, Texas 77011

Cathodic Protection Services
P. O. Box 4076
Houston, Texas 77006

Cobro International, Inc.
6501 Ferris
Bellaire, Texas 77401

Marine Corrosion Engineers
Marine and Industrial Agents

Wilson, Walton International Inc.
66 Hudson Street, PO Box M-890, Hoboken, New Jersey 07030, USA
Tel. (212) 227-6657, (201) 795-2044 Telex 1-25919 Cable: Wazadens

CORROSION EXPERIENCE RESUME

Charles S. Potosnak

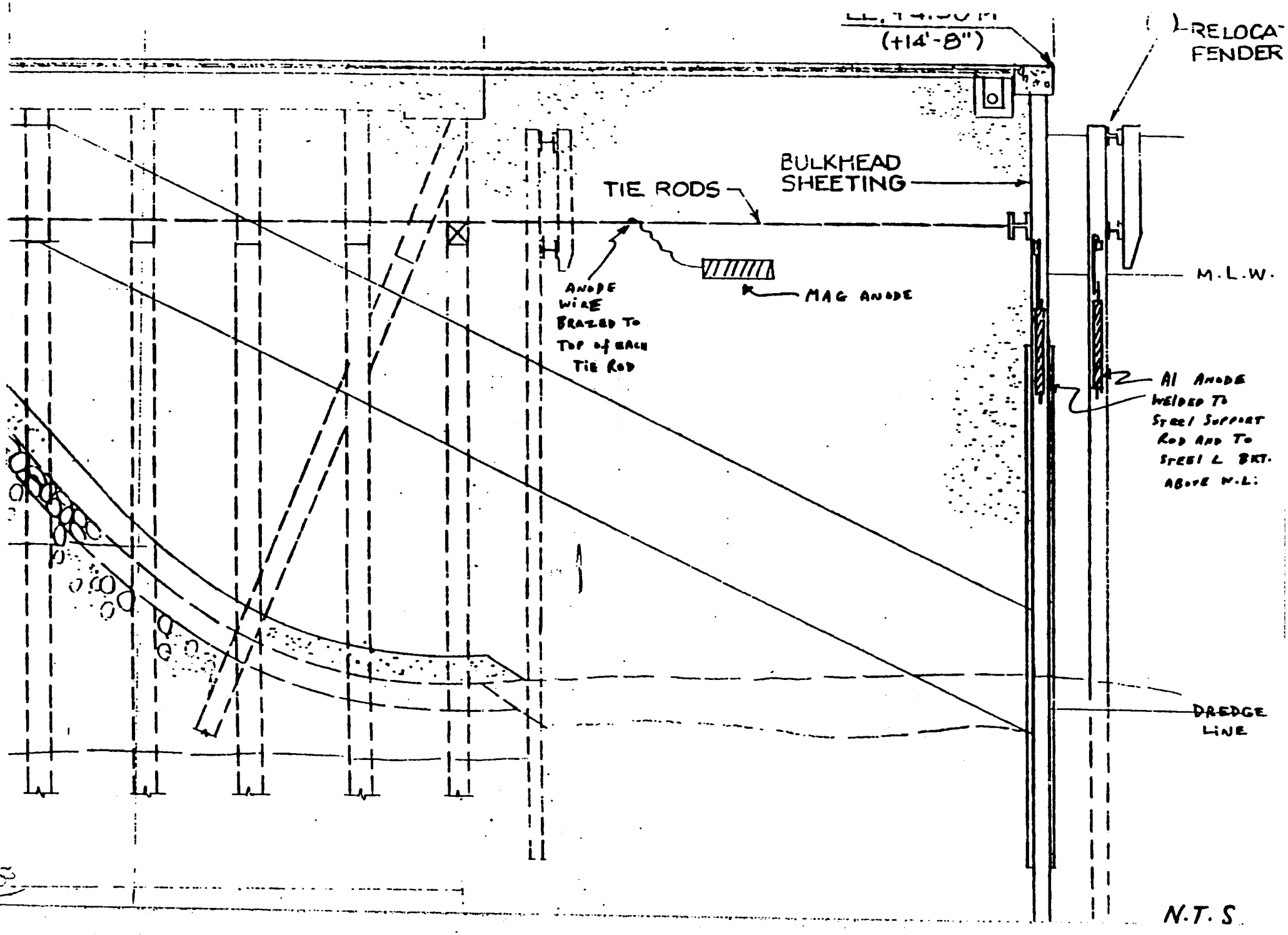
College - New York University - B.A. (Chemistry) 1949
Newark College of Engineering - M.S. (Chem. Eng.) 1956

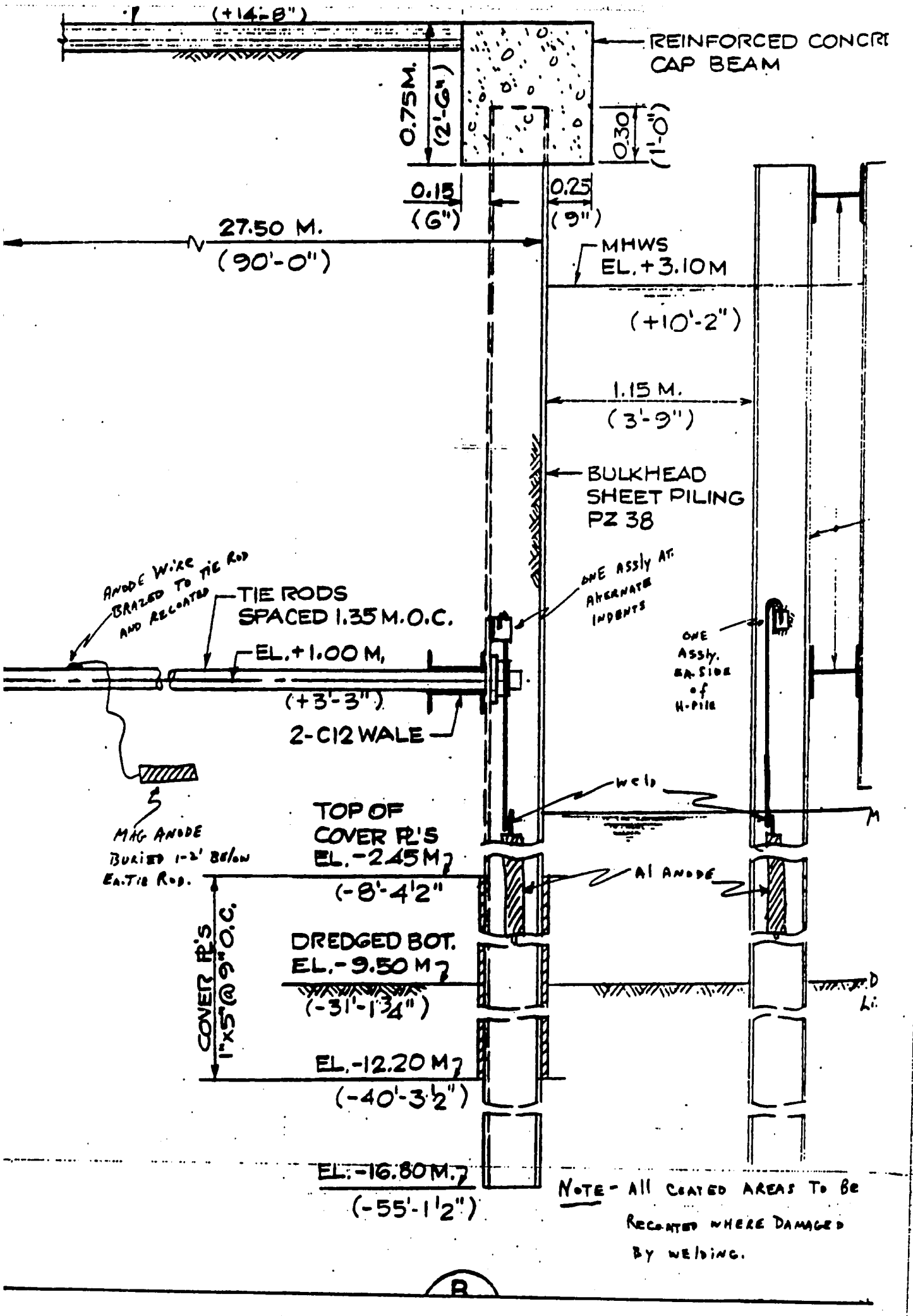
Certification by National Association of Corrosion Engineers - "Corrosion Specialist" - No. 541 issued 1971.

Professional Corrosion Engineer's License - No. 182 - issued 1976 (California)

Wallace & Tiernan - (1957 - 1961) Design and Engineering of Cathodic Protection Systems for Ships, Barges, Docks, Piers and Submerged Pipelines.

Wilson, Walton International Inc. - (1961 - Present) Design and Engineering of all phases of Cathodic Protection Systems for buried or submerged steel structures on land or offshore. Supervision and/or commissioning and trouble-shooting cathodic protection installations. Corrosion surveys and material failure evaluation and analysis.


(+14'-8")
RELOCA
FENDER
BULKHEAD
SHEETING
TIE RODS
ANODE
WIRE
BRAZED TO
TOP OF EACH
TIE ROD
MAG ANODE
M.L.W.
Al ANODE
WELDED TO
STEEL SUPPORT
ROD AND TO
STEEL L BKT.
ABOVE M.L.
DREDGE
LINE
N.T.S


(+14'-8")
REINFORCED CONCRETE CAP BEAM
0.75M.
(2'-6")
0.30
(1'-0")
0.15
(6")
0.25
(9")
27.50 M.
(90'-0")
MHWS
EL. +3.10M
(+10'-2")
1.15 M.
(3'-9")
BULKHEAD SHEET PILING PZ 38
ANODE WIRE BRAZED TO TIE ROD AND RECOATED
TIE RODS SPACED 1.35 M.O.C.
EL. +1.00 M.
(+3'-3")
2-C12 WALE
ONE ASSY AT ALTERNATE INDENTS
ONE ASSY. EA. SIDE of H-PILE
weld
MAG ANODE BURIED 1-2' BELOW EA. TIE ROD.
TOP OF COVER PL'S
EL. -2.45 M.
(-8'-4½")
Al ANODE
COVER PL'S 1"x5" @ 9" O.C.
DREDGED BOT.
EL. -9.50 M.
(-31'-1¾")
EL. -12.20 M.
(-40'-3½")
EL. -16.80 M.
(-55'-1½")
NOTE - All COATED AREAS TO BE RECOATED WHERE DAMAGED BY WELDING.
B

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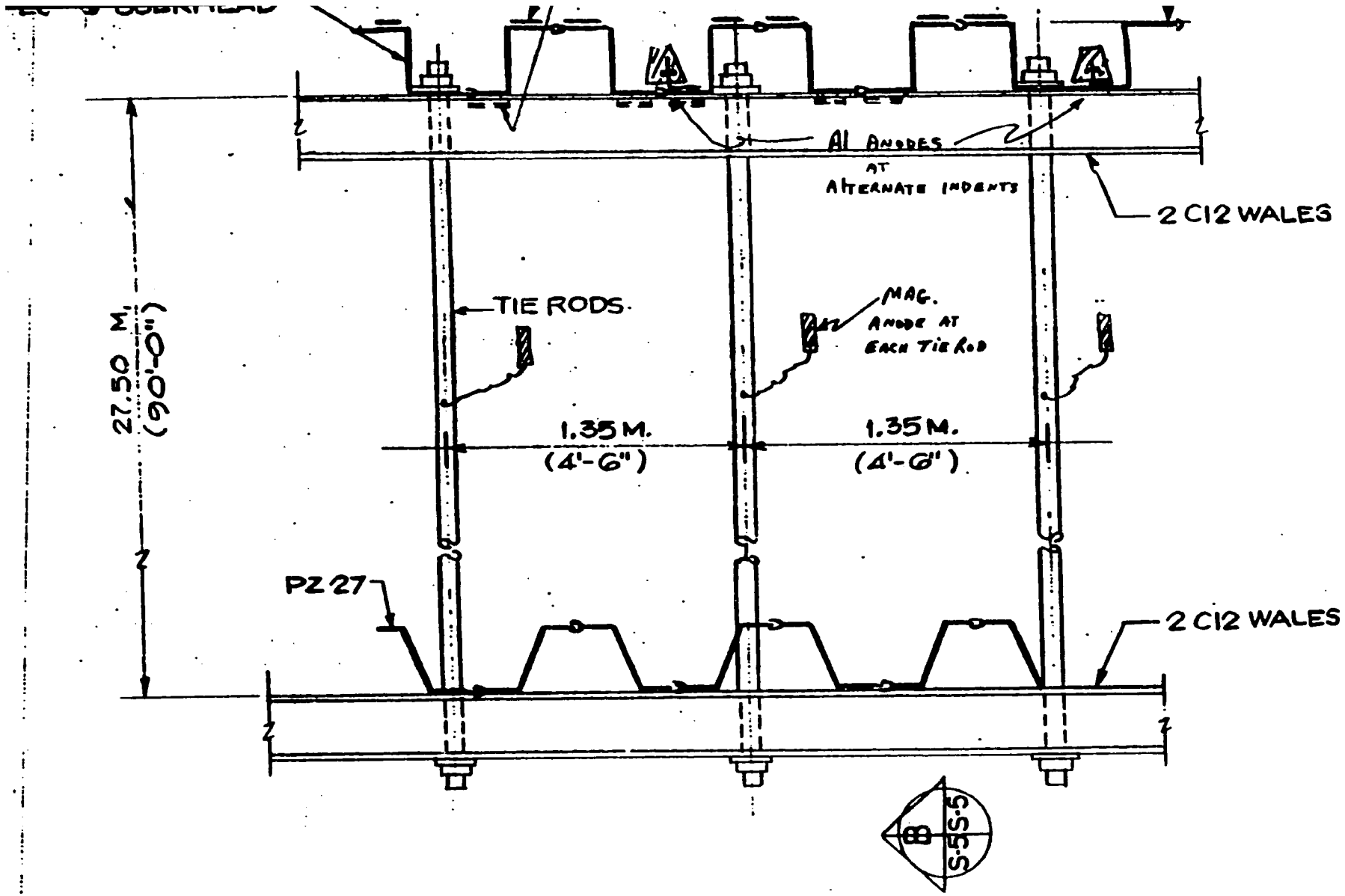
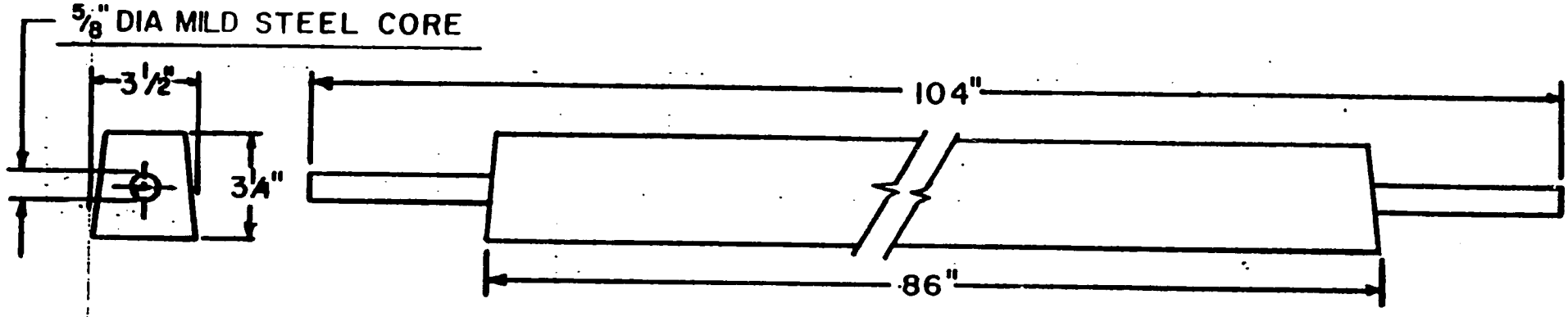


PLAN
BULKHEAD AND FENDERING



NOMINAL WT 90 Lbs.

