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UNDERWATER INSPECTION CRITERIA

By

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EXECUTIVE SUMMARY

The Marine Facilities Division (MFD) of the California State Lands Commission (CSLC) is in the process of reviewing and formulating various design and inspection criteria for waterfront facilities. The MFD has a regulatory requirement to require a thorough examination of each marine terminal in the State to determine whether the structural integrity of the terminal, the oil transfer operations system, and the safety equipment are designed and being maintained in a safe working condition. To meet this regulatory objective the CSLC has developed a procedure for performing an in-depth structural and safety system audit of existing marine loading and discharge terminals located onshore, near-shore, and offshore California. These procedures apply to pier and wharf terminals, and offshore multi-point mooring marine terminals.

The Naval Facilities Engineering Service Center (NFESC) has been tasked to provide input to the review and formulation of design and inspection criteria for waterfront facilities, based on the Navy's extensive experience and expertise in this area. This document addresses the underwater inspection component of the overall effort. This underwater inspection criteria is intended to provide guidance to the CSLC on the inspection of the underwater components of a marine oil terminal facility with the intent on identifying structural damage or weaknesses that might affect the continued fitness-for-purpose of the terminal.

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1.0 INTRODUCTION

This California State Lands Commission's (CSLC) has the following regulatory requirement:

> "At least once every three years, the Marine Facilities Division (MFD) shall cause to be carried out a thorough examination of each marine terminal in the state to determine whether the structural integrity of the terminal, the oil transfer operations system and the safety equipment are designed and being maintained in a safe working condition."

To meet this regulatory objective the CSLC has developed a procedure for performing an in-depth structural and safety system audit of existing marine loading and discharge terminals located onshore, near-shore and offshore California. These procedures apply to pier and wharf terminals, and offshore multi-point mooring marine terminals. Mooring equipment on the vessel used to secure the vessel to the wharf/pier or offshore multi-point mooring is a part of this audit procedure, too.

The objective of the audit should be prevention as well as cure. In addition to the correction of an individual non-conformance item, the audit team should look for improvements to the safety system or structure, which would prevent its recurrence elsewhere. Ideally, the participants in the audit work as a team and the objective of the audit is not only to document and assess the criticality of deficiencies, but also to enhance reliability, safety and structural integrity of the terminal and its operation.

Terminal audits should compare the facility with the standards and practices used for its original design and operation. However, it should also be compared against current standards and those areas where upgrading would provide a significant improvement in safety should be identified. The purpose of the audit procedure is to:

(1) Identify safety system, mechanical, and electrical deficiencies at the marine terminal,

(2) Identify structural damage or weaknesses that might affect the continued fitness-for-purpose of the terminal,

(3) Advise whether these deficiencies have been properly assessed, and,

(4) Advise what steps should be taken to prevent, or minimize these potential risks.

This underwater inspection criteria is intended to provide guidance to the CSLC on the inspection of the underwater components of a marine oil terminal facility with the intent on identifying structural damage or weaknesses that might affect the continued fitness-for-purpose of the terminal.

2.0 GENERAL CONSIDERATIONS

The fundamental purpose of any inspection is to provide the information necessary to assess the condition (capacity, safety, and rate of deterioration) of a structure. A waterfront inspection encompasses the examination of structures such as: piers, pilings, wharves, quaywalls, fender systems, dolphins, dry docks, and coastal protection structures. The usefulness of an inspection depends upon establishing a clear and complete record. Although the level of inspection will determine the extent of information to be provided, in general the inspection will address the following:

(a) Identification and description of all major damage and deterioration of the facility.

(b) Estimate of the extent of damage and deterioration.

(c) Identification of any problems associated with mobilization of equipment, personnel, and materials to accomplish repairs/maintenance.

(d) Updated layouts of pile plans (which occasionally differ significantly from the drawings available at the activity).

(e) Documentation of types and extent of marine growth (to help plan future inspections), as well as damage caused by their presence.

(f) Water depths at each facility.

(g) Water visibility, tidal range, and water current.

(h) Information for the database of waterfront facilities and data to assist in planning future inspections.

(i) Assessment of general physical condition including projected load capacities of the in-water structures of each facility inspected.

(j) Recommendations for required maintenance and repair (M&R).

(k) Budgetary estimates of costs of this M&R, including examples of the derivation of the estimates.

(l) Estimate of expected life of each facility.

(m) Recommendations for types and frequencies of future underwater inspections.

There are several types of inspections, including:

(a) Baseline - to obtain data on an uninspected facility. This type involves the greatest "pre-inspection" effort.

(b) Routine - to obtain data on general condition, confirm drawings, estimate repair costs, etc.

(c) Design Survey - to obtain data for specifications or for detailed cost estimates.

(d) Acceptance - to obtain data confirming that a repair has been completed according to plan or specification.

(e) Research - to obtain data for research on deterioration rates, etc.

A number of Government reference documents dealing with waterfront inspections exist. The inspection procedures and planning factors outlined in this document have been taken from several of them. These references are listed in the bibliography at the end of this document.

3.0 SCOPE OF UNDERWATER INSPECTIONS

Underwater inspections are primarily visual observations of the facility being inspected. Quantitative measurements, such as underwater voltmeter readings on metal structures and thickness measurements on mooring chain and steel piling, are often taken. Before making the observation, it is usually necessary to clean the structure of marine growth and fouling. Several techniques are used to accomplish this cleaning, ranging from hand cleaning with scrapers and wire brushes to the use of waterblasting jets and hydraulically powered mechanical abrasive tools.

This document has been arranged to present a general description of:

- Waterfront facilities (Chapter 4)
- General inspection procedures (Chapter 5)

And detailed descriptions of the procedures to be used for:

- Inspecting steel structures (Chapter 6)
- Compliant moorings (Chapter 7)
- Concrete structures (Chapter 8)
- Timber structures (Chapter 9)
- Stone masonry structures (Chapter 10)
- Coastal protection structures (Chapter 11)
- Synthetic Materials and Components (Chapter 12)
- Quaywalls (Chapter 13)

Each of these sections also includes a description of the causes of deterioration of the relevant type of structural material.

4.0 INTRODUCTION TO WATERFRONT FACILITIES

The following discussion provides a very brief introduction to the types of waterfront facilities that may be encountered. The following Government handbooks provide useful information:

MIL-HDBK-1025/1 - Piers and Wharves
MIL-HDBK-1025/6 - General Criteria for Waterfront Construction
MO-104.1 - Maintenance of Fender Systems and Camels
MO-104.2 - Specialized Underwater Waterfront Facilities Inspections
MO-306 - Maintenance and Operation of Cathodic Protection Systems
DM-26.1 - Harbors
DM-26.5 - Fleet Moorings

Marine facilities include:

- Berthing facilities
- Drydocks
- Coastal protection structures
- Components of waterfront structures: fender systems, piling, and dolphins
- Compliant moorings
- Underwater cables and pipelines

Berthing facilities and coastal protection structures are described in more detail below.

4.1 Berthing Facilities

Berthing facilities provide space for: mooring, shore utilities, hotel services, loading and unloading of cargo, personnel, ordnance, and fuel, and maintenance, repair, and fitting out. Piers are also used to support specific functions such as magnetic silencing facilities for submarines. Some typical configurations of piers and wharves are shown in Figure 4-1.

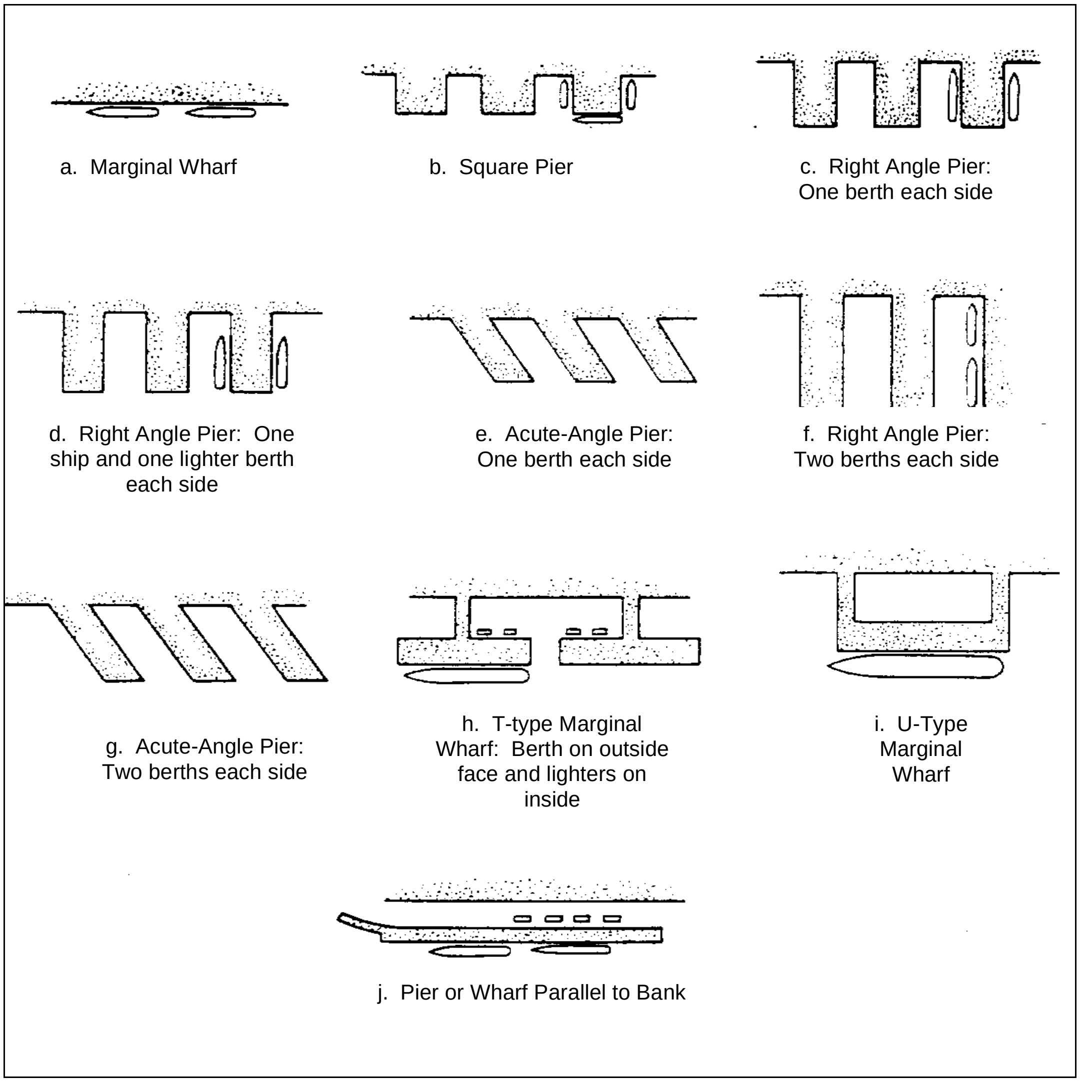


Figure 4-1. Typical configurations of piers and wharves.