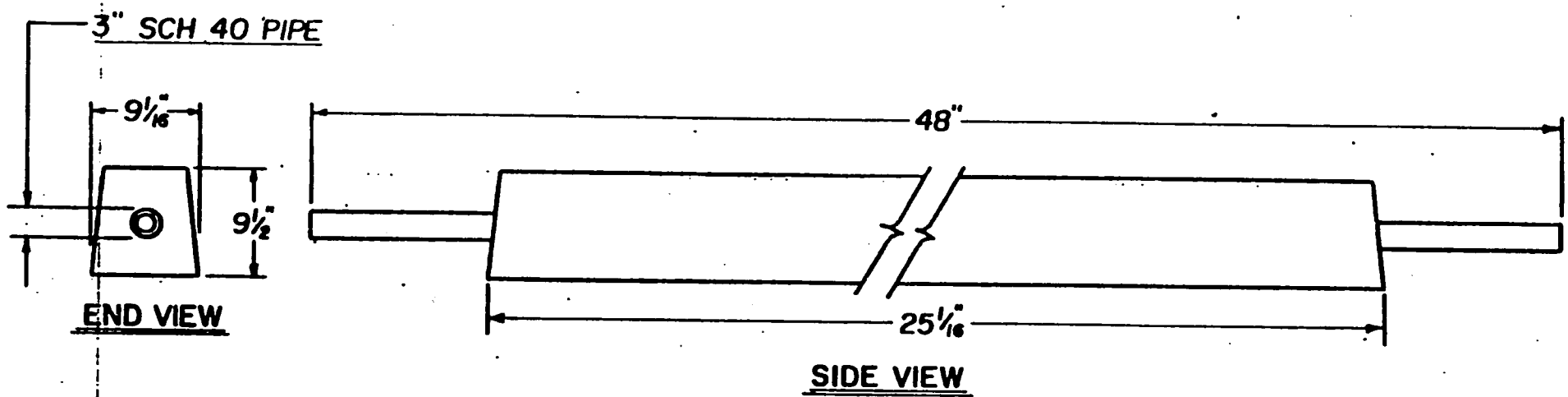
WILSON, WALTON INTERNATIONAL
NEW ORLEANS, LA. HOBOKEN, N. J.

W-92

"ALOLINE" ANODE

Date: 02-12-81	Scale: N.T.S.	DWG. NO.
Drwn. by: R E M		W-92
Apprvd. by: T.S.		

Rev. No.	Date	Description	By



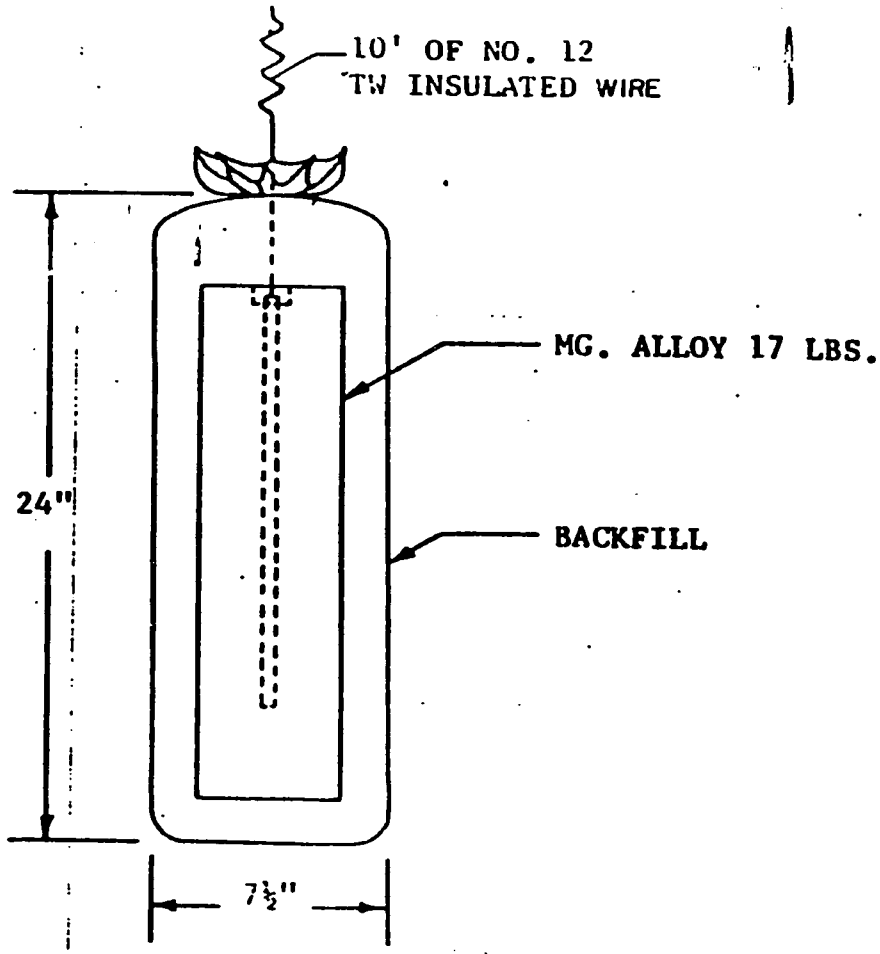
NOMINAL WT. 211 LBS

WILSON, WALTON INTERNATIONAL
NEW ORLEANS, LA. HOBOKEN, N. J.

W-211
"ALOLINE" ANODE

Date: 2-14-79	Scale: N.T.S.	DWG. NO. W-211
Drwn. by: J. DORSO		
Apprvd. by: T.S.		

Rev. No.	Date	Description	By



GROSS WEIGHT: 45 LBS.

COMPOSITION OF THE ANODE:

Zinc	-	2.5 - 3.5% range
Aluminum	-	5.3 - 6.7% range
Manganese	-	.15% Minimum
Iron	-	.003% Maximum
Nickel	-	.002% Maximum
Copper	-	.02% Maximum
Other elements	-	.05% Max. each and .3% total.
Magnesium	-	Remainder

COMPOSITION OF THE BACKFILL:

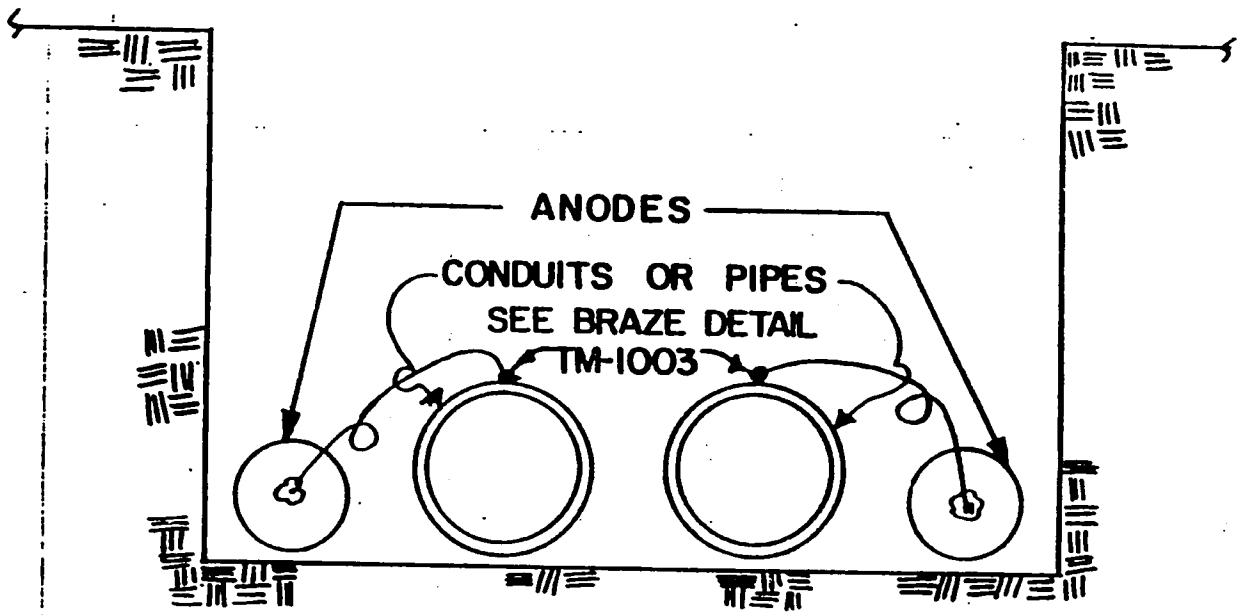
75% hydrated Gypsum, 20% Bentonite and 5% sodium sulphate.

WILSON, WALTON INTERNATIONAL
HOBOKEN, N. J., U.S.A. CROYDON, SURREY, ENGLAND

PACKAGED MG. ANODE
17 LB.

Date: 1-22-71	Scale N.T.S.	DWG NO
Drawn by: E.T.G		TM-1012
Approved by E.T.G		

Rev No.	Date	Description	By



TRENCH

NOTES:

1- ANODE TO BE THOROUGHLY WETTED BEFORE BACKFILLING.

2- SOIL BACKFILL SURROUNDING ANODE TO WELL TAMPED.

3- COAT BRAZE WITH PIPE ENAMEL AND EXPOSED LEAD WIRE WITH A COATING HAVING DIELECTRIC AND PHYSICAL STRENGTH EQUIVALENT TO ORIGINAL CONDUIT COATING.

4- ANODE TO BE INSTALLED HORIZONTALLY IN TRENCH.

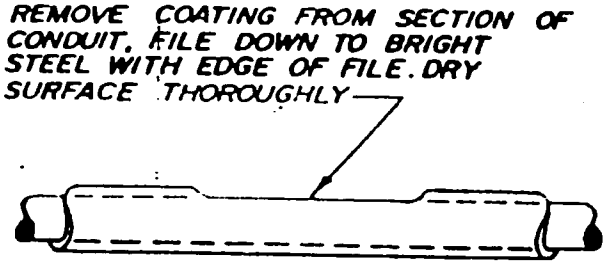
Description	By

WILSON, WALTON INTERNATIONAL
NEW ORLEANS, LA. HOBOKEN, N. J.

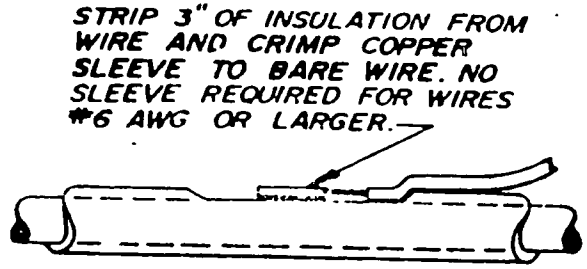
TYPICAL DOUBLE PIPE

DOUBLE ANODE INSTALLATION

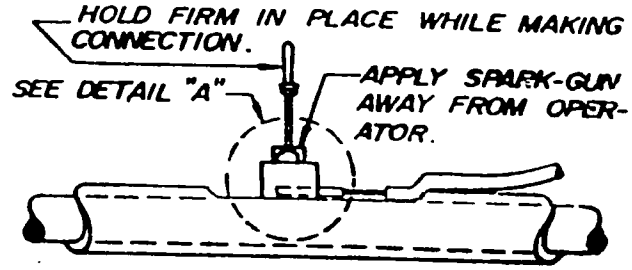
Date: 8 OCT. 82	Scale: N.T.S.	DWG. NO.
Drwn. by: J. SUAREZ		TM-1001-I
Apprvd. by: D. D.M.		



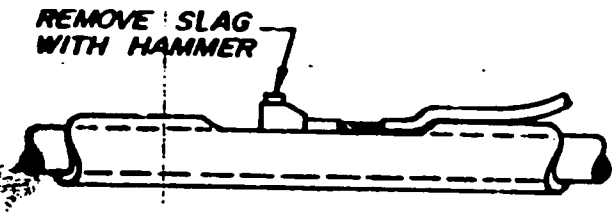
STEP 1.



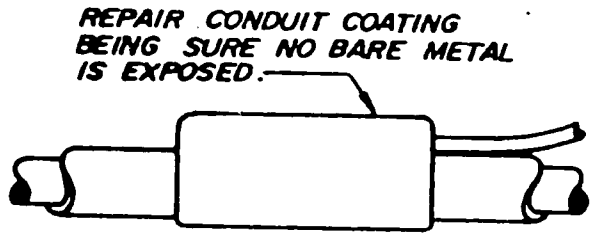
STEP 2.



STEP 3.



STEP 4.



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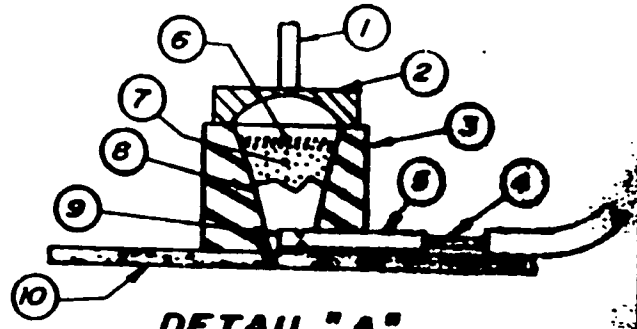

DETAIL "A"

1 HANDLE
2 GRAPHITE COVER
3 GRAPHITE MOLD
4 COPPER WIRE
5 COPPER SLEEVE
6 STARTING POWDER
7 METAL POWDER
8 METAL DISC
9 CRIMP
10 CLEANED PIPE SECTION

NOTE:

AFTER CONNECTION IS MADE REMOVE LOOSE SLAG AND COAT OVER ALL EXPOSED BARE METAL TO EQUAL DIELECTRIC & PHYSICAL STRENGTH OF CONDUIT COATING.

WILSON, WALTON INTERNATIONAL
HOBOKEN, N. J., U.S.A. CROYDON, SURREY, ENGLAND

TYPICAL THERMITE CONNECTION

Date: 8-15-68 Scale:
Drawn by:
Approved by:

	Description	By

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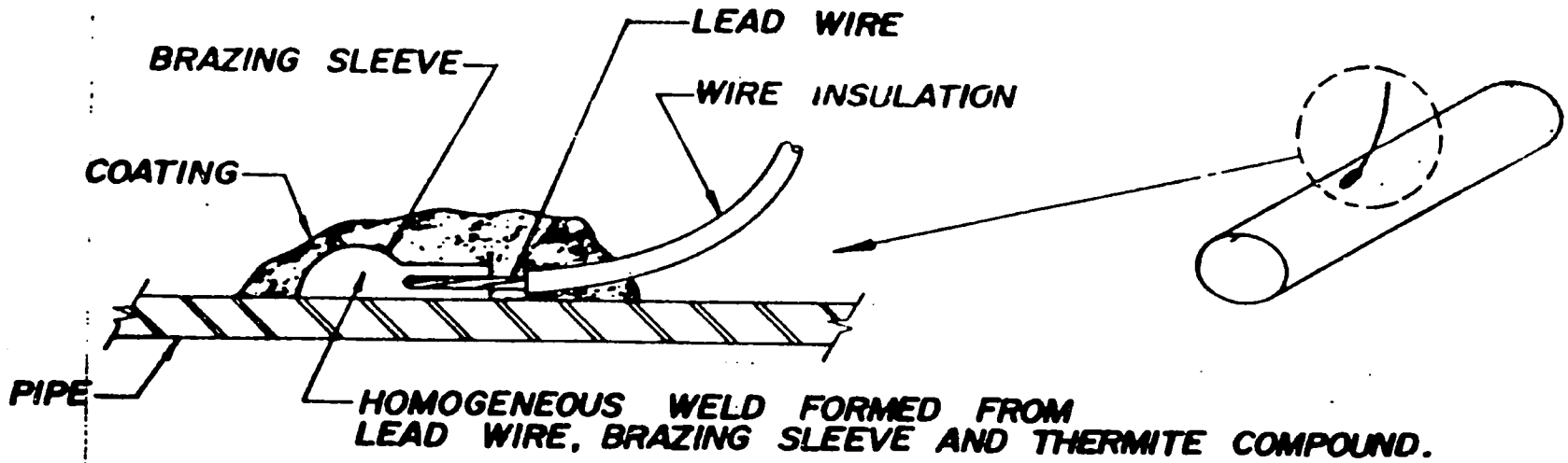

CLEAN PIPE SURFACE AT BRAZE TO EXPOSE RAW METAL. AREA MUST BE FREE OF DIRT, RUST, MILL SCALE, MOISTURE OR GREASE TO ASSURE PROPER BRAZE.

IF THE PIPE IS BARE, THE COMPLETED BRAZE AND EXPOSED LEAD WIRE ARE TO BE HEAVILY COATED WITH BITUMASTIC No. 50 ENAMEL. OTHERWISE COAT TO EQUAL DIELECTRIC AND PHYSICAL STRENGTH OF PIPE COATING.