4.1.1 Piers. Piers are docks that extend outward from the shore into the water. There are basically four types of pier structures with distinct differences in configuration: open, closed, combination, and floating. These piers are:

(a) Open piers are pile-supported platform structures which allow water to flow underneath. Conventionally open piers are single deck structures although some are double deck.

(b) Closed piers are constructed so that water is prevented from flowing underneath. The solid fill pier is surrounded along the perimeter by a bulkhead that holds back the fill.

(c) Floating piers can be constructed of steel or concrete and are connected to the shore with access ramps. Guide piles or anchor systems prevent lateral movement. Floating piers may be either single or double deck.

4.1.2 Piling. Piling is a common element found on piers, wharves, and some fender systems. Figure 4-2 provides some typical pile cross sections for steel, wood, and concrete piles with dimensions typically found in marine structures.

The basic types of piling are:

(a) Vertical bearing piles are used to support the dead weight of the pier as well as the live loads on the pier.

(b) Batter piles primarily provide lateral and longitudinal stability but do provide limited load carrying capacity.

(c) Fender piles absorb the impact of berthing ships.

(d) Sheet piling is used with various waterfront facilities to retain fill.

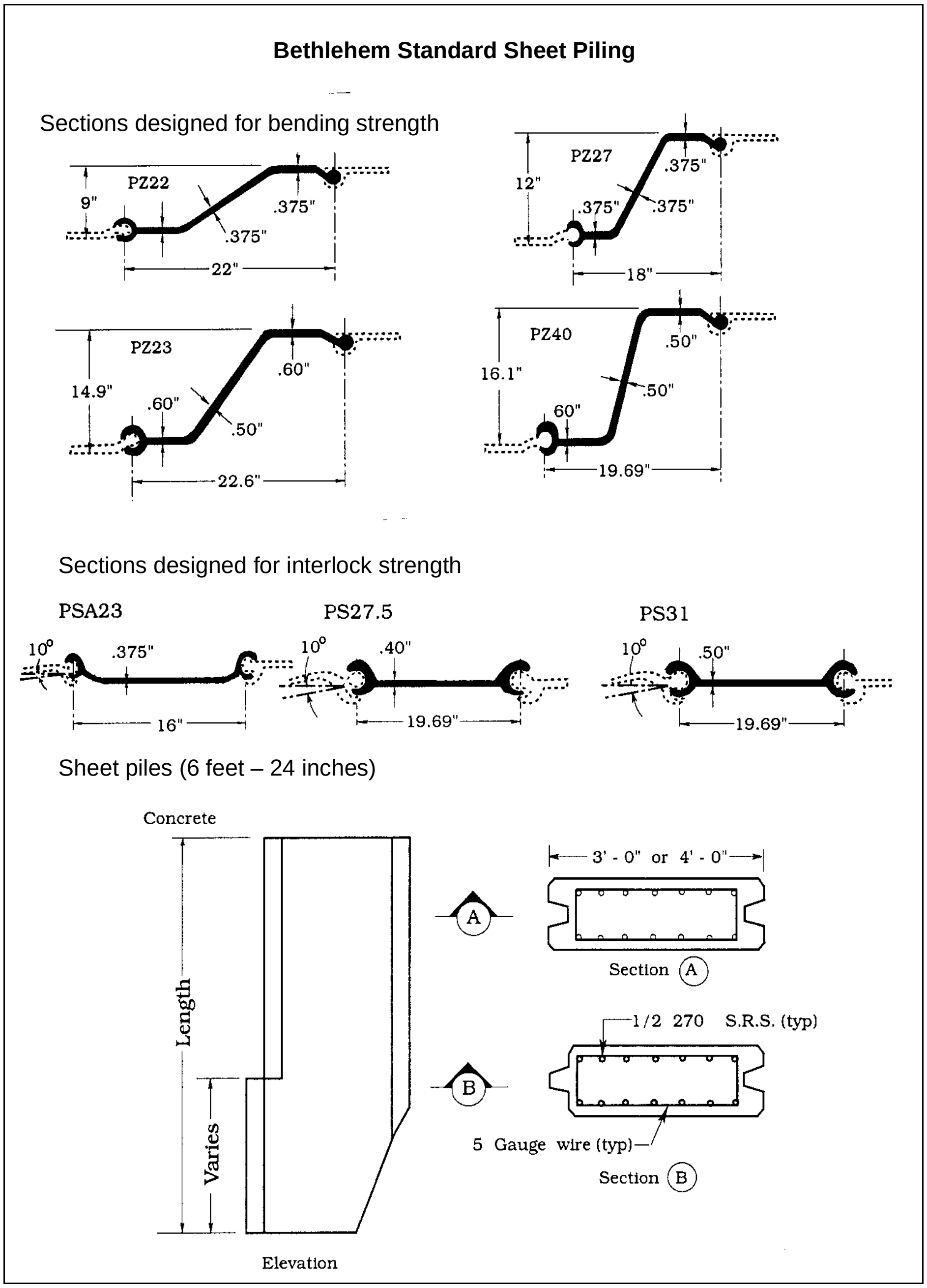


Figure 4-2. Typical pile cross sections for steel, wood, and concrete piles.

4.1.3 Wharves and Quaywalls. Wharves are docks which are oriented approximately parallel to the shore and are connected to shore along their entire length. The retaining structure used to contain the backfill is commonly referred to as the quaywall or bulkhead. Several types of these structures are shown in Figure 4-3.

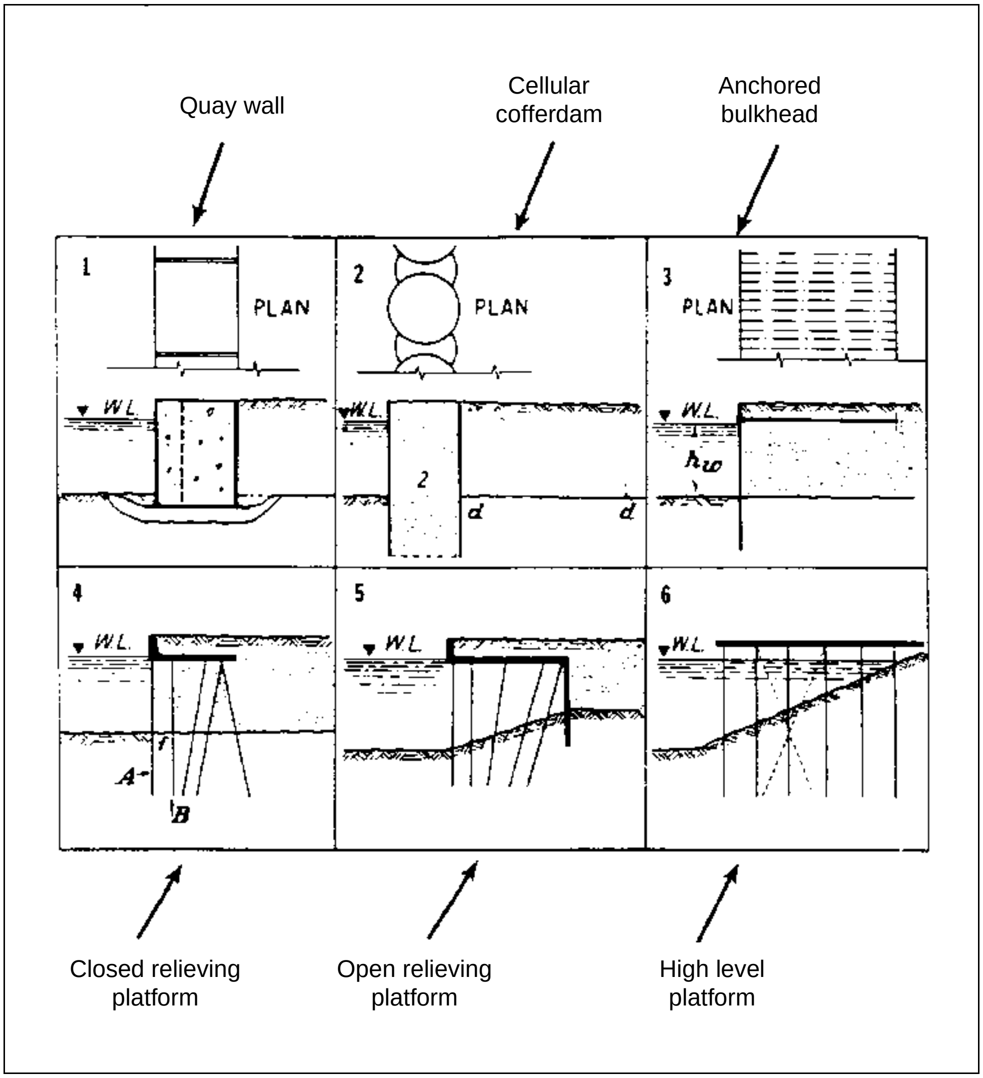


Figure 4-3. Types of Quaywalls/Bulkheads.

4.1.4 Fender Systems. Fender systems are used on piers to protect the ship and the pier during berthing operations and while the ship is moored. On relatively inflexible piers and wharves the fender acts as a buffer in absorbing or dissipating the impact energy of the ship without damaging the ship. Where ships are berthed against pile-supported structures, protection of the structure is of more serious concern. The main type of fenders and components that are found on older and smaller piers are fender pile systems. For modern larger piers, various types of fenders are attached to the pier, and they include:

- Rubber units in compression or shear (various shapes: cylindrical, rectangular, trapezoidal, wing, etc.).

- Buckling column (various shapes).
- Pneumatic (air filled) shapes.

- Foam filled (typically cylindrical shape).

4.1.5 Dolphins. Dolphins (Figure 4-4) are groups of piles placed near piers and wharves or in turning basins and ship channels. These structures are used to guide vessels into their moorings, to mark underwater structures, to moor vessels to, to berth vessels against, and to support navigational aids.