WILSON, WALTON INTERNATIONAL
HOBOKEN, N. J., U.S.A. CROYDON, SURREY, ENGLAND

SECTION THROUGH
COMPLETED BRAZE

Date: 7-7-67	Scale: N.T.S.	Drawing No.
Drawn by:	"PIPE"	
Approved by:		

Rev. No.	Date	Description	By

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NACE Standard RP-01-69
(1983 Revision)
Item No. 53002

technical practices committee

Recommended Practice

Control of External Corrosion on Underground or Submerged Metallic Piping Systems

This National Association of Corrosion Engineers Standard represents a consensus of those individual members who have reviewed this document, its scope, and provisions. This Standard is intended to aid the manufacturer, the consumer, and the general public. Its acceptance does not in any respect preclude anyone, whether he has adopted the Standard or not, from manufacturing, marketing, purchasing, or using products, processes, or procedures not in conformance with this Standard. NACE Standards are subject to periodic review, and the user is cautioned to obtain the latest edition.

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Approved August, 1969
Revised January, 1972
Revised September, 1976

National Association of Corrosion Engineers
P.O. Box 218340
Houston, Texas 77218
713/492-0535

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The National Association of Corrosion Engineers issues this Standard in conformity to the best current technology regarding the specific subject. This Standard represents minimum requirements and should in no way be interpreted as a restriction on the use of better procedures or materials. Neither is this Standard intended to apply in any and all cases relating to the subject. Unpredictable circumstances may negate the usefulness of this Standard in specific instances.

The National Association of Corrosion Engineers assumes no responsibility for the interpretation or use of this Standard.

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Foreword

This NACE Standard Recommended Practice was prepared by NACE Task Group T-10-1, composed of corrosion consultants, corrosion control personnel from oil and gas transmission companies, gas distribution companies, power companies, communications companies, the Federal Energy Regulatory Commission, the National Bureau of Standards, the Department of Transportation, the American Water Works Association, representatives from steel, cast iron, copper, and aluminum piping manufacturers, and coating applicators, manufacturers, and others concerned with corrosion control. The Standard is issued by NACE under the auspices of Group Committee T-10 on Underground Corrosion Control.

The purpose of this Recommended Practice is to present procedures and practices for achieving effective control of external corrosion on buried or submerged metallic piping systems. These recommendations are also applicable to many other buried or submerged metallic structures. The Recommended Practice describes the use of electrically insulating coatings, electrical isolation, and cathodic protection as corrosion control methods. It contains specific provisions for the application of cathodic protection to existing bare, existing coated, and new piping systems. Also included are procedures for control of interference currents on pipelines. This Recommended Practice does not include corrosion control methods based on chemical control of the environment or on the use of electrically conductive coatings.

RECOMMENDED PRACTICE

Control of External Corrosion on Underground or Submerged Metallic Piping Systems

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Best Available Document

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Section 1: General

1.1 This Recommended Practice presents acknowledged practices for the control of external corrosion on buried or submerged steel, cast iron, ductile iron, copper, and aluminum piping systems under the following headings:

Section 2: Definitions
Section 3: Determination of Need for Corrosion Control
Section 4: Structure Design
Section 5: Coatings
Section 6: Criteria for Cathodic Protection
Section 7: Design of Cathodic Protection Systems
Section 8: Installation of Cathodic Protection Systems
Section 9: Control of Interference Currents
Section 10: Operation and Maintenance of Cathodic Protection Systems
Section 11: Corrosion Control Records

1.2 This Recommended Practice is intended to serve as a guide for establishing minimum requirements for control of corrosion on the following systems:

1.2.1 New piping systems: Corrosion control by coating supplemented with cathodic protection, or by some other proved method, should be provided in the initial design and should be maintained during the service life of the piping system, unless investigations indicate that corrosion control is not required.

1.2.2 Existing coated piping systems: Cathodic protection should be provided and maintained on all existing coated piping systems, unless investigations indicate that cathodic protection is not required.

1.2.3 Existing bare piping systems: Studies should be made to determine the extent and rate of corrosion on existing bare piping systems. When these studies indicate that corrosion will affect the safe or economic operation of the system, adequate corrosion control measures should be employed.

1.3 This Recommended Practice does not designate practices for every specific situation due to the complexity of environmental conditions to which buried or submerged piping systems are exposed which precludes standardizing corrosion control practices.

1.4 This Recommended Practice does not include corrosion control methods based on chemical control of the environment or on the use of electrically conductive coatings.

1.5 The provisions of this Recommended Practice should be applied under the direction of competent persons who, by reason of knowledge of the physical sciences and the principles of engineering and mathematics, acquired by professional education and related practical experience, are qualified to engage in the practice of corrosion control on buried or submerged metallic piping systems. Such persons may be registered professional engineers or persons recognized as being qualified or accredited as corrosion specialists by the National Association of Corrosion Engineers if their professional activities include suitable experience in corrosion control on buried or submerged metallic piping systems.

1.6 Deviation from the Recommended Practice may be warranted in specific situations provided that corrosion control personnel in responsible charge are able to demonstrate that the objectives expressed in the Recommended Practice have been achieved.

Section 2: Definitions[1]

Anode: An electrode at which oxidation of its surface or some component of the solution is occurring. Antonym: cathode.

Beta Curve: See Appendix D.

Cathodic Protection: A technique to prevent the corrosion of a metal surface by making that surface the cathode of an electrochemical cell.

Continuity Bond: A metallic connection that provides electrical continuity.

Corrosion: The deterioration of a material, usually a metal, because of a reaction with its environment.

Current Density: The current per unit area.

Electrical Isolation: The condition of being electrically separated from other metallic structures and the environment.

Electro-Osmotic Effect: Passage of a charged particle through a membrane under the influence of a voltage. Soil may act as the membrane.

Electrode Potential: The potential of an electrode as measured against a reference electrode. The electrode potential does not include any loss of potential in the solution due to current passing to or from the electrodes, i.e., it represents the reversible work required to move a unit charge from the electrode surface through the solution to the reference electrode.

Electrolyte: A chemical substance or mixture, usually liquid, containing ions that migrate in an electric field. For the purpose of this Recommended Practice, electrolyte refers to the soil or liquid adjacent to and in contact with a buried or submerged metallic structure, including the moisture and other chemicals contained therein.

Foreign Structure: Any structure that is not intended as a part of the system of interests.

Galvanic Anode: A metal which, because of its relative position in the galvanic series, provides sacrificial protection to metal or metals that are more noble in the series, when coupled in an electrolyte. These anodes are the current source in one type of cathodic protection.

Galvanic Series: A list of metals and alloys arranged according to their relative potentials in a given environment.

[1] Definitions in this section reflect common usage among practicing corrosion control personnel. In many cases, in the interests of brevity and practical usefulness, the strictly scientific definitions are abbreviated or paraphrased.

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Half Cell Reference Electrode: See Reference Electrode.

Holiday: A discontinuity of coating that exposes the metal surface to the environment.

Impressed Current: Direct current supplied by a power source external to the electrode system.

Insulating Coating System: All components comprising the protective coating, the sum of which provide effective electrical insulation of the coated structure.

Interference Bond: A metallic connection designed to control electrical current interchange between metallic systems.

IR Drop: The voltage across a resistance in accordance with Ohm's Law.

Isolation: See Electrical Isolation.

Line Current: The direct current flowing on a pipeline.

Polarization: The deviation from the open circuit potential of an electrode resulting from the passage of current. In this Recommended Practice, polarization is considered to be the change of potential of a metal surface resulting from the passage of current directly to or from an electrolyte.

Reference Electrode: A device whose open circuit potential is constant under similar conditions of measurement.

Reverse-Current Switch: A device that prevents the reversal of direct current through a metallic conductor.

Sacrificial Protection: Reduction or prevention of corrosion of a metal in an electrolyte by galvanically coupling it to a more anodic metal.

Stray Current: Current flowing through paths other than the intended circuit.

Stray Current Corrosion: Corrosion resulting from direct current flowing through paths other than the intended circuit.

Structure-to-Electrode Voltage: (Also Structure-to-Soil Potential or Pipe-to-Soil Potential). The voltage difference between a buried metallic structure and the electrolyte which is measured with reference to an electrode in contact with the electrolyte.

Structure-to-Structure Voltage: (Also Structure-to-Structure Potential). The difference in voltage between metallic structures in a common electrolyte.

Tafel Segment, Tafel Line, Tafel Slope, Tafel Diagram: When an electrode is polarized, it frequently will yield a current-potential relationship over a region which can be approximated by:

$$\eta = \pm B \log \frac{i}{i_o}$$

where η = change from open circuit potential, i = the current density, B and i_o = constants. The constant (B) is also known as the Tafel slope. If this behavior is observed, a plot on semilogarithmic coordinates is known as the Tafel line and the overall diagram is termed a Tafel diagram.

The Tafel segment is that portion of the diagram which appears as a straight line when current is plotted on the logarithmic scale and potential change is plotted on the linear scale. The beginning of the Tafel segment is that point on the curve where the current-potential relationship follows the straight line with increasing current increments and deviates from the straight line with decreasing current increments.

Voltage: An electromotive force or a difference in electrode potentials expressed in volts.

Section 3: Determination of Need for Corrosion Control

3.1 Introduction

3.1.1 The purpose of this section is to recommend practices for determining when an underground or submerged metallic piping system requires corrosion control.

3.1.2 Metallic structures buried in soil or submerged under water are subject to corrosion. Adequate corrosion control procedures should be adopted to assure metal integrity for safe and economical operation.

3.2 The decisions governing the need for corrosion control should be based on data obtained from corrosion surveys, operating records, prior test results from similar systems in similar environments, and on a study of design specifications and engineering, operating, safety, and economic requirements.

3.2.1 Environmental and physical factors

3.2.1.1 Corrosion rate of the particular metallic piping system in a specific environment (See Appendix A).

3.2.1.2 The nature of the product being transported and working pressure of the piping system as related to design specifications.

3.2.1.3 Location of the piping system as related to density of population and frequency of visits by personnel.

3.2.1.4 Location of the piping system as related to other facilities.

3.2.1.5 Stray direct current sources foreign to the system (See Section 9).

3.2.2 Economic factors

3.2.2.1 Costs of maintaining the piping system in service for its expected life (See Appendix A).

3.2.2.2 Contingent costs of corrosion (See Appendix B).

3.2.2.3 Costs of corrosion control (See Appendix C).

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4.1 Introduction

4.1.1 The purpose of this section is to provide accepted corrosion control practices for the design of an underground or submerged piping system. A person qualified to engage in the practice of corrosion control should be consulted during all phases of pipeline design and construction (See Paragraph 1.5). These recommendations should not be construed as taking precedence over recognized electrical safety practices.

4.2 Electrical Isolation

4.2.1 Insulating devices consisting of flange assemblies, prefabricated insulating joints, unions, or couplings should be installed within piping systems where electrical isolation of portions of the system is required to facilitate the application of corrosion control. These devices should be properly rated for temperature, pressure, and dielectric strength. Installation of insulating devices should be avoided in enclosed areas where combustible atmospheres are likely to be present. Typical locations where electrical insulating devices may be considered are as follows:

4.2.1.1 Points at which facilities change ownership such as meter stations and well heads.

4.2.1.2 Connections to main line piping systems such as gathering or distribution system laterals.

4.2.1.3 Inlet and outlet piping of inline measuring and/or pressure regulating stations.

4.2.1.4 Compressor or pumping stations, either in the suction and discharge piping or in the main line immediately upstream and downstream of the station.

4.2.1.5 In stray current areas.

4.2.1.6 At the junction of dissimilar metals for protection against galvanic corrosion.

4.2.1.7 At the termination of service life connections and entrance piping to prevent electrical continuity with other metallic systems.

4.2.1.8 At the junction of a coated pipe and a bare pipe.

4.2.2 The need for lightning and fault current protection at insulating devices should be considered. Cable connections from insulating devices to arrestors should be short, direct, and of a size suitable for short term, high current loading.

4.2.3 Where metallic casings are required as part of the underground piping system, the pipeline should be electrically isolated from such casings.

4.2.4 Where casing seals are used, they should be installed to resist the entry of foreign matter into the casing.

4.2.5 Where electrical contact would adversely affect cathodic protection, piping systems should be electrically isolated from supporting pipe stanchions, bridge structures, tunnel enclosures, piling, or reinforcing steel in concrete. However, piping can be attached directly to a bridge without installation if insulating devices are installed on each side of the bridge to electrically isolate the bridge piping from adjacent underground piping.

4.2.6 Where an insulating joint is required, a device manufactured to perform this function should be used, or, if permissible, a section of nonconductive pipe, such as plastic pipe, may be installed. In either case, these should be properly rated and installed in accordance with manufacturer's instructions.

4.2.7 River weights, pipeline anchors, and metallic reinforcement in weight coatings should be electrically isolated from the carrier pipe and installed so that coating damage will not occur.

4.2.8 Metallic curb boxes and valve enclosures should be designed, fabricated, and installed in such a manner that electrical isolation from the piping system will be maintained.

4.2.9 Where a metallic wall sleeve is used, and where it is intended to maintain electrical isolation between the sleeve and the pipe, insulating type spacing materials should be used.

4.2.10 Underground piping systems should be installed so that they may remain electrically isolated from all foreign underground metallic structures. Where practicable, a 30 cm (12 inch) minimum separation should be maintained between all buried metallic structures at crossings. Where it is impractical to achieve the recommended separation, insulating materials between the structures or other methods used to maintain electrical isolation may be required.

4.2.11 A minimum separation of 3 m (10 feet) should be maintained between pipelines and transmission tower footings, ground cables, and counterpoise. Regardless of separation, consideration should always be given to lightning and fault current protection of pipeline(s) and safety of personnel (See NACE Standard RP-01-77, Latest Revision).

4.3 Electrical Continuity

4.3.1 Consideration should be given to the electrical properties of non-welded pipe joints. Where it is the objective to ensure electrical continuity, this should be achieved either by using fittings manufactured for this purpose or by bonding the mechanical joints in an approved, effective manner.

4.4 Coatings

4.4.1 New piping systems should be coated unless thorough investigations indicate that coatings are not required (See Section 5).

4.5 Corrosion Control Test Stations

4.5.1 Test stations for potential, current, or resistance measurements should be provided at sufficient locations to facilitate cathodic protection testing. Such locations may include, but not be limited to, the following:

(a) Pipe casing installations.
(b) Foreign metallic structure crossings.

(c) Insulating joints.
(d) Waterway crossings.
(e) Bridge crossings.
(f) Valve stations.
(g) Galvanic anode installations.

4.5.2 The span of pipe used for line current test stations should exclude:

(a) Foreign metallic structure crossings.
(b) Lateral connections.
(c) Mechanical couplings or connections such as screwed joints, flanges, anode or rectifier attachments, or metallic bonds.

4.5.3 Attachment of test lead wires to steel and other ferrous type pipes.

4.5.3.1 Attention should be given to the manner of installing test lead wires used for corrosion control testing in order to avoid harmful effects to the pipe at the point of attachment.

4.5.3.2 Test lead wires are usually attached directly to the pipe by soldering or by the thermit welding process. Mechanical connections which remain secure and electrically conductive may also be used.

4.5.4 Methods of attaching test lead wire to aluminum pipes.

4.5.4.1 Aluminum test lead wire, or aluminum wire tabs attached to aluminum wire, may be welded to aluminum pipe using TIG process (tungsten inert gas shielded arc) or MIG process (metal inert gas shielded arc). Welded attachments should be made to flanges or at butt weld joints. Attachment at other sites may adversely affect the mechanical properties of the pipe because of the heat of welding.

4.5.4.2 Test lead wire may be attached to aluminum pipe by soldering. If low melting point soft solders are used, a flux will be required. Flux residues may cause corrosion unless removed. The use of copper test lead wire may cause preferential galvanic attack on the aluminum pipe. Where copper wire or flux is used, care must be taken to seal the attachment areas against moisture. In the presence of moisture, the connection may disbond and be damaged by corrosion.

4.5.4.3 Aluminum tabs to which test lead wires have been TIG welded can be attached by an explosive bonding technique called "High Energy Joining" or HEJ Process.

4.5.4.4 Mechanical connections which remain secure and electrically conductive may also be used.

4.5.5 Coating of test lead wire attachments

4.5.5.1 All test lead wire attachments and all bare test lead wires should be coated with an electrically insulating material. Where the pipe is coated, the insulating material should be compatible with the pipe coating and wire insulation.