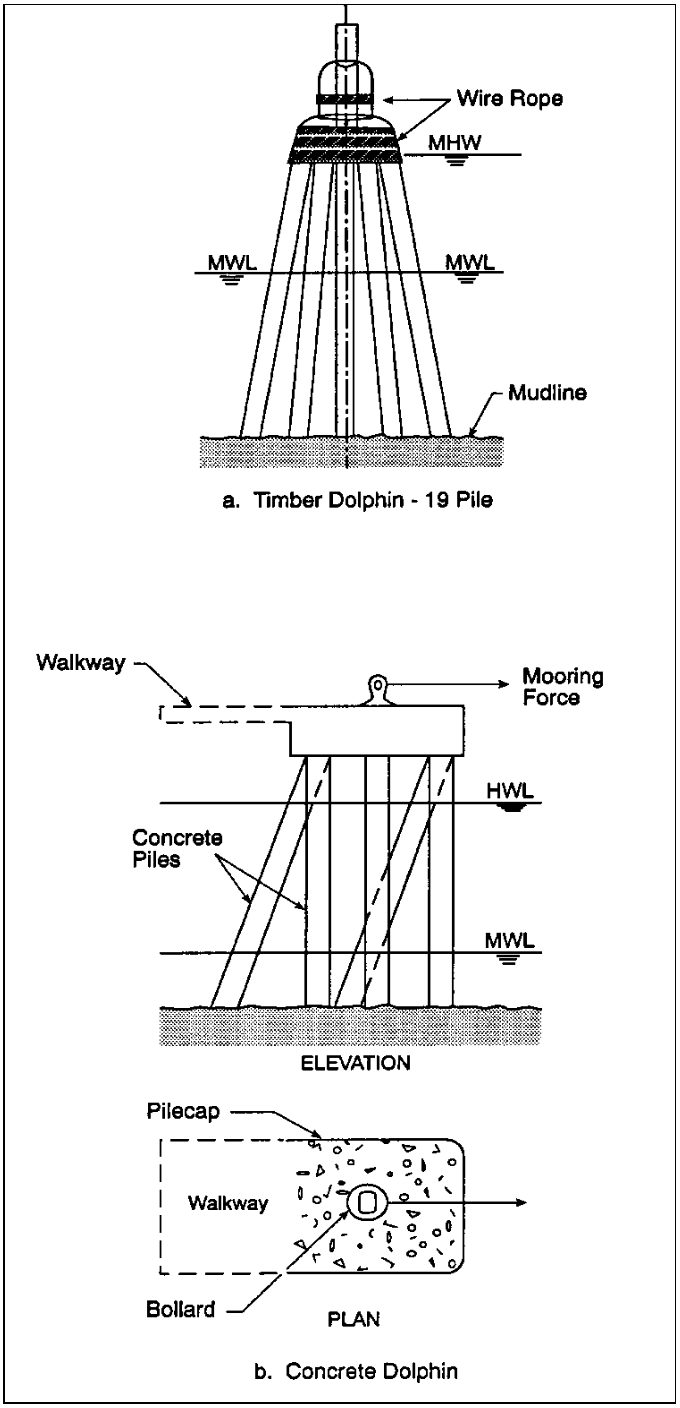


Figure 4-4. Mooring Dolphins.

4.2 Coastal Protection Structures

Coastal protection structures are designed to reduce the effects of wave action, so as to protect harbors and reduce the formation of sandbars. They can be fabricated out of a variety of materials including concrete, rock rubble, granite masonry, and reinforced precast concrete armor units as shown in Figure 4-5. Typical coastal structures include seawalls, groins, jetties, and breakwaters. These structures are:

(a) Seawalls are massive coastal structures built along the shoreline. Their primary function is to protect areas from erosion caused by waves or flooding.

(b) Groins (Figure 4-6) are designed to minimize coastal erosion by controlling the rate of shifting sand by influencing offshore currents and waves. Groins project outward, perpendicular to the shoreline.

(c) Jetties extend outward from shore to prevent the formation of sandbars and direct the flow of water from currents, tides, and waves.

(d) Breakwaters are generally located outside the entrance of a harbor, anchorage, or coastline. They are designed primarily to protect the inner waters and shoreline from the effects of heavy seas. Breakwaters may be connected or detached from the shore.

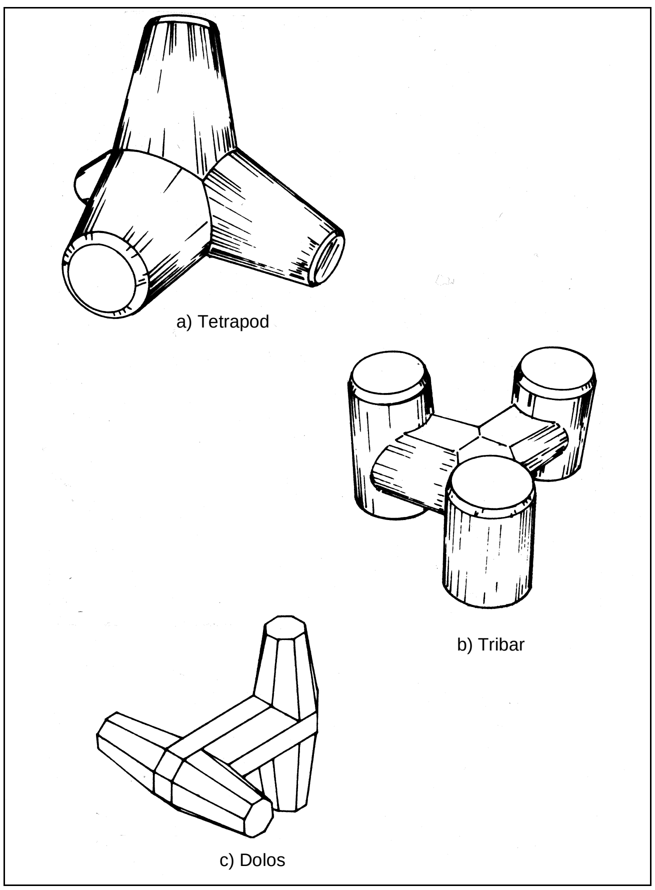


Figure 4-5. Precast Concrete Armor Units used in Jetties, Breakwaters, and Groins.