4.6 Cathodic Protection

4.6.1 Refer to Sections 6, 7, and 8 of this Recommended Practice for the design and installation of cathodic protection.

Section 5: Coatings

5.1 Introduction

5.1.1 The purpose of this section is to recommend practices for handling, inspecting, and installing coated piping systems, and for testing, evaluating, and selecting coating systems for corrosion control.

5.1.2 The function of such coatings in corrosion control is to isolate the external surface of underground and submerged piping from the environment. This can be substantially accomplished by different types of coatings. These coatings can be formed on the pipe surface or prefabricated as films on wrappers and then applied.

5.1.2.1 Desirable characteristics of coatings:

(a) Effective electrical insulator.
(b) Effective moisture barrier.
(c) Applicable to pipe by a method that will not adversely affect the properties of the pipe.
(d) Applicable to piping with a minimum of defects.
(e) Good adhesion to pipe surface.
(f) Ability to resist development of holidays with time.
(g) Ability to resist damage during handling, storage, and installation.
(h) Ability to maintain substantially constant electrical resistivity with time.
(i) Resistant to disbonding when under cathodic protection.
(j) Ease of repair.

5.1.2.2 Typical factors to consider when selecting a pipe coating:

(a) Type of environment.
(b) Accessibility of pipeline.
(c) Operating temperature of pipeline.
(d) Ambient temperatures during application, shipping, storage, construction, installation, and pressure testing.
(e) Geographical and physical location.
(f) Type coating on existing pipe in the system.
(g) Handling and storage.
(h) Pipeline installation methods.
(i) Costs.

5.1.3 Information in this section is primarily by reference to other documents. It is important that the latest revision of the pertinent reference be used.

5.1.3.1 Table 1 is a general listing of all references used, giving title and sponsoring source. In this

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table each document is given a reference number for convenient use thereafter.

5.1.3.2 Table 2 is a listing of types of coating systems showing the appropriate references for material specifications and/or recommended practices for application.

5.1.3.3 Table 3 is a grouping of references for general use during installation and inspection, irrespective of coating type.

5.1.3.4 Table 4 is a list of coating system characteristics related to environmental conditions containing suggested laboratory test references for various properties.

5.1.3.5 Table 5 is a list of coating system characteristics related to design and construction, with appropriate suggested laboratory tests for evaluating these properties.

5.1.3.6 Table 6 lists the references that are useful in field evaluation of coating systems after the pipeline has been installed.

5.2 Handling, Inspection, and Installation

5.2.1 Handling

5.2.1.1 Damage to coating can be minimized by careful handling and by using proper pads and slings.

5.2.2 Inspection

5.2.2.1 Qualified personnel should keep every phase of the coating operation under surveillance.

5.2.2.2 Surface preparation, primer application, coating thickness, temperatures, bonding, and other specific requirements should be checked periodically, using suitable test procedures for conformance with specifications.

5.2.2.3 The use of holiday detectors is recommended to detect faults that would not be observed visually. The holiday detector should be operated in accordance with manufacturer's instructions and at a voltage level appropriate to the electrical characteristics of the coating system.

5.2.3 Installation

5.2.3.1 Joints, fittings, and tie-ins should be coated with a material compatible with the existing coating.

5.2.3.2 Coating defects should be repaired.

5.2.3.3 Materials used to repair coatings must be compatible with existing pipe coating.

5.2.3.4 The ditch bottom should be graded and free of rock or other foreign matter that can damage the coating. Under difficult conditions, consideration should be given to padding the pipe or the ditch bottom.

5.2.3.5 Pipe should be lowered carefully into the ditch, avoiding coating damage.

5.2.3.6 Care should be taken when backfilling so that rocks and debris will not strike and damage the pipe coating.

5.3 Methods for Evaluating Coating Systems

5.3.1 Established system proven by successful use

5.3.1.1 Coating systems that have given satisfactory service for at least five years should continue to provide good service in the same environment. Such coating systems may be selected for use under similar conditions. Satisfactory service is indicated if no significant current increase, attributable to deterioration of the coating, has been required to maintain adequate cathodic protection.

5.3.1.2 Alternative methods of evaluating coating condition are given in NACE Technical Committee Report 2D157,[2] "Methods for Measuring Leakage Conductance of Coating on Buried or Submerged Pipelines" (Ref. 6a, Table 1). This may be used in making periodic measurements of the conductance of the coating in place.

5.3.2 Established or modified system for new environments

5.3.2.1 This method is intended for use where coating systems will continue to be used and are qualified under Section 5.3.1 but where application will be extended to new environments or where it is desired to revise a system to make use of new developments.

5.3.2.1.1 The use of applicable material requirements, material specifications, standards, and recommended practice for application as given in Table 2 is recommended.

5.3.2.1.2 The use of applicable references in Table 3 is recommended unless previously covered in applicable references in Table 2.

5.3.3 New coating system by use of laboratory tests and in-service field performance.

5.3.3.1 The purpose of this method is to qualify a new coating material by subjecting it to laboratory tests appropriate for the intended service. After laboratory tests have been conducted and indicate that the coating system appears to be suitable, application and installation are carried out in accordance with recommended practices. In-service field performance tests are made to confirm the success of the previous steps. The steps of the method are: (1) laboratory tests, (2) application under recommended practices, (3) installation under recommended practices, (4) in-service field performance tests. If good results are obtained after five years, only Steps 2 and 3 are required thereafter.

5.3.3.1.1 Applicable sections of Tables 4 and 5 are recommended for the initial laboratory test methods.

5.3.3.1.2 Applicable sections of Tables 2 and 3 are recommended for conditional use during Steps 2 and 3.

5.3.3.1.3 During a period of five years or

[2]This publication no longer available from NACE.

more, the use of the evaluation methods given in Table 6, Item 1, 2, or 3 (or all three) is recommended. The test method in Item 4 may be used as a supplementary means for obtaining relative data for correlation with laboratory tests.

5.3.4 Method for evaluating a coating system by in-service field performance only.

5.3.4.1 The purpose of this method is to qualify a coating system where none of the first three methods given in 5.3 have been or will be used. It is intended that this method should be limited to minor pilot installations.

5.3.4.1.1 The use of at least one of the first three methods given in Table 6 is recommended on the basis of at least one investigation per year for five consecutive years.

Section 6: Criteria for Cathodic Protection

6.1 Introduction

6.1.1 This section lists criteria for cathodic protection which, when complied with either separately or collectively, will indicate that adequate cathodic protection of a metallic piping system in its electrolyte has been achieved.

6.2 General

6.2.1 The objective of using cathodic protection is to control the corrosion of metallic surfaces in contact with electrolytes.

6.2.2 The selection of a particular criterion for achieving this objective depends, in part, upon past experience with similar structures and environments wherein the criterion has been used successfully.

6.2.3 The criteria in Section 6.3 have been developed through laboratory experiment or have been empirically determined by evaluating data obtained from successfully operated cathodic protection systems. It is not intended that persons responsible for corrosion control be limited to these criteria if it can be demonstrated by other means that the control of corrosion has been achieved.

6.2.4 Voltage measurements on pipelines are to be made with the reference electrode located on the electrolyte surface as close as practicable to the pipeline. Such measurements on all other structures are to be made with the reference electrode positioned as close as feasible to the structure surface being investigated. Consideration should be given to voltage (IR) drops other than those across the structure-electrolyte boundary, the presence of dissimilar metals, and the influence of other structures for valid interpretation of voltage measurements.

6.2.5 No one criterion for evaluating the effectiveness of cathodic protection has proved to be satisfactory for all conditions. Often a combination of criteria is needed for a single structure.

6.3 Criteria

6.3.1 For steel and cast iron structures:

6.3.1.1 A negative (cathodic) voltage of at least 0.85 volt as measured between the structure surface and a saturated copper-copper sulfate reference electrode contacting the electrolyte. Determination of this voltage is to be made with the protective current applied.

6.3.1.2 A minimum negative (cathodic) voltage shift of 300 millivolts, produced by the application of protective current. The voltage shift is measured between the structure surface and a stable reference electrode contacting the electrolyte. This criterion of voltage shift does not apply to structures in contact with dissimilar metals.

6.3.1.3 A minimum negative (cathodic) polarization voltage shift of 100 millivolts measured between the structure surface and a stable reference electrode contacting the electrolyte. This polarization voltage shift is to be determined by interrupting the protective current and measuring the polarization decay. When the current is initially interrupted, an immediate voltage shift will occur. The voltage reading after the immediate shift shall be used as the base reading from which to measure polarization decay.

6.3.1.4 A structure-to-electrolyte voltage at least as negative (cathodic) as that originally established at the beginning of the Tafel segment of the E-log-I curve. This structure-to-electrolyte voltage shall be measured between the structure surface and a stable reference electrode contacting the electrolyte at the same location where voltage measurements were taken to obtain the E-log-I curve.

6.3.1.5 A net protective current from the electrolyte into the structure surface as measured by an earth current technique applied to pre-determined current discharge (anodic) points of the structure.

6.3.2 For aluminum structures:

6.3.2.1 A minimum negative (cathodic) voltage shift of 150 millivolts, produced by the application of protective current. The voltage shift is measured between the structure surface and a stable reference electrode contacting the electrolyte. (See precautionary notes in 6.3.2.3 and 6.3.2.4.)

6.3.2.2 A minimum negative (cathodic) polarization voltage shift of 100 millivolts measured between the structure surface and a stable reference electrode contacting the electrolyte. This polarization voltage shift is to be determined by interrupting the protective current and measuring polarization decay. When the current is initially interrupted, an immediate voltage shift will occur. The voltage reading after the immediate shift shall be used as the base reading from which to measure polarization decay. (See precautionary notes in 6.3.2.3 and 6.3.2.4.)

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6.3.2.3 PRECAUTIONARY NOTE—Excessive Voltages: Notwithstanding the alternative minimum criteria in 6.3.2.1 and 6.3.2.2, aluminum, if cathodically protected at voltages more negative than −1.20 volts measured between the structure surface and a saturated copper-copper sulfate reference electrode contacting the electrolyte and compensated for the voltage (IR) drops other than those across the structure-electrolyte boundary, may suffer corrosion as the result of the build-up of alkali on the metal surface. A voltage more negative than −1.20 volts should not be used unless previous test results indicate no appreciable corrosion will occur in the particular environment.

6.3.2.4 PRECAUTIONARY NOTE—Alkaline Soil Conditions: Since aluminum may suffer from corrosion under high pH conditions and since application of cathodic protection tends to increase the pH at the metal surface, careful investigation or testing should be made before applying cathodic protection to stop pitting attack on aluminum structures in environments with a natural pH in excess of 8.0.

6.3.3 For copper structures:

6.3.3.1 A minimum negative (cathodic) polarization voltage shift of 100 millivolts measured between the structure surface and a stable reference electrode contacting the electrolyte. This polarization voltage shift is to be determined by interrupting the protective current and measuring the polarization decay. When the current is initially interrupted, an immediate voltage shift will occur. The voltage reading after the immediate shift shall be used as the base reading from which to measure polarization decay.

6.3.4 For dissimilar metal structures:

6.3.4.1 A negative (cathodic) voltage between all structure surfaces and a stable reference electrode contacting the electrolyte equal to that required for the most anodic metal should be maintained. Amphoteric materials which could be damaged by high alkalinity should be electrically isolated with insulating flanges or the equivalent (See precautionary notes 6.3.2.3 and 6.3.2.4).

6.4 Alternative Reference Electrodes

6.4.1 Other standard reference electrodes may be substituted for the saturated copper-copper sulfate reference electrodes. Two commonly used reference electrodes are listed below along with their voltage equivalent to −0.85 volt referred to a saturated copper-copper sulfate reference electrode:

6.4.1.1 Saturated KCl calomel reference electrode: −0.78 volt

6.4.1.2 Silver-silver chloride reference electrode used in sea water: −0.80 volt.

6.4.2 In addition to these standard reference electrodes, an alternative metallic material or structure may be used in place of the saturated copper-copper sulfate reference electrode if the stability of its electrode potential is assured and if its voltage equivalent referred to a saturated copper-copper sulfate reference electrode is established.

6.5 Special Considerations

6.5.1 Special cases such as those involving stray currents and stray electrical gradients may exist which require the use of criteria different from those listed above. Measurements of current loss and gain on the structure and current tracing in the electrolyte have been useful in such cases.

6.5.2 Abnormal conditions sometimes exist where protection is ineffective or only partially effective. Such conditions may include elevated temperatures, disbonded coatings, shielding, bacterial attack, and unusual contaminants in the electrolyte.

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7.1 Introduction

7.1.1 The purpose of this section is to recommend procedures for designing cathodic protection systems which will provide effective corrosion control by satisfying one or more of the criteria listed in Section 6, and which will exhibit maximum reliability over the intended operating life of the systems.

7.1.2 In the design of a cathodic protection system, the following items should be considered:

7.1.2.1 Recognition of hazardous conditions prevailing at the proposed installation site(s) and the selection and specification of materials and installation practices which will assure the safe installation and operation of the cathodic protection system.

7.1.2.2 Specification of materials and installation practices to conform with applicable codes, National Electrical Manufacturers Association (NEMA)[3] Standards, and Recommended Practices of the National Association of Corrosion Engineers.

7.1.2.3 Selection and design of the cathodic protection system for optimum economy of installation, maintenance, and operation.

7.1.2.4 Selection and specification of materials and installation practices which will assure dependable operation throughout the intended operating life of the cathodic protection system.

7.1.2.5 Selection of a system to minimize excessive protective currents or earth potential gradients, which can cause detrimental effects on pipe, coating, or neighboring buried or submerged metallic structures.

7.1.2.6 Direction of cooperative investigations to determine mutually satisfactory solution(s) of interference problems (See Section 9).

7.2 Major Objectives of Cathodic Protection System Design

7.2.1 Provide sufficient current to the structure to be protected and distribute this current so that the selected criteria for cathodic protection are efficiently attained.

7.2.2 Minimize the interference currents on neighboring underground structures (See Section 9).

7.2.3 Provide a design life of the anode system commensurate with the required life of the protected structure, or provide for periodic rehabilitation of the anode system.

7.2.4 Provide adequate allowance for anticipated changes in current requirements with time.

7.2.5 Place anodes where the possibility of disturbance or damage is minimal.

7.3 Information Useful for Design

7.3.1 Piping system specifications and practices

(a) Route maps and atlas sheets
(b) Construction dates
(c) Pipe, fittings, and other appurtenances
(d) Coatings
(e) Casings
(f) Corrosion control test stations
(g) Electrically insulating devices
(h) Electrical bonds
(i) Aerial, bridge, and underwater crossings

7.3.2 Piping system site conditions

(a) Existing and proposed cathodic protection systems
(b) Possible interference sources (see Section 9)
(c) Special environmental conditions
(d) Neighboring buried metallic structures (including location, ownership, and corrosion control practices)
(e) Structure accessibility
(f) Power availability
(g) Feasibility of electrical isolation from foreign structures

7.3.3 Field survey, corrosion test data, and operating experience.

(a) Protective current requirements to meet applicable criteria
(b) Electrical resistivity of the electrolyte
(c) Electrical continuity
(d) Electrical isolation
(e) Coating integrity
(f) Cumulative leak history
(g) Interference currents
(h) Deviation from construction specifications
(i) Other maintenance and operating data

7.3.4 Field survey work prior to actual application of cathodic protection is not always required if prior experience or test data is available to estimate current requirements, electrical resistivities of the electrolyte, and other design factors.

7.4 Types of Cathodic Protection Systems

7.4.1 Galvanic anode systems

7.4.1.1 Galvanic anodes can be of materials such as alloys of magnesium, zinc, or aluminum. These are installed in the soil or water, either bare or packaged in special backfill. The anodes are connected to the pipe, either singly or in groups. Galvanic anodes are limited in current output by the pipe-to-anode driving voltage and the earth resistivity. Cathodic protection of large bare or poorly coated piping may not be attainable by using galvanic anodes.

7.4.2 Impressed current anode systems

7.4.2.1 Impressed current anodes can be of materials such as graphite, high silicon cast iron, lead-silver alloy, platinum, or steel. These anodes are installed in the soil or water, either bare or in special backfill material. They are connected with an

[3]National Electrical Manufacturers Association (NEMA), 2101 L. St., N.W., Washington, DC 20037.

insulated conductor, either singly or in groups, to the positive terminal of a direct current source, such as a rectifier or generator. The pipeline is connected to the negative terminal of the direct current source.

7.5 Considerations Influencing Selection of the Type of Cathodic Protection System

7.5.1 Stray currents causing significant potential fluctuations between the pipeline and earth may preclude the use of galvanic anodes.