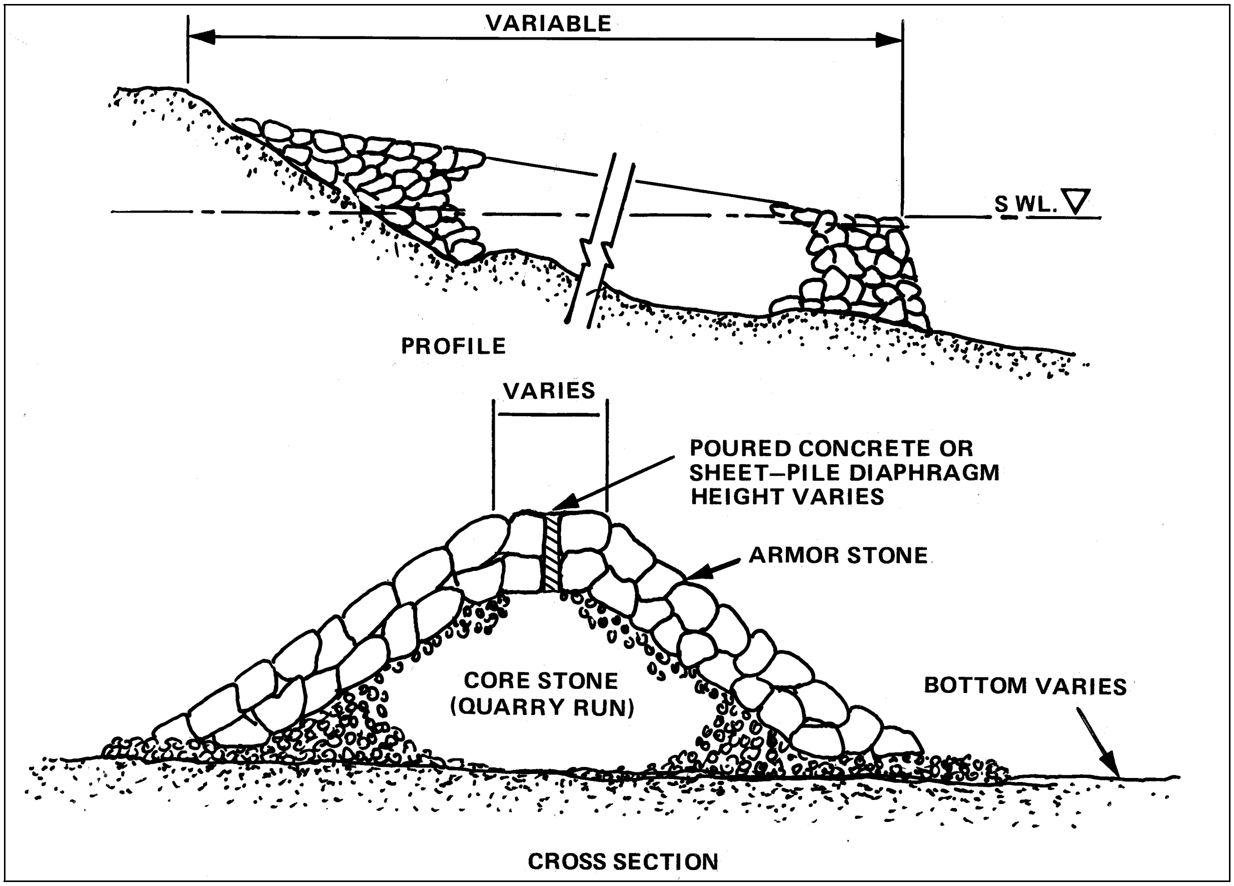


Figure 4-6. Groins.

5.0 GENERAL INSPECTION PROCEDURES

The purpose of any inspection is to provide the information necessary to assess the condition (capacity, safety, and rate of deterioration) of a structure. The usefulness of an inspection depends, therefore, on the suitability and recording of the data (observations) obtained for use in later engineering evaluations. An underwater inspection is a condition survey; therefore, the diver should make and report observations and measurements that can be used by an engineer to make the engineering assessments. Ideally, the engineer making the engineering assessments is also a diver and dives on the facility for at least a portion of the inspection. A part of the engineering assessment will be to determine the cause of the failure or damage; therefore, detailing and documenting the inspection is important.

For example, the diver should observe, measure, and report that a sheet pile wall has a hole measuring 2 feet by 3 feet, at a depth of 2 feet below mean low water (MLW), and that behind the hole is a 6-foot deep cavity. These data may be supplemented by the diver's opinion regarding the structural adequacy of the wall if the nature of its condition is obvious. A final conclusion, however, can only be reached after an analysis of the structure's existing condition has been conducted.

Since divers' observations and measurements are often the only data available for the topside personnel to make an engineering assessment, the reliability of such data is critically important. Therefore, the quality control of the measurements becomes an important issue. At least 10 percent of all measurements and observations must be rechecked by a second diver to ensure accuracy. If any discrepancy is discovered, all measurements and observations must be rechecked.

An important part of any inspection operation is the recording of the diver's observations. Observations, both qualitative and quantitative, can be recorded underwater on a Plexiglas slate with a grease pencil. However, direct hardwire communication between the diver and topside is much more efficient. In addition, use a video recording system, a photographic camera, and a voice recorder whenever possible. The dive supervisor or inspection team leader should debrief the working diver as soon after the dive as possible. This valuable information should be recorded for later reference.

5.1 Levels of Inspection

Three basic types or levels of inspection are used for inspecting marine facilities. The resources and preparation needed to do the work distinguish the level of inspection. Also, the level of inspection determines the type of damage/defect that is detectable:

- Level I - General Visual Inspection. The Level I effort can confirm as-built structural plans and detect obvious major damage or deterioration due to overstress (collisions, ice), severe corrosion, or extensive biological growth and attack. The Level I will provide initial input for an inspection strategy. Although this is an overview, close attention should be given to confirming or providing information to update available facility drawings and condition evaluations.