7.5.2 The effects of cathodic protection interference currents on adjacent structures may limit the use of impressed current cathodic protection systems.

7.5.3 The lack of a source of external power may preclude the use of an impressed current system.

7.5.4 On pipelines where stray currents are not present and where an external power source is available, the magnitude of protective current required is a dominant factor. The feasibility of protection with galvanic anodes can be established when current requirements, electrical resistivity of the electrolyte, and anode-to-pipe voltage have been reasonably estimated, calculated, or determined by field testing.

7.5.5 The physical space available, proximity of foreign structures, easement procurement, surface conditions, presence of streets and buildings, river crossings, and other construction and maintenance aspects should be considered.

7.5.6 Future development of the right-of-way area and future extensions to the pipeline system should be considered.

7.5.7 The costs of installation, operation, and maintenance.

7.6 Factors Determining Anode Current Output, Operating Life, and Efficiency

7.6.1 Various anode materials have different rates of deterioration when discharging a given current density from the anode surface in a specific environment. Therefore, for a given current output, the anode life will depend on the anode material as well as the anode weight and the number of anodes in the cathodic protection system. Established anode performance data may be used to calculate the probable deterioration rate.

7.6.2 Data on the dimensions, depth, and configuration of the anodes and electrolyte resistivities may be used to calculate the resultant resistance-to-electrolyte of the anode system. Formulas and graphs relating to these factors are available.

7.6.3 Proper design of a galvanic anode system must consider pipe-to-anode potential with resultant current output and, in special cases, anode lead wire resistance.

7.6.4 Where galvanic anodes are installed individually or in large numbers, there are many situations where it is impractical to individually design each installation. In such cases, the use of statistical techniques is suggested to determine the anode design that will best provide cathodic protection in a high percentage of installations. Sampling techniques can be used to establish the success of such anode designs as a percentage of the total installations.

7.6.5 Galvanic anode performance in most soils can be improved by using special backfill material. Mixtures of gypsum, bentonite, and salt cake (sodium sulfate) are most commonly used.

7.6.6 The number of impressed current anodes required can be reduced and their useful life lengthened by the use of special backfill around the anodes. The most common materials are coal coke, calcined petroleum coke, and natural or manufactured graphite.

7.6.7 In the design of an extensive distributed anode impressed current system, the voltage and current attenuation along the anode connecting wire should be considered. In such cases, the design objective is to optimize anode system length, anode spacing and size, and conductor size in order to achieve efficient corrosion control at the extremities of the protected structure.

7.6.8 Where it is anticipated that entrapment of gas generated by anodic reactions could impair the ability of the impressed current groundbed to deliver the required current, suitable provision should be made for venting the anodes. An increase in the number of anodes may reduce gas blockage.

7.6.9 Where it is anticipated that electro-osmotic effects could impair the ability of the impressed current groundbed to deliver the required current output, suitable provisions should be made to ensure adequate soil moisture around the anodes. Increasing the number of impressed current anodes may further reduce the electro-osmotic effect.

7.7 Design Drawings and Specifications

7.7.1 Suitable drawings should be prepared to designate the overall layout of the piping to be protected and the location of significant items of structure hardware, corrosion control test stations, electrical bonds, electrical insulators, and neighboring buried or submerged metallic structures.

7.7.2 Layout drawings should be prepared for each impressed current cathodic protection installation, showing the details and location of the components of the cathodic protection system with respect to the protected structure(s) and to major physical landmarks. These drawings should include right-of-way information.

7.7.3 The locations of galvanic anode installations should be recorded on drawings or in tabular form, with appropriate notes as to anode type, weight, spacing, depth, and backfill.

7.7.4 Specifications should be prepared for all materials and installation practices which are to be incorporated in construction of the cathodic protection system.

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Section 8: Installation of Cathodic Protection Systems

8.1 Introduction

8.1.1 The purpose of this section is to recommend procedures that will result in the installation of cathodic protection systems that achieve protection of the structure when design considerations recommended in Sections 4 and 7 have been followed.

8.2 Construction Specifications

8.2.1 All construction work on cathodic protection systems should be performed in accordance with construction drawings and specifications. The construction specifications should be in accordance with recommended practices in Sections 4 and 7.

8.3 Construction Supervision

8.3.1 All construction work on cathodic protection systems should be performed under the surveillance of trained and qualified personnel to verify that the installation is made in strict accord with the drawings and specifications. Exceptions may be made only with the approval of qualified personnel responsible for corrosion control.

8.3.2 All deviations from construction specifications should be noted on as-built drawings.

8.4 Galvanic Anodes

8.4.1 Inspection and handling

8.4.1.1 Packaged anodes should be inspected and steps taken to assure that backfill material completely surrounds the anode. The individual container for the backfill material and anode should be intact. If individually packaged anodes are supplied in waterproof containers, that container must be removed before installation. Packaged anodes should be kept dry during storage.

8.4.1.2 Lead wire must be securely connected to the anode. Lead wire should be inspected for assurance that it is not damaged.

8.4.1.3 Other galvanic anodes, such as unpackaged "bracelet" type or ribbon, should be inspected for assurance that dimensions conform to design specifications and that any damage during handling does not affect application. If a coating is used on bands and the inner side of "bracelet" anode segments, it should be inspected and, if damaged, repaired before the anodes are installed.

8.4.2 Installing Anodes

8.4.2.1 Anodes should be installed according to contruction specifications.

8.4.2.2 Packaged galvanic anodes should be backfilled with compacted native soil. Where anodes and special chemical backfill are provided separately, anodes should be centered in special backfill which should be compacted prior to backfilling with native soil. Care should be exercised so that lead wires and connections are not damaged during backfill operations. Sufficient slack should exist in lead wires to avoid strain.

8.4.2.3 Where anodes in bracelet form are used, pipe coating beneath the anode should be free of holidays. Care should be taken to prevent damage to the coating when installing bracelet anodes. After applications of concrete (if used) to pipe, all coating and concrete should be removed from anode surface. If reinforced concrete is used, there must be no metallic contact between anode and reinforcing mesh or between reinforcing mesh and pipe.

8.4.2.4 Where ribbon type anode is used, it can be trenched or plowed in, with or without special chemical backfill as specified, generally parallel to the section of pipeline to be protected.

8.5 Impressed Current Systems

8.5.1 Inspection and handling

8.5.1.1 The rectifier or other power source should be inspected for assurance that internal connections are mechanically secure and that no damage is apparent. Rating of the direct current power source should comply with construction specifications. Care should be exercised in handling and installing.

8.5.1.2 Impressed current anodes should be inspected for comformance to specifications concerning correct anode material and size, length of lead

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wire, and secure cap, if used. Care should be exercised to avoid cracking or damaging anodes during handling and installation.

8.5.1.3 Lead wire should be carefully inspected to detect defects in insulation. Care should be taken to avoid damage to insulation on wire. Defects in the lead wire must be repaired or the anode must be rejected.

8.5.1.4 Anode backfill material should conform to specifications.

8.5.2. Installation provisions

8.5.2.1 Rectifier or other power source should be installed so that the possibility of damage or vandalism is minimized.

8.5.2.2 Wiring to rectifiers shall comply with local and national electrical codes and requirements of utility supplying power. An external disconnect switch on AC wiring should be provided. Rectifier case shall be properly grounded.

8.5.2.3 On thermoelectric generators, a reverse current device should be installed to prevent galvanic action between anode bed and pipe if flame is extinguished.

8.5.2.4 Impressed current anodes can be buried vertically, horizontally, or in deep holes as indicated in construction specifications. Backfill material should be placed to assure that there are no voids around anodes. Care should be exercised during backfilling to avoid damage to the anode and wire.

8.5.2.5 The conductor (negative lead wire) to pipe should be connected as described in Section 8.6. Conductor connections to the rectifier must be mechanically secure and electrically conductive. Before the power source is energized, it must be verified that the negative conductor is connected to the structure to be protected and that the positive conductor is connected to the anodes. After the direct current power source has been energized, suitable measurements should be made to verify that these connections are correct.

8.5.2.6 Underground splices on header cable (positive lead wire) to groundbed should be kept to a minimum. Connections between header cable and conductors from anodes should be mechanically secure and electrically conductive. If buried or submerged, these connections must be sealed to prevent moisture penetration so that electrical isolation from the environment is assured.

8.5.2.7 Care must taken when installing direct burial cable to the anodes (positive lead wire) to avoid damage to insulation. Sufficient slack should be left to avoid strain on all wires. Backfill material around the cable should be free of rocks and foreign matter that might cause damage to the wire insulation when wire is installed in trench. Cable can be installed by plowing if proper precautions are taken.

8.5.2.8 If insulation integrity on the buried or submerged header cable (positive lead wire), including splices, is not maintained, this cable will fail from electrolytic corrosion.

8.6 Corrosion Control Test Stations, Connections, and Bonds (See Section 4.5)

8.6.1 Installation Provisions

8.6.1.1 Pipe and test lead wires should be clean, dry, and free of foreign materials at points of connection when the connections are made. Connections of test lead wires to pipe must be installed so they will remain mechanically secure and electrically conductive.

8.6.1.2 All test lead wire attachments and all bared test lead wires should be coated with an electrically insulating material. Where the pipe is coated, the insulating material should be compatible with the pipe coating and wire insulation.

8.6.1.3 Conductors should be color coded or otherwise permanently identified. Wire should be installed with slack. Damage to insulation should be avoided, but repairs should be made if damage occurs. Test leads should not be exposed to excessive heat and sunlight. Above ground test stations are preferred. If test stations are flush with the ground, adequate conductor slack should be provided within the test station to facilitate test connections.

8.6.1.4 Conductor connections at bonds to other structures or across insulating joints should be mechanically secure, electrically conductive, and suitably coated. Bond connections should be accessible for testing.

8.7 Other Considerations

8.7.1 Casing Installations

8.7.1.1 Sufficient inspection should be made to ensure that no metallic contacts exist or are likely to develop between casing and carrier pipe (See also Paragraphs 4.2.3, 4.2.4, and 10.7.7).

8.7.2 Insulating devices

8.7.2.1 Inspection and electrical measurements should assure that electrical isolation is adequate.

9.1 Introduction

9.1.1 The purpose of this section is to recommend practices for the detection and control of interference currents. The mechanism and detrimental effects are described.

9.2 Mechanism of Interference Current Corrosion (Stray Current Corrosion)

9.2.1 Interference current corrosion on buried or submerged metallic structures differs from other causes of corrosion damage in that the direct current, which causes the corrosion, has a source foreign to the affected structure. Usually the interfering current is collected from the electrolyte by the affected structure from a direct current source not metallically bonded to the affected structure.

9.2.1.1 Detrimental effects of interference currents usually occur at locations where the currents are discharged from the affected structure to the electrolyte.

9.2.1.2 Amphoteric metal structures such as aluminum and lead may be subject to corrosion damage from a build-up of alkalinity at or near the metal surface collecting interference currents.

9.2.1.3 Coatings may become disbonded at the area where voltage gradients in the electrolyte force current onto the affected structure. This interference effect, of itself, is not considered damaging to nonamphoteric metals. However, as the coating becomes disbonded, a larger area of metal will be exposed. This can increase the demand for cathodic protection current and may create shielding problems.

9.2.2 The severity of corrosion (metal loss) resulting from interference currents depends on several factors:

9.2.2.1 Separation and routing of the interfering and affected structures and location of the interfering current source.

9.2.2.2 Magnitude and density of the current.

9.2.2.3 Quality of the coating, or absence of a coating on the structures involved.

9.2.2.4 Presence and location of mechanical joints having high electrical resistance.

9.2.3 Sources of interference currents

9.2.3.1 Constant current: These sources have essentially constant direct current output, such as cathodic protection rectifiers and thermoelectric generators.

9.2.3.2 Fluctuating current: These sources have a fluctuating direct current output such as direct current electrified railway systems, coal mine haulage systems and pumps, welding machines, direct current power systems, and telluric currents.

9.3 Detection of Interference Currents

9.3.1 During corrosion control surveys, personnel should be alert for electrical or physical observations which could indicate interference from a neighboring source.

9.3.1.1 Structure-to-soil potential changes on the affected structure caused by the foreign direct current source.

9.3.1.2 Changes in the line current magnitude or direction caused by the foreign direct current source.

9.3.1.3 Localized pitting in areas near to or immediately adjacent to a foreign structure.

9.3.1.4 Breakdown of protective coatings in a localized area near an anode bed or near any other source of stray direct current.

9.3.2 In areas where interference currents are suspected, appropriate tests should be conducted. All affected parties shall be notified before tests are made for the purpose of establishing an interference bond. (Notification should be channeled through Corrosion Control Coordinating Committees, where they exist.) Any one or combination of the following test methods can be employed.

9.3.2.1 Measurement of structure-to-soil potentials with recording or indicating instruments.

9.3.2.2 Measurement of current flowing on the structure with indicating or recording instruments.

9.3.2.3 Development of Beta curves to locate area of maximum current discharge from the affected structure (See Apendix D).

9.3.2.4 Measurement of the variations in current output of the suspected source of interference current and correlations with measurements obtained in Paragraphs 9.3.2.1 and 9.3.2.2.

9.4 General Methods for Resolving Interference Corrosion Problems. (It should be understood that interference problems are individual in nature and the solution should be mutually satisfactory to the parties involved.)

9.4.1 Prevention of the pick-up or limitation of the flow of interfering current through a buried or submerged metallic structure.

9.4.2 Removal of the detrimental effects of interfering current from a buried metallic structure by means of a metallic conductor connected to the return (negative) side of the interfering current source.

9.4.2.1 Before bonds are installed, approval must be obtained from the affected parties.

9.4.3 Counteraction of the effect of interfering current by means of cathodic protection.

9.4.4 Removal or relocation of interfering current source.

9.5 Specific Methods of Resolving Interference Corrosion Problems. (These methods may be used individually or in combination.)

9.5.1 Design and installation of metallic bonds of proper resistance between the affected structures is a common technique for interference control. The metallic bond electrically conducts interference current from an affected structure to the interfering structure and/or current source.

9.5.1.1 Uni-directional control devices, such as diodes or reverse current switches, may be required in conjunction with metallic bonds if fluctuating currents are present. These devices prevent reversal of current flow.

9.5.1.2 A resistor may be necessary in the metallic bond circuit to control the flow of electrical current from the affected to the interfering structure. At the proper bond resistance, the discharge of interfering current from the structure to electrolyte is stopped.

9.5.1.3 If cathodic protection exists on the interfering structure, the attachment of metallic bonds can reduce the magnitude of protective voltage. Supplementary cathodic protection may then be required on the interfering structure to compensate for this effect.

9.5.1.4 A metallic bond may not perform properly in the case of a cathodically protected bare or poorly coated pipeline which is causing interference on a coated pipeline. A metallic bond may increase the current discharge. Coating the bare pipe or installing local galvanic anodes on the coated pipe may reduce the interference effects (See Paragraph 9.5.2).

9.5.2 Cathodic protection current can be applied to the affected structure at those locations where the interfering current is being discharged. This discharge will usually occur at locations where the structures are in close proximity. Anodes should be placed immediately adjacent to that portion of the affected structure that is discharging current.

9.5.2.1 The source of cathodic protection current may be galvanic or impressed current anodes.

9.5.2.2 The amount of cathodic protection current should be adjusted to restore either the original or protective potential level, whichever is less negative.

9.5.3 Adjustment of the current output from mutually interfering cathodic protection rectifiers may resolve interference problems.

9.5.4 Relocation of the groundbeds of cathodic protection rectifiers can reduce or eliminate the pick-up of interference current on nearby structures.

9.5.5 Rerouting of proposed pipelines may avoid sources of interference current.

9.5.6 Properly located insulating fittings in the affected structure may reduce or resolve interference problems.

9.5.7 Application of coating to strategic area(s) may reduce or resolve interference problems by decreasing the circuit conductance.

9.6 Indications of Resolved Interference Problems

9.6.1 Restoration of the structure-to-soil potentials on the affected structure to those values which existed prior to the interference.

9.6.2 Measurement of line currents on the affected structure to ensure that interference current is not being discharged to the electrolyte.

9.6.3 Adjustment of the slope of the Beta curve at the location of maximum exposure (See Appendix D).

9.6.4 Neutralization of interference current discharge may be observed by use of earth current measurement techniques applied in the soil electrolyte between the affected and interfering structures at the area of maximum current discharge (See Paragraph 6.3.1.5).

Section 10: Operation and Maintenance of Cathodic Protection Systems

10.1 Introduction

10.1.1 The purpose of this section is to recommend procedures and practices for energizing and maintaining continuous effective and efficient operation of cathodic protection systems.

10.1.1.1 Electrical measurements and inspection are necessary to determine that protection has been established according to applicable criteria and that each part of the cathodic protection system is operating properly. Conditions which affect protection are subject to change with time. Corresponding changes may be required in the cathodic protection system to maintain protection. Periodic measurements and inspection are necessary to detect changes in the cathodic protection system. Conditions may exist where operating experience indicates that testing and inspections need to be made more frequently than recommended herein.

10.1.1.2 Care should be exercised in selecting the location, number, and type of electrical measurements used to determine the adequacy of cathodic protection.

10.2 A survey should be conducted after each cathodic protection system is energized to determine if it satisfies applicable criteria and operates efficiently. This survey should include one or more of the following measurements:

(a) Pipe-to-soil potential (see Section 6.3)
(b) Earth current (see Section 6.3.1.5)
(c) Structure-to-structure potential (see Section 6.4.2)
(d) Line current (see Section 6.5.1)

10.3 Periodic tests to assure the continuity of cathodic protection are suggested as follows (The electrical measurements used in the tests may include one or more of the measurements listed in Section 10.2.):

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10.3.1 An annual survey should be conducted where cathodic protection of the entire piping system is the objective.

10.3.2 Surveys should be conducted at intervals of five years on structures where localized protection is the objective.

10.3.3 Where complete periodic surveys are impractical, tests should be made on a sampling basis consistent with accepted engineering principles.

10.4 Inspection and tests of cathodic protection facilities should be made to assure their proper operation and maintenance as follows:

10.4.1 All sources of impressed current should be checked at intervals of two months. Evidence of proper functioning may be current output, normal power consumption, a signal indicating normal operation, or satisfactory electrical state of the protected piping.

10.4.2 All impressed current protective facilities should be inspected annually as part of a preventive maintenance program to minimize in-service failure. Inspections may include a check for electrical shorts, ground connections, meter accuracy, efficiency, and circuit resistance.

10.4.3 Reverse current switches, diodes, and interference bonds, whose failure would jeopardize structure protection, should be inspected for proper functioning at intervals of two months.

10.4.4 The effectiveness of insulating fittings, continuity bonds, and casing insulators should be evaluated during the periodic surveys. This may be accomplished by on-site inspection or by evaluating corrosion test data.

10.5 Where pipe has been uncovered, it should be examined for evidence of corrosion and, if coated, for condition of the coating.

10.6 The test equipment used for obtaining each electrical value should be of an appropriate type. Instruments and related equipment should be maintained in good operating condition and checked annually for accuracy.

10.7 Remedial measures should be taken where periodic tests and inspections indicate that protection is no longer adequate according to applicable criteria. These measures may include the following:

10.7.1 Repair, replace, or adjust components of cathodic protection systems.

10.7.2 Provide supplementary facilities where additional protection is necessary.

10.7.3 Thoroughly clean and properly coat bare structures if required to attain cathodic protection.

10.7.4 Repair, replace, or adjust continuity and interference bonds.

10.7.5 Remove accidental metallic contacts.

10.7.6 Repair defective insulating devices.

10.7.7 Where shorted casings (metallic contact between casing and carrier pipe) cannot be repaired without removing the carrier pipe, the annular space can be filled with an inert material. Additional cathodic protection may be necessary to compensate for the shorted casing.

Section 11: Corrosion Control Records

11.1 Introduction

11.1.1 The purpose of this section is to describe corrosion control records which will document in a clear, concise, workable manner, data pertinent to the design, installation, operation, maintenance, and effectiveness of corrosion control measures.

11.2 Relative to the determination of the need for corrosion control, the following should be recorded:

11.2.1 Corrosion leaks, breaks, and replacements.

11.2.2 Pipe and coating condition observed when a buried structure is exposed.

11.3 Relative to structure design, the following should be recorded:

11.3.1 Coating material and application specifications.

11.3.2 Design and location of insulating devices, test leads and other test facilities, and details of other special corrosion control measures taken.

11.4 Relative to the design of corrosion control facilities, the following should be recorded:

11.4.1 Results of current requirement tests, where made.

11.4.2 Results of soil resistivity surveys at groundbed locations, where made.

11.4.3 Interference tests and design of interference bonds and drainage switch installations.

11.4.3.1 Scheduling of interference tests, correspondence with Coordinating Committees, including Coordinating Committee minutes, and direct communication with the concerned companies.

11.4.3.2 Record of interference tests conducted, including location of tests, name of company involved, and results.

11.5 Relative to the installation of corrosion control facilities, the following should be recorded:

11.5.1 Installation of cathodic protection facilities.

11.5.1.1 Impressed current systems
(a) Location and date placed in service.
(b) Type, size, depth, backfill, and spacing of anodes

(c) Specifications of rectifier or other energy source.

11.5.1.2 Galvanic anode systems

(a) Location and date placed in service.
(b) Type, size, backfill, and spacing of anodes.

11.5.2 Installation of interference bonds and drainage switches.

11.5.2.1 Details of interference bond installation

(a) Location and name of company involved.
(b) Resistance value or other pertinent information.
(c) Magnitude and polarity of drainage current.

11.5.2.2 Details of drainage switch installation

(a) Location and name of companies involved.
(b) Type switch or equivalent device.
(c) Data showing effective operating adjustment.

11.5.2.3 Details of other remedial measures

11.6 Record of surveys, inspection, and tests set forth in Sections 6, 7, 9, and 10 should be maintained to demonstrate that applicable criteria for interference control and cathodic protection have been satisfied.

11.7 Relative to the maintenance of corrosion control facilities, the following information should be recorded:

11.7.1 Maintenance of cathodic protection facilities.

11.7.1.1 Repair of rectifiers and other dc power sources.

11.7.1.2 Repair or replacement of anodes, connections, and cable.

11.7.2 Maintenance of interference bonds and drainage switches.

11.7.2.1 Repair of interference bonds.

11.7.2.2 Repair of drainage switches or equivalent devices.

11.7.3 Maintenance, repair, and replacement of coating, insulating devices, test leads, and other test facilities.

11.8 Records sufficient to demonstrate the evaluation of the need for and the effectiveness of corrosion control measures should be maintained as long as the facility involved remains in service. Other related corrosion control records should be retained for such period as satisfies individual company needs.

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TABLE 1 — Index of Coating References

Reference Number		Title	Source[1]
1	a	Standard for Coal-Tar Protective Coatings and Linings for Steel Water Pipelines—Enamel and Tape—Hot-Applied AWWA C203-78	AWWA Standards Committee on Steel Pipe
	b	Tentative Recommended Specifications and Practices for Coal Tar Coatings for Underground Use	NACE 2G156
	c	Synthetic Resin Primer for Coal-Tar Enamel, Research Report No. 8, U.S. Dept. of the Interior, Bureau of Reclamation	U.S. Govt. Printing Office
	d	Specification for Bituminous Saturated Glass Pipe Wrap	NACE 2J162
	e	Proposed Standard for 3/16-inch Thick Pipeline Padding	NACE 2J164
	f	Specifications for Fibrous Glass, Reinforced Type Underground Pipe Wrap	NACE 2J262
	g	Specifications for Asbestos Pipeline Felt	NACE 2J362
2	a	Extruded Asphalt Mastic Type Protective Coatings for Underground Pipelines	NACE RP-02-76
	b	Tentative Recommendations for Asphalt Type Protective Coating for Underground Pipeline—Wrapped Systems	NACE 2H157
	c	Asphalt Protective Coatings for Pipelines—Construction Series No. 7—Wrapped and Mastic Systems	The Asphalt Institute
	d	Tentative Recommended Specifications for Asphalt-Type Protective Coatings for Underground Pipeline	NACE 2H158
	e	For appropriate pipe wraps, refer to 1d, e, f, and g above	NACE
3	a	Application and Handling of Wax-Type Protective Coatings and Wrapper Systems for Underground Pipelines	NACE RP-03-75
	b	For appropriate pipe wraps, refer to 1d, e, f, and g above	NACE
4	a	Material Requirements in Prefabricated Plastic Films for Pipeline Coatings	NACE MR-02-74
	b	For appropriate pipe wraps, refer to 1d, e, and g above	NACE
5	a	Control of Pipeline Corrosion, A. W. Peabody, Dec., 1967, pp. 9-18.	NACE
	b	Application of Organic Coatings to the External Surface of Steel Pipe for Underground Service	NACE RP-02-75
	c	NACE Task Group T-10D-10 (Fusion Bonded Thin Film Coatings MR)	NACE
	d	Standard for Fusion-Bonded Epoxy Coatings for the Interior and Exterior of Steel Water Pipelines AWWA C213-79	AWWA Standards Committee on Steel Pipe
	e	Specifications, Mill Applied Fusion Bonded Epoxy Coatings NAPCA Bulletin 12-78, April 11, 1979	National Association of Pipe Coating Applicators
6	a	Methods for Measuring Leakage Conductance of Coating on Buried or Submerged Pipelines	NACE 2D157[2]
	b	High Voltage Electrical Inspection of Pipeline Coatings Prior to Installation	NACE RP-02-74
7		"Underground Corrosion," Nat. Bureau of Standards, Circular 579, April, 1957, pp. 180-186	National Technical Information Service

[2]No longer available from NACE.

TABLE 1 — Index of Coatings References (continued)

Reference Number		Title	Source[1]
8		Standard Method for Nondestructive Measurement of Film Thickness of Pipeline Coatings on Steel	ASTM G12-77
9	a	Standard Test Method for Cathodic Disbonding of Pipeline Coatings	ASTM G8-79
	b	Standard Test Method for Disbonding Characteristics of Pipeline Coatings by Direct Soil Burial	ASTM G19-77
	c	Method for Cathodic Disbonding of Pipeline Coatings Subjected to Elevated or Cyclic Temperatures	ASTM G42-80
10		Standard Test Method for Water Penetration into Pipeline Coatings	ASTM G9-77
11	a	Standard Test Method for Rockwell Hardness of Plastics and Electrical Insulating Materials	ASTM D785-65 (1981)
	b	Standard Test Method for Penetration of Bituminous Materials	ASTM D5-73 (1978)
	c	Standard Test Method for Penetration Resistance of Pipeline Coatings (Blunt Rod)	ASTM G17-77
	d	Standard Test Method for Rubber Property-Durometer Hardness	ASTM D2240-81
12	a	"Underground Corrosion," National Bureau of Standards Circular 579, April 1957, pp. 134-135 (Out of print, but reproduced as PB-168350 Underground Corrosion)	National Technical Information Service
	b	Standard Test Method for Shrinkage Factor of Soils	ASTM D427-61 (1974)
13	a	Standard Test Method for Resistance of Plastics to Chemical Reagents	ASTM D543-67 (1968)
	b	Test Method for Resistance of Plastics to Chemical Reagents, Federal Test Standard No. 406 Method 7011	General Services Administration
	c	Standard Test Method for Chemical Resistance of Pipeline Coatings	ASTM G20-77
14	a	Standard Method for Thermal Evaluation of Rigid Electrical Insulating Materials	ASTM D2304-79
	b	Standard Recommended Practice for Determining the Effect of Overbaking on Organic Coatings	ASTM D2454-79
	c	Standard Test Method for Coatings Designed to be Resistant to Elevated Temperatures During Their Service Life	ASTM D2485-68 (1973)
15	a	Standard Recommended Practice for Determining Resistance of Synthetic Polymeric Materials to Fungi	ASTM G21-70 (1980)
	b	Test Method for Mildew Resistance of Plastics by Mixed Culture Method, Agar Medium, Federal Test Standard No. 406, Method 6091	General Services Administration
	c	Military Specification and Test Method for Fungus Resistance, MIL-F-8261A (USAF)	U.S. Naval Publication
16		Standard Test Method for Effects of Outdoor Weathering on Pipeline Coatings	ASTM G11-79

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TABLE 1 — Index of Coatings References (continued)

Reference Number		Title	Source[1]
17		Standard Test Method for Abrasion Resistance of Pipeline Coatings (Rolling Drum Method)	ASTM G6-77
18		Standard Test Method for Bendability of Pipeline Coatings	ASTM G10-77
19		Standard Test Method for Adhesion of Organic Coatings	ASTM D2197-68 (1979)
20	a	Standard Test Method for Impact Resistance of Pipeline Coatings (Limestone Drop Test)	ASTM G13-77
	b	Standard Test Method for Impact Resistance of Pipeline Coatings (Falling Weight Test)	ASTM G14-77
21	a	Standard Test Methods for Joints, Fittings, and Patches in Coated Pipelines	ASTM G18-77
	b	Standard Method for Pipeline Coatings and Patch Materials Evaluating	ASTM G55-77

[1]Addresses of Sources:

American Society for Testing & Materials (ASTM), 1916 Race St., Philadelphia, PA 19103
American Water Works Association (AWWA), 2 Park Avenue, New York, NY 10016
Asphalt Institute, Asphalt Institute Bldg., College Park, MD 10740
National Technical Information Service (NTIS), Springfield, VA 22161
General Services Administration, Business Service Center, Washington, DC 20025
National Association of Corrosion Engineers (NACE), P.O. Box 218340, Houston, TX 77218
U.S. Government Printing Office, Washington, DC 20420
U.S. Naval Publications and Forms Center, 5801 Tabor Road, Philadelphia, PA 19120

TABLE 2 — Generic Coating Systems With Material Requirements and Recommended Practice for Application

(NOTE: Many other references are available and this table is not comprehensive. Listing does not constitute endorsement of any coating system in preference to another. Omission of a system may be due to unavailability of reference standards or lack of data).

Item No.	Generic Coating System	Reference No. (See Table 1)
1	Coal Tar	1
2	Asphalt	2
3	Wax	3
4	Prefabricated Films	4
5	Fusion Bonded Coatings	5

TABLE 3 — Reference for General Use in the Installation and Inspection of Coating Systems for Underground Piping

Item No.	Reference	Reference No. (See Table 1)
1	Application of Organic Pipeline Coatings	5
2	Film Thickness of Pipeline Coatings	8
3	Inspection of Pipeline Coatings	6

TABLE 4 — Coating System Characteristics Relative to Environmental Conditions

(NOTE: Apply only those factors pertinent to the installation.)

Item No.	Environmental Factor	Recommended Test Methods[1] (See Table 1 for Reference)
1	General Underground Exposure with or without Cathodic Protection	9
2	Resistance to Water Penetration and its Effect on Choice of Coating Thickness	10
3	Resistance to Penetration by Stones in Backfill	11,20
4	Soil Stress	12
5	Resistance to Specific Liquids not Normally Encountered in Virgin Soil	13
6	Resistance to Thermal Effects	14
7	Suitability of Supplementary Materials for Joint Coating nd Field Repairs	9,10,21
8	Resistance to Microorganisms	15

[1]No specific criteria are available. Comparative tests are recommended subject to evaluation as supplementary information only.

TABLE 5 — Coating System Characteristics Related to Design and Construction

Item No.	Design and Construction Factor	Recommended Test Methods[1] (See Table 1 for Reference)
1	Yard Storage, Weathering	16
2	Yard Storage, Penetration Under Load	11
3	Handling Resistance, Abrasion	17
4	Handling Resistance, Impact	20
5	Field Bending Ability	18
6	Driving Ability (Resistance to Sliding Abrasion)	17,19
7	Special Requirements for Mill-Applied Coating	1,2,3,4,5
8	Special Requirements for Application of Coating Over the Ditch	1,2,3,4,5
9	Backfill Resistance	20
10	Resistance to Thermal Effects	9,14
11	Suitability of Joint Coatings and Field Repairs	9,10,21

[1]No specific criteria are available. Comparative tests are recommended subject to evaluation on basis of any tolerable compensating measures that may be required.

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TABLE 6 — Methods for Evaluating In-Service Field Performance of Coatings

Item No.	Title or Subject of Method	Ref. No. (See Table 1)	Criteria or Basis for Rating
1	Measuring Leakage Conductance of Pipeline Coatings	6	Comparison of Initial Measurements with Subsequent Periodic Measurements
2	Rate of Change in Current Required for Cathodic Protection	7	Comparison of Initial Current Requirement with Subsequent Periodic Determination of Current Requirement
3	Inspection of Pipeline Coating	6	a. With Cathodic Protection: No active corrosion found b. Without Cathodic Protection: No new holidays showing active corrosion
4	Cathodic Disbondment	9	Purpose is to Obtain Data Relative to Specific Conditions for Comparison with Laboratory Data

Appendix A

Method for Determining Probable Corrosion Rate and Costs of Maintaining Service

Maintenance of a piping system may include repairing corrosion leaks and reconditioning or replacing all or portions of the system.