This type of inspection does not involve cleaning of any structural elements and can therefore be conducted much more rapidly than the other types of inspections. The Level I effort is essentially a general inspection "swim-by" overview. It does not involve cleaning of structural elements, which allows the inspection to be conducted rapidly. The underwater inspector relies primarily on visual and/or tactile observations (depending on water clarity) to make condition assessments. These observations are made over the specified exterior surface area of the underwater structure, whether it is a quaywall, bulkhead, seawall, pile, or mooring.

- Level II - Close-Up Visual Inspection. Level II efforts are complete, detailed investigations of selected components or subcomponents, or critical areas of the structure, directed toward detecting and describing damaged or deteriorated areas that may be hidden by surface biofouling. Limited deterioration measurements are obtained. These data are sufficient for gross estimates of facility load capability. This type of inspection will generally involve prior or concurrent cleaning of part of the structural elements. Since cleaning is time consuming, it is generally restricted to areas that are critical or that may be typical of the entire structure. The amount and thoroughness of cleaning to be performed are governed by what is necessary to determine the general condition of the overall facility. Simple instruments such as calipers and measuring scales are commonly used to take physical measurements. Subjective judgments of structural integrity are occasionally made by probing wood with ice picks and by pounding concrete with hammers.

- Level III - Highly Detailed Inspection. This level of inspection is primarily designed to provide data that can be used to perform a structural assessment and will often require the use of Nondestructive Testing (NDT) techniques. The procedures are conducted to detect hidden or imminent damage, loss in cross-sectional area, and material homogeneity. The training, cleaning, and testing requirements will vary depending on the type of damage/defect that is to be investigated and the type of inspection equipment to be used. A Level III examination will normally require prior cleaning. In some cases, Level III inspections will require the use of partially destructive techniques such as sample coring in wood or concrete, material sampling, and in-situ surface hardness. The use of Level III inspection techniques is usually limited to key structural areas that may be suspect, or to structural areas that may be representative of the overall structure. Level III inspections will require considerably more experience and training than Level I or Level II inspections, and should be accomplished by qualified engineering or testing personnel. This type of inspection is covered in MO-104.2 (see Bibliography).

On steel H-piles, pipe piles, and sheet piles, metal thickness measurements are made with ultrasonic thickness equipment. In addition, electrical potential measurements, using a half-cell, are taken to verify the performance of the cathode protection system for steel structures. Concrete surfaces can be evaluated for hardness using a rebound hammer. A magnetic rebar locator can be used to establish the location and depth of rebar. There are few underwater instruments currently available for assessment of the interior of wood structures. Wood is inspected using calipers, ice picks, and hammers, and in some cases an incremental borer is used to obtain a core sample.

Table 5-1 summarizes the type of damage that is detectable with the three types of inspection. The level of inspection to be used for a particular task is usually decided early in the planning phase. However, depending upon visibility, marine growth, and extent of deterioration, this may be adjusted as the inspection proceeds. Often, the requirements of the local staff civil engineer or other authority will dictate the level of inspection. The underwater inspection may be accomplished by a qualified engineering diver or by a qualified, certified diver, supervised by an engineer. An experienced engineer skilled in inspection procedures and techniques must perform the structural assessment.

Table 5-1. Capability of Each Level of Inspection For Detecting Damage to Waterfront Structures.

Level	Purpose	Detectable Defects		
		Steel	Concrete	Wood
I	General visual to confirm as-built condition and detect severe damage	Extensive corrosion Severe mechanical damage	Major spalling and cracking Severe reinforce-ment corrosion Broken piles	Major losses of wood Broken piles and bracings Severe abrasion or marine borer attack
II	Detect surface defects normally obscured by marine growth	Moderate mechanical damage Major corrosion pitting	Surface cracking and crumbling Rust staining Exposed rebar and/ prestressing strands	External pile damage due to marine borers Splintered piles Loss of bolts and fasteners Early borer and insect infestation
III	Detect hidden and imminent damage	Thickness of material	Location of rebar Beginning of corrosion of rebar Internal voids Change in material strength	Internal damage due to marine borers (internal voids) Decrease in material strength

The time and effort required to carry out the three different levels of inspection are quite different. The time required for any particular level will depend on a number of factors, including visibility, currents, wave action, water depth, severity of marine growth, and the skill and experience of the diver.

Table 5-2 provides a guide for estimating the time required to conduct Level I and Level II inspections. This information is based on:

(1) A water depth of 30 to 40 feet
(2) Visibility of 4 to 6 feet
(3) Warm, calm water
(4) Moderate marine growth (about 2 inches thick)
(5) An experienced diver of average skill

Table 5-2. Production Rate for Surface and Underwater Inspection of Structural Elements.

Structural Element	Inspection of Time Per Structural Element (min)			
	Level I		Level II	
	Surface	U/W	Surface	U/W
12-in. steel H-pile	2	5	15	30
12-in. wide strip of steel sheet pile	1	3	8	15
12-in. square concrete pile	2	4	12	25
12-in. wide strip of concrete sheet pile	1	3	8	15
12-in. diameter timber pile	2	4	10	20
12-in. wide strip of timber sheet pile	1	3	7	15

For the Level II inspection it has been assumed that 3 feet of the structural element in the splash zone, 1 foot at mid-depth, and 1 foot at the bottom will be completely cleaned of marine growth. It has also been assumed that the most efficient method of removing marine growth will be used.

Level III inspections depend on the extent of existing damage, the type of inspection techniques, the equipment used (ultrasonic thickness measurements, increment borings, caliper measurements, etc.), and the degree of cleaning required. Therefore, estimates of time for Level III inspections are not included in Table 5-2.

Table 5-3 depicts typical daily rates for swimming-by, cleaning, and taking measurements on piles and linear feet of bulkhead.