In order to make estimates of the costs involved, it is necessary to determine the probability of corrosion or the rate at which corrosion is proceeding. The usual methods used in predicting the probability or rate of corrosion are as follows:

(a) Study of corrosion history on the piping system in question or on other systems of the same material in the same general area or in similar environments. Cumulative leak frequency curves are valuable in this respect.

(b) Study of the environment surrounding a piping system: resistivity, pH, and composition. Redox potential tests may also be used to a limited extent. Once the nature of the environment has been determined, the probable corrosiveness is estimated by reference to actual corrosion experience on similar metallic structures where environmental conditions are similar. Consideration should be included in such a study of possible environmental changes such as might result from irrigation, spillage of corrosive substances, pollution, and seasonal changes in soil moisture content.

(c) Investigation for corrosion on a piping system by visual inspection of the pipe and/or by instruments which mechanically or electrically inspect the condition of the pipe. Condition of the piping system should be carefully determined and recorded each time a portion of the line is excavated for any purpose.

(d) Maintenance records detailing leak locations, soil studies, structure-to-soil-potential surveys, surface potential surveys, line current studies, and wall thickness surveys, used as a guide for locating areas of maximum corrosion.

(e) Statistical treatment of available data.

(f) Results of pressure testing. Under certain conditions, this may help to determine the existence of corrosion.

Appendix B

Contingent Costs of Corrosion

In addition to the direct costs that result from corrosion, contingent costs include:

(a) Public liability claims.
(b) Property damage claims.
(c) Damage to natural facilities, such as municipal or irrigation water supplies, forests, parks, and scenic areas.
(d) Clean up of product lost to surroundings.
(e) Plant shut-down and start-up costs.
(f) Cost of lost product.
(g) Loss of revenue through interruption of service.
(h) Loss of contract or goodwill through interruption of service.
(i) Loss of reclaim or salvage value of piping system.

Appendix C

Costs of Corrosion Control

The usual costs for protecting buried or submerged metallic structures are for complete or partial cathodic protection or for coatings supplemented with cathodic protection. Other corrosion control costs include:

(a) Relocation of piping to avoid known corrosive conditions. This may include installing lines above ground.
(b) Reconditioning and coating the piping system.
(c) Use of corrosion resistant materials.
(d) Use of selected or inhibited backfill.
(e) Electrical isolation to limit possible galvanic action.
(f) Correction of conditions in or on the pipe that might accelerate corrosion.

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Appendix D

A Beta Curve is a plot of dynamic (fluctuating) interference current or related proportional voltage (ordinate axis), versus values of correlating structure-to-soil potentials at a selected location on the affected structure (abscissa axis). If the correlation is reasonably linear, the plot will indicate whether the affected strucuture is receiving or discharging current at the location where the structure-to-soil potential was measured. Dynamic interference investigation involves many Beta Curve plots to search for the point of maximum interference current discharge. Interference is resolved when the correlation of maximum current discharge has been changed to a correlation which shows that current pickup is being achieved in the exposure area by the corrective measures taken. These corrective measures may be accomplished by metallic bonding or other interference control techniques.

For more information on the field techniques commonly used, refer to NACE Publication 56-12 "Contributions of J. M. Pearson to Mitigation of Underground Corrosion."

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HIGH CAPACITY ALUMINUM ALLOY CATHODIC PROTECTION SYSTEM

Wilson Walton International

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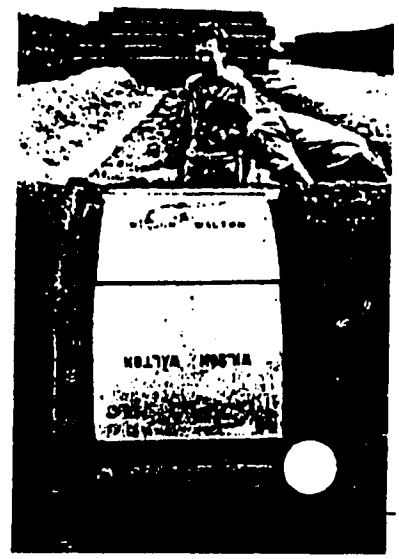
Wilson Walton Aloline anodes are produced from patented aluminum alloys originally developed in Great Britain and now available in the United States for the first time. Suitably formulated for specific applications, they are characterized by light weight, smooth corrosion pattern, high electrical capacity and stability. Compared to other materials substantially lower costs are achieved on each system installed since fewer anodes are needed.

Casting an Aloline aluminum anode at a Wilson Walton foundry

Three different alloy formulations specially designed for different applications are available. BA777 and BA780 are Al/In/Zn/Mg compositions for use in seawater of differing characteristics while BA778 is free from Mg and contains Bismuth and other additions. BA778 is specifically designed for use in ships' tanks and has been found to be the most reliable anode material available for use in hot saline mud. This characteristic makes BA778 a suitable material for bracelet anodes applied to offshore pipelines.

Aloline anodes are cast in alloys of aluminum and indium plus other materials that have been developed specifically for use in seawater. These substances are very stable in driving potential and efficiency, even in electrolytes of varying conductivity and temperature. In normal seawater having resistivity of about 25 ohms cms, approximately 1225 ampere hours of current are provided by each pound of alloy which will maintain a potential of – 1170 mV when measured against a copper/copper sulphate reference half cell. These alloys have a higher driving potential than zinc or aluminum/mercury alloys which are common in use for cathodic protection purposes and operate successfully in very cold seawater and at great depths.

Wilson Walton International specializes in designing and producing anodes to meet any individual requirement making their own molds to do so. The optimum solution to each problem and the total control over the quality of the finished anode is thus ensured.



Aloline anodes are suitable for a wide variety of applications, including the hulls and tanks of ships, fixed offshore structures, semi-submersibles, pipelines and jetties.

esigned specifically for optimum performance under a variety of nvironmental conditions which operate effectively at both low and gh temperatures. They employ a range of alloy compositions suited meet specific application requirements which are performance oven with over 20 years of application and research testing.

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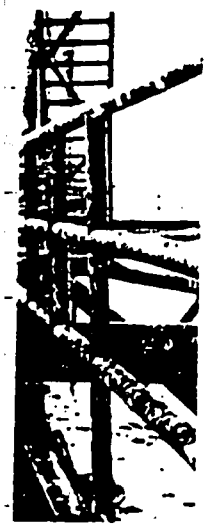

A remote potential monitoring system in use offshore

Aloline retrofit bracelet anode for a tubular leg on an offshore structure

An Aloline segmented shell bracelet anode fitted to a submarine pipeline

Available as cast or flexible extrusions in a variety of shapes and sizes, lightweight Aloline fittings provide a number of important benefits to the user:

- Reduce repair costs
- Reduce construction costs (reduced scantlings)
- Increase structure life
- Eliminates costs for shot-blasting and ineffective coatings
- Eliminates corrosion of steel in inaccessible areas
- Maintains higher resale values

ALOLINE® composition

	BA777 %	BA778 %	BA780 %
Copper	0.01 max	0.01 max	0.01 max
Magnesium	0.50 — 0.90	—	1.20 — 2.00
Silicon	0.05 — 0.20	0.05 — 0.20	0.05 — 0.20
Iron	0.05 — 0.15	0.05 — 0.15	0.05 — 0.15
Zinc	3.5 — 5.0	3.5 — 5.0	3.5 — 5.0
Titanium	0.01 — 0.05	0.01 — 0.05	0.01 — 0.05
Bismuth	0.01 max	0.05 — 0.15	0.01 max
Indium	0.020—0.050	0.020—0.050	0.020—0.050
Aluminum	Remainder	Remainder	Remainder
Electrical Capacity	1225 amp hrs/lb.	1225 amp hrs/lb.	1225 amp hrs/lb.
Solution Potential	— 1150 mV copper/ copper sulphate reference cell	— 1100 mV copper/ copper sulphate reference cell	— 1170 mV copper/ copper sulphate reference cell

Developed in conjunction with the British Aluminum Company and first introduced in 1969 as a general purpose aluminum alloy conforming to the specification above. Its current use is to protect fixed jetty and external marine applications, in particular where the environment is in the temperature range of 50 - 86°F.

Designed to replace BA777 for the protection of cargo ballast tanks in ships. This alloy, magnesium free, has undergone further research to confirm its suitability for protecting buried pipelines at elevated temperatures in the range of 122 - 212°F.

An extension of BA777 was specifically developed to improve the electrochemical properties when operating at North Sea temperatures of 39°F and under pressures equivalent to 300 p.s.i.

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Corrosion control
Sacrificial anode systems
Aloline . . . Zincoline . . .

Impressed current systems
Aquamatic systems for the protection of ships' hulls and cooling water systems

Industrial cathodic protection systems
Offshore well head and production platforms, tank bottoms, buried pipelines, submarine pipelines, well casings, seawater cooling systems, water storage tanks, jetties

Descaling
Electroline descaling systems

Tanker safety
Wilson Walton International inert gas systems
Martin Hi-Jet inert gas venting systems

Anti-pollution equipment
Elsan marine sewage systems
Heishin oily/water separators
Incymar marine incinerators

Ancillary services to ship owners
Cathometer – Portable corrosion control indicator
Ultrasonic nondestructive thickness measurements
Plugaline – Spurling pipe sealant

Australia	Melbourne Wilson Walton International (Pty) Limited
Benelux	Barendrecht BV Materiaal Metingen (Wilson Walton International)
Curacao	Willamstad Materiaal Metingen Caribbean (Wilson Walton International)
France	Gentilly Wilson Walton International S.A.F.
Greece	Piraeus Wilson Walton International
Italy	Genoa Wilson Walton International SpA Italiana
Japan	Tokyo Wilson Walton International
Norway	Uskedalen Wilson Walton International A/S
Portugal	Lisbon Catonave - Proteccao Catodica LDA
Singapore	Wilson Walton Eastern PTE Ltd.
Spain	Madrid Wilson Walton International SA Espanola
UK	Croydon Wilson Walton International Limited Stockton on Tees Technometal (N.E.) Ltd.
USA	Wilson Walton International Inc. Hoboken, New Jersey Houston, Texas Kenner, Louisiana

P.O. Box M-890 • 66 Hudson Street • Hoboken, New Jersey 07030
Telephone: (201) 795-2044 • (212) 227-6657 • Telex: 125919 • Cable: WAZEDENS

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APPENDIX D

FENDERING

CALCULATIONS
BROCHURE

Parsons Brinckerhoff Computation Sheet

Subject: Port of Kismayo
New Fendering System

Page 6 of 9
Made by: N. Secker
Date: 1-13-84
Checked by:
Date:

Berthing Energy

Design ship $W' = 10{,}000$ DWT, 13300 Displacement Ton

$L = 150\ m = 492\ ft$

Draft $= 8.3\ m = 27.2'$

W = Virtual Weight = 13300 Ton (W') + 7900 Ton (W'' = add'l weight) (col. of water) = 21,200 Ton

$V = 0.1\ m/sec$

Seibu's Monograph for W = 21200T & V = 10cm/sec

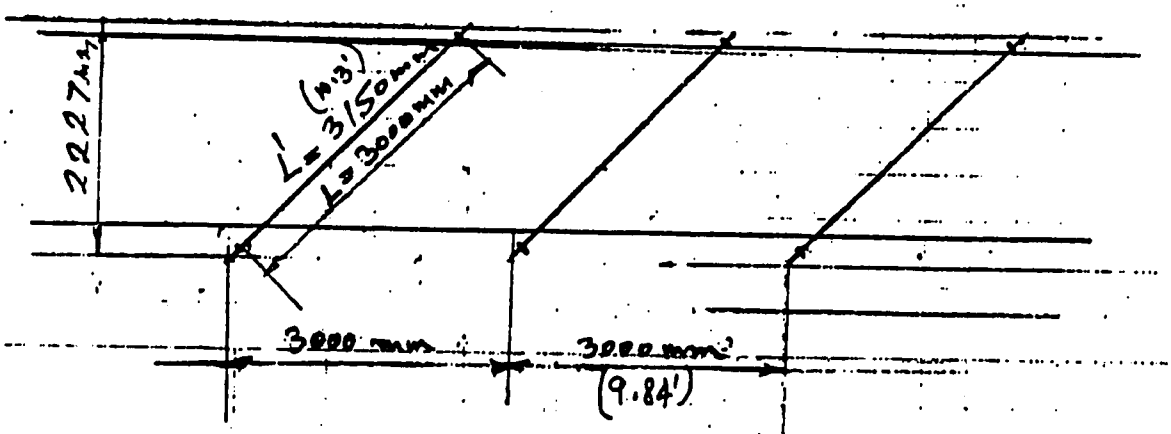
$E = 40$ ft·kip $= 5.47$ t·m

Statistical Method for W' 10000 DWT & V = 10cm/sec

$E = 7^{IK} / 1000$ DWT

$E = \frac{10000}{1000} \times 7^{IK} = 70$ ft·kips $> 40^{IK}$

USE $E = 70^{IK}$ for design purposes



Assume 2 Fenders (spaced 13m o.c) absorb the Energy

Subject Port of Kismayo
New Fendering System

Rubber Fenders

USING LORD'S SUPE-ARCH Marine Fender (FV004)

H = 300 mm Width = 600 mm L = 3000 mm

and using next to the softest rubber FV000-0-3 (Hull pressure < 18 kips/ft²)

USE FV 004-5-3 spaced @ 3000 mm

Energy absorbing capacity = 2 fenders × 36.2 IK = 72.4 IK > 70 IK

Reative Force = 2 × 112.4 K = 224.8 K

Spacing of Fenders

Assume Radius of hull = 80' (small boats)

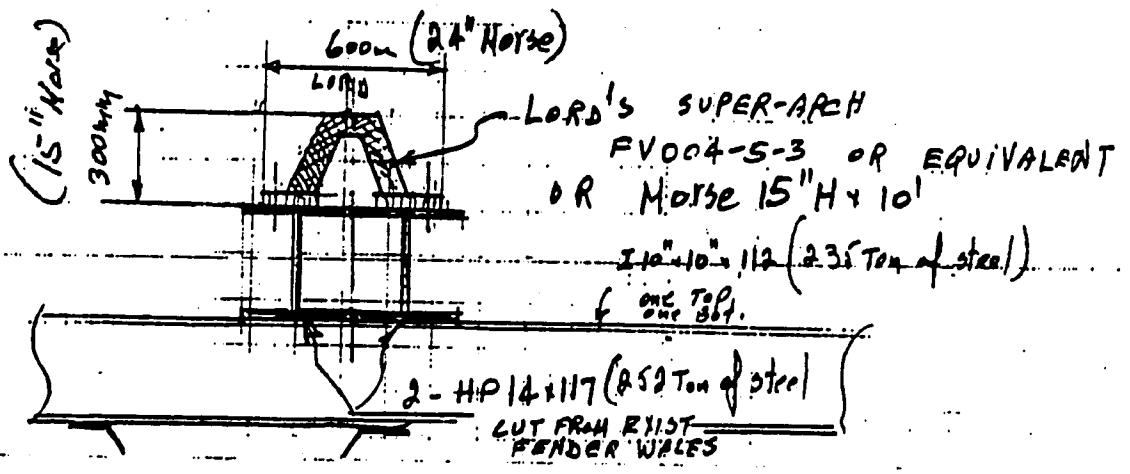
max spacing for FV 004 = 17' = 5.18 m

USE 3 m spacing < 5.18 m o.k

Force on Bulkhead

R = Force = 224.8 K on an bulkhead face area = 6 m × 2.23 m

Avarage pressure on bulkhead = $\frac{224.8}{6 \times 2.22 \times 3.28^2}$ = 1.57 KSF



Best Available Document

Parsons Brinckerhoff Computation Sheet

Subject: Port of Kismayo
New Fendering system
Description of Alternates

Page 3 of 9
Made by: N. Seeker
Date: 1-13-84
Checked by:
Date:

Fendering System Alternates (see attached sketches)

Alternate I

Reinstalling existing fendering system at new location, incl. replacing missing or damaged steel and rubber
Cost based on Preliminary Design Report

Alternate II

Removing existing fendering, discarding the rubber, using part of existing steel piling (1H 10"x10"x112#) as 2 rows of continous wales attached to the new sheetpiles, attaching cut up pieces of the existing wales (H 14"x14½"x117#) as diagonally mounting pieces, a pair of H14, 11' long for each.
rubber fender super arch 300H, L=3000mm @ 3m o.c
by Lord or 15"H L=10' @ 10' o.c By Norse 15"H x 10' Long @ 10'
Existing steel to be reused

H 10"x10"x112# – 2 x 2100' x 112# = 470,400#
H 14"x14½"x117# – 2 x 2100'/9.84' x 11' x 117# = 550,800#
} 511 Ton

cutting, retrofitting of existing steel $400/T Labor + $200 Material

New 15" x 10' long V section rubber

Fenders	215 pieces	@ $1070 =	230,000	Installation say $800/piece
shipping	215	@ 400 =	86,000	
Hardware	215	@ 350 =	75,000	
Total	215	@ 1820 =	$391,000	

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Best Available Document

Subject Port of Kismayo
New Fendering System
Description of Alternates (Continued)

Alternate III

same as alternate II except mounting piece attached directly to sheetpiling without use of wales

Existing steel to be reused (H 14"x14½"x117#) = 550,800# = 275 Ton

Alternate IV

Removing Existing Fenders and discard steel & rubber. Extending concrete cap Beam/Facia to below MLW attaching new rubber Fenders (24" OD Tube) (12" ID) 10' long @10' o.c. by a chain directly to the concrete.

Additional concrete $9'' + \frac{16''}{2} = 17''$ thick for PZ40
$9'' + \frac{15}{2} = 16.5''$ thick for PZ35
$9'' + \frac{12}{2} = 15''$ thick for PZ38
} USE 16" AVARAGE

$12.3' \times 1.33' \times 2890' \times \frac{1}{27} = 1588$ CY

Labor $205/cy (from Preliminary Design Report) Material & Equipment $221/cy

Fenders	215 pieces	@ 1473 =	$317,000
Shipping	215	@ 400 =	86,000
Hardware	215	@ 400 =	86,000
	215 pieces	@ 2273 =	$489,000

Installation say $300 a piece

Alternate V

Removing existing fender and discarding steel & rubber attach new Seaguard floating fenders 3'φ x 10' long at 30' o.c (Foam filled, fillament wound urethane outer skin), attached by long chains directly to the steel Bulkhead.

Fenders	72 pieces	@ 4750 =	$342,000
Hardware	72	@ 350 =	25,000
Shipping	72	@ 400 =	29,000
	72 pieces	@ 5500 =	$396,000

Allow $300 for installation

Alternate VI

Similiar to Alternate II except, attaching 3 lines of Wales (from existing H 10 piles) to the sheetpiling, The lower two replace to 2-C12 which anchor the tie rods to the sheetpiles.

Add Additional existing steel to be used = $\frac{2100' \times 112^{\#}}{2000}$ = 118 Ton
@ 200/Ton material and 440/Ton Labor

Deduct 2 - C12x25 x 2100 Long = $\frac{2 \times 2100 \times 25}{2000}$ = 53 Ton
@ $1229/Ton material + 357 labor
(2195 - 1.25 x 773) = 1229

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Parsons Brinckerhoff Computation Sheet

Subject: Port of Kismayo
New Fendering System
Costing of Different Alternates

Page 6 of 9
Made by: N. Seckri
Date: 1-13-84
Rev. 1/23/84
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Date:

Cost Estimate

Existing Fendering System

Piles	186 piles × 74' × 112#/'	=	1,541,600#	(68.2%)
Wales	2 × 2100' × 117#/'	=	491,400	(21.8%)
Mounting Pieces	176 × 11' × 117#/'	=	226,500	(10.0%)
Total Tonnage		=	2,259,500#	= 1130 Ton

Alternate I (From Preliminary Design Report)

	Labor	Material + Equip.	Total
1) Remove Existing Fendering	174,000	111,000	285,000
2) Restore & Replace (100 Ton)	43,000	152,000	195,000
3) Reinstall	235,000	137,000	372,000
Total	$452,000	$400,000	$852,000

Alternate II

	LABOUR	MATERIALS/EQUIP.	TOTAL
1. Remove Existing Fendering (same as Alternate I)	174,000	111,000	285,000
2. Cut exist. steel & Attach to bulkhead (511 Ton of steel - 8400/Ton Labor, 200/Ton Material)	204,000	102,000	306,000
3. Supply & install new, fender rubber (215 pieces @ 1880 material; 8200 piece Labor)	43,000	391,000	434,000
TOTAL	421,000	604,000	$1,025,000

Parsons Brinckerhoff **Computation Sheet**

Subject: Port of Kismayo
New Fendering System
Costing of Different Alternates (Contin.)

Page 7 of 9
Made by: D. Seckel
Date: 1-13-84
Checked by: Rev. 1/23/83
Date:

Alternate III

	Labor	Material + Equip	Total
1. Remove Existing Fendering (Same as Alternate I)	174,000	111,000	285,000
2. Cut Existing Steel & Attach to Bkhd (275 Ton, $400/ton Labor + $200/Ton Mat'l)	110,000	55,000	165,000
3. Supply & Instal new rubber fenders (Same as alternate II)	43,000	391,000	434,000
	327,000	557,000	$ 884,000

Alternate IV

	Labor	Material + Equip	Total
1. Remove Existing Fendering (Same a Alternate I)	174,000	111,000	285,000
2. Addition Concrete Facia (1338 cy @ $205 labor + 221 Material)	274,000	296,000	570,000
3. Supply & Install new Rubber Fenders & Hardware (215 pieces @ $273 material + $300 labor/piece)	65,000	489,000	554,000
TOTAL	513,000	896,000	$ 1,409,000

Parsons Brinckerhoff Computation Sheet

Subject: Port of Kismayo
New Fendering System
Costing of Different Alternates (Contin.)

Page 8 of 9
Made by: N. Seckel
Date: 1-13-82
Checked by: Rev. 1/23/82
Date:

Alternate V

	Labor	Material & Equip.	Total
1. Remove Existing Fendering (Same as Alternate I)	174,000	111,000	285,000
2. Supply & install new floating fenders (72 pieces @ 5500 material + $300 labor/piece)	22,000	396,000	418,000
Total	196,000	507,000	$703,000

Alternate VI

	Labor	Material + Equip.	Total
1. Remove Existing Fendering (Same a Alternate I)	174,000	111,000	285,000
2. Cut existing steel & attach to Bulkhead (511+118) = 629 Ton @ 400/Ton Lab + $200/Ton Material)	252,000	126,000	378,000
3. Supply & Install new rubber fender (215 pieces @ 1820 + $200/piece Labor)	43,000	391,000	434,000
4. Deduct (2-C12x25 Wales x 2100' long = 53 Ton $357/Ton labor + $1229 Ton/material)	(19,000)	(65,000)	(84,000)
Total	450,000	563,000	$1,013,000

Parsons Brinckerhoff **Computation Sheet**

Subject: Port of Kismayo
New Fendering System
Costing of Different Alternates (Contin.)

Page 9 of 9
Made by: N. Seckel
Date: 1-13-84
Checked by: Rev. 1/23/84
Date:

FENDERING SYSTEMS COST ESTIMATE

SUMMARY

SCHEME	COST US $		
	LABOUR	MATERIAL & EQUIP	TOTAL
ALT I	452,000	400,000	852,000
ALT II	421,000	604,000	1,025,000
ALT III	327,000	557,000	884,000
ALT IV	513,000	896,000	1,409,000
ALT V	196,000	507,000	703,000
ALT VI	450,000	563,000	1,013,000

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Parsons Brinckerhoff

COST ESTIMATE ANALYSIS

FENDER SYSTEM

Date 5/6/83 Modified 1/23/84

Sheet P15 of P 24

PROJECT PORT OF KISMAYO REHABILITATION

LOCATION SOMALI DEMOCRATIC REPUBLIC

Estimator YJM

Checked by

DESCRIPTION	QUANTITY No. of Units	QUANTITY Unit	LABOR Unit Price	LABOR Cost	EQUIPMENT Unit Price	EQUIPMENT Cost	MATERIAL Unit Price	MATERIAL Cost	SUBCONTRACT Unit Price	SUBCONTRACT Cost	TOTAL Unit Price	TOTAL
a) REMOVE EXISTING FENDERING												
REMOVE FENDERS, VERTICALS, & WALES & PILES	50	SHIFT	2114	105,700	1200	60,000	200	10,000				175,700
INSPECT, RESTORE STEEL d/or	100	TON	ALLOW	25,000		–	900	90,000				115,000
REPLACE RUBBER	18	200		3600		2000	500	9000				14,600
REHANDLE	5	SH	2114	10,570	700	3500	100	500				14,570
b) REINSTALL												
PILES	19	SH	2114	40,180	1200	22,800	200	3800				66,770
WALLS, KERT, RUBBER STRIP	33	SH	1914	64,020	800	26,400	100	3300				93,730
MISC. – LADDERS, ETC.	ALLOW			2000				5000				7000
20% (SOMALI PERSONNEL) X 251060				50,210								50,210
33% SUPPLIES 10% X 301300								30,130				30,130
				301,270		114,700		151,930				567,700
							25%	MOB & OH				141,930
												709,630
				LABOR		53%		CONTINGENCY	20%			141,930
				NAT'L & EQUIP		47%						851,560
										call	$	852,000

SEAWARD INTERNATIONAL, INC.

technical report

PRODUCT APPLICATION REPORT

SEA GUARD FENDERS: DOCK APPLICATION

DESCRIPTION

SEA GUARD fenders were selected to improve the fendering system at the Dundalk Marine Terminal in the Port of Baltimore, U.S.A. The original timber fender piles with wooden chocks were frequently damaged, and did not provide sufficient standoff. The piles also caused damage to, and displacement of, the concrete pier cap because they absorbed none of the berthing energy and passed the entire vessel impact directly through to the dock. Six 4 × 20 foot SEA GUARD units were quickly installed and proved less costly than the replacement of the timber fender piles. The four foot diameter fenders adequately protect the pier, yet do not hamper crane operations. The SEA GUARDs also spread the berthing force over a large area of both the pier and the vessel hull.

SEA GUARD Fenders: Dock Application

SPECIFICATIONS

TYPE OF OPERATION	*Berth 1—Dundalk Marine Terminal* *Ro-Ro, Container and General Cargo Vessels*
VESSEL CHARACTERISTICS	
Size:	*Disp. T: 40,000 L: 738 ft. D: 25 ft. (design)*
Berthing Velocity:	*0.5 ft./s (0.15 m/s) (estimated)*
Berthing Energy:	*216 ft.-kips (29.9 ton-meters) (calculated)*
FENDER CHARACTERISTICS	
Number, Size & Type:	*6 ea. 4 × 20 foot SEA GUARD fenders*
Spacing:	*150 feet (46 m) apart along pier*
Rated Energy Absorption (per unit):	*224 ft.-kips (30.98 ton-meters) @ 60% compression*
Reaction Force (per unit):	*228 kips (103 tons) @ 60% compression*
Weight (per unit):	*2690 lbs. (1220 Kg)*
End Connector Working Load:	*25 tons Safe Working Load*
RIGGING HARDWARE	
Attachment Line:	*1¼ inch stud-link chain, 130,000 lbs. (59 tons) ultimate strength*
Shackle:	*1¼ inch (32 mm) anchor shackle, 144,000 lbs. (65 tons) ultimate strength. A "weak link" ¾ inch (19 mm) anchor shackle with 57,000 lb. (26 tons) ultimate strength is also used.*
Swivel:	*Fenders have built-in swivel-type end fittings*

SEAWARD INTERNATIONAL, INC.

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APPENDIX E

ROLL-ON/ROLL-OFF RAMP

TELEX FROM MESSINA LINES

LIST OF VESSELS THAT CALL ON SOMALI PORTS

RCA JAN 06 0924GP
232117 PKLP UR
270450 IMECGE I
OURTLX NR 574/84 TR/CERVETTO/IT

FM MESSINA GENOA
TO 232117 PKLP UR

REF. YR MSG OF JAN 5:
WE CALLED LAST YEAR KISMAYO WITH A RO-RO AND BERTHING WAS DIFFICULT BECAUSE OF THE ABSENCE OF A RO-RO RAMP.
GLAD TO REALIZE THAT NOW A RAMP WILL BE BUILT.
WE HAVE MANY DIFFERENT TYPES OF RO-RO, OPERATING POSTLY STERN TO QUAY, AND WE WILL PERFORM, IN A VERY NEAR FUTURE, A COORDINATED SERVICE TOGETHER WITH ''LLOYD TRIESTINO'' OF TRIESTE (TO WHOM WE QUOTED YR TELEX).
BEFORE GIVING YOU MORE DETAILS, PLS INFORM WHICH KIND OF RAMP YOU HAVE IN MIND, I.E. IF FOR MOORING STERN TO QUAY OR ALONGSIDE OR BOTH.
JUST TO GIVE YOU AN IDEA THE NEW RAMP OF MOGADISHU IS GOOD ENOUGH FOR US, EXCEPTED THE ORIENTATION WHICH DOES NOT TAKE CARE OF THE DIRECTION OF THE PREVAILING WINDS.
BEST REGARDS.

232117 PKLP UR
270450 IMECGE I

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(1)

Parsons Brinckerhoff Computation Sheet

Subject: Names of Ro/Ro Vessels collecting at Mogadishu

Page ____ of ____

Made by ____

Date ____

Checked by ____

Date ____

		Name of Vessel	Flag.
	1)	Adria	Italy.
	(2)	Jolly Blue	"
	(3)	Apulia	"
	4	Jolly Marone	"
x	5	Jolly oro	"
x	6	Jolly Geleste	"
x	7	Serenissima	"
	8	Jolly Nero	"
x	9	Jolly Greco	SINGAPORE
x	10	Berbera 2.	Greece
x	11	TFL Progress	"
	12	Jolly Argente	Panama
	13	JIM Traspart	U.A.E
	14	Seki beech	Pana
	15	Taibah II	S. Arabia
	16	Nopa Verd.	Liberia. (Side Ramp.)

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(2)

Parsons Brinckerhoff **Computation Sheet**

Subject _____

Page ____ of ____

Made by _____

Date _____

Checked by _____

Date _____

	Name of Vessel	Flag
17	Project Arabia	W. Germany
18	Tore Del Greco	Italy.

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Table A

CO & Ship	Year Built	Gross Tonnage	L (M)	B (M)	DPT (M)	Ramp Type (if known)
Messina						
Jakeramme	49	1565	96.6	14.3	(20)	-
Jolly Argento			163	20	?	-
Jolly Azzurro	70	2681	130	19.6	(19.5)	-
Jolly Blanco	69	2793	129	16.74	(19.5)	Stern door/ramp
Jolly Blu	69	2463	130	19.21	(19.5)	Stern door
Jolly Marrone	70	2643	130	19.24	(19.5)	Stern door/ramp
Jolly Nero	72	2693	130	19.24	(19.5)	Stern door
Jolly Verde	67	1597	88	14.64	(20)	-
Jumboemme	56	2972	115	15.0	?	Stern door(s)
Rollerme	50	1565	96	14.33	(20)	-
Lloyd Triestino						
Adria	81	7441	148	22.7	(20.7)	-
Apulia	81	5400	148	22.7	(21.7)	Quarter Stern door & ramp
Buona Speranza	76	2651	117	17.5	(16.9)	-
Julia	81	6225	146	22.7	(21)	-
Nedlloyd						
Happy Runner	6	1198	81.8	15.5	?	Stern door/ramp
Nedlloyd Rokanje	72	4301	137	22.3	(32)	Stern doors
Pointe La Rose	74	6561	155	21	(26.8)	Stern door/ramp; side doors
Pointe Madame	73	6561	155	21	(26.8)	Stern door/ramp; side doors
Pointe Sans Souci	73	6561	155	21	(26.8)	Stern door/ramp; side doors
L'Ardeche	78	1127	90.7	14	(20)	Stern door/ramp
L'Aude	78	1127	90.7	14	(20)	Stern door/ramp
L'Isere	71	984	105.3	15	?	Stern side doors
La Durance	72	2239	99	16	(19)	Stern door
Saint Servan	72	3445	?	?	?	-
Manta						
Ro/Ro Trader	71	1552	109	19.21	(4.95m)	Stern door

Sources: Lloyd's Register of Shipping
U.S. Bureau of Shipping