Table 5-3. Typical Daily Rates for Underwater Inspection Tasks.*****

Inspection Task	**Piles/Day**	**Bulkheads in LF/Day**
Swim-By	300-600	500-1500
Cleaning	30-70 at 3-15% of each pile	500-1500 at 50-300 LF intervals
Measurement	50-200 for Wood at 5-15% of each pile 30-60 for Steel at 3-10% each 30-70 for Concrete 3-15% each	500-1500 at 50-300 LF intervals

*****Rates can vary widely depending on the effects of many factors such as water visibility, facility size and age, marine growth, and type of construction.

5.2 Planning for Inspection

Before starting a facility inspection, all available information about the facility should be obtained. This will usually require a preliminary visit to the facility. The Engineer in Charge should meet with the local staff civil engineer and obtain copies of the facility drawings and general background about the existing condition of the facility. Any unique features or special problems that may be encountered should be noted. Local information that should be obtained includes:

- Wave action
- Atmospheric temperature range
- Water temperature range
- Tidal range
- Water depths
- Water visibility
- Currents
- Any condition that could have a direct impact on the time needed to perform an inspection, such as amount of biofouling growth on piles or any other condition that would inhibit the performance of an inspection such as ice or seasonal flooding.
- Ship traffic and facility berthing requirements.

The bathymetric and oceanographic data, as well as information on nearby obstructions or activities, will accelerate the planning process and will aid in determining the levels of inspection to be used. The time and effort required to carry out the three different levels of inspection will vary considerably. The factors affecting the time required will include whether the inspection is surface or underwater; the environmental factors mentioned above; and the skill and experience of the inspector.

Information about the local support, equipment, and utilities should be acquired prior to the inspection. Once the information about the facility has been collected, an inspection plan should be developed. The written plan should be like a statement of work containing a scope of work, specifying the sampling criteria (if any work is contracted out, a separate SOW will be required). It should specify responsibilities, tasks, schedules, and equipment to be used.

Of critical importance to the effectiveness of each survey is the proper and adequate selection of the areas to be examined. It is important to select a sufficient number of inspection areas to provide representative information on the overall structure. Making this selection requires an understanding of the facility structural behavior to determine which areas are subjected to maximum stress, fatigue, and impact forces. Knowledge of deterioration and damage theory is also useful. Consequently, the inspection plan must be prepared in cooperation with qualified engineers familiar with the structure. The inspection plan should include the identification of the inspection equipment most appropriate to the specific tasks. For older facilities where little or no data, including drawings, is available, the inspection plan should allot time for developing and/or confirming the structural layout, and confirming whether previously identified repairs have been made.

A suitable scheme should be devised for designating individual piles and other structural members. The inspection team should use the pile numbering/ designation systems available on existing "as-built" drawings where available. Usually, combinations of numbers and letters are used with the number designating the bent and letter indicating the pile within the bent. Legends may be created to represent such things as the degree of deterioration of individual structural members, the level of inspection given to designated portions of a facility, the shape of individual piles, and the type of materials. Pile plans should be prepared for piers showing the lengths, widths, and spacing of bents. The plans must also include the numbering system used in the inspection and in the report, and these must be correlated with existing drawings of the facility. It is desirable to also include design live load data on all pile plans.

5.3 Inspection Frequency

The inspection frequency will depend upon whether the inspection is surface or underwater, and the expected rate of deterioration and damage. A typical example requiring more frequent inspection is an area experiencing damage by ships' berthing that results in advanced deterioration to both fender and structural piling. The frequency and level of inspection should, therefore, be closely tied to the historical deterioration rate of the facility. Recommended frequencies are listed in Volume 4 of NAVFAC MO-322, Inspection of Shore Facilities. Research by the Navy on inspection sampling criteria and procedures is published in several technical reports (see Bibliography). Statistical software has been developed which identifies inspection frequencies based on cost when known or estimated structural data is inputted. The frequencies obtained will be unique to the facility's situation. As a general guide, recommended frequencies of inspection for the different types of waterfront structures are as follows:

- All superstructure and piling/sheet piling above the waterline, including the splash and tidal zones (Figure 5-1), should be inspected annually.

- Concrete/steel structural members at the splash/tidal zones and downward should be inspected at least every 6 years. As deterioration is discovered, the level of inspection and frequency needs to be increased accordingly. For steel structures, the age of the structures is a primary factor since the rate of deterioration due to corrosion is fairly constant. Likewise, concrete in a saltwater environment deteriorates chemically with time, especially if cracks are present to allow the seawater to reach the structure's interior.

- Timber members should be inspected at least every three years and, as above, more frequently and intently as deterioration is discovered. In areas where marine animal infestation is known to be a problem, increased inspection frequency is especially important.

Additionally, if it is not feasible to thoroughly inspect all elements of a structure (e.g. underwater inspection of a series of piers containing many piles), selecting an optimum number of structural elements or members is crucial to obtaining accurate information representative of the overall condition of the structure. Development and validation of sampling criteria and procedures have been reported by NFESC (formerly NCEL) in NCEL TN-1762 "Sampling Criteria and Procedures for Inspection of Waterfront Facilities". Statistical sampling techniques using probability theory provide a method for determining condition parameters for the entire population based on information from the sample elements, with a calculated confidence level and precision. Three methods of random sampling have been identified as being applicable to waterfront facilities: simple, systematic, and cluster.

These methods are described in detail in NCEL TN-1762. Excellent correlation between the statistical data and actual conditions is obtainable when inspecting for natural deterioration (e.g. biological or wave action). However, the statistical techniques are not accurate when considering damage due to improper construction and mechanical overloading.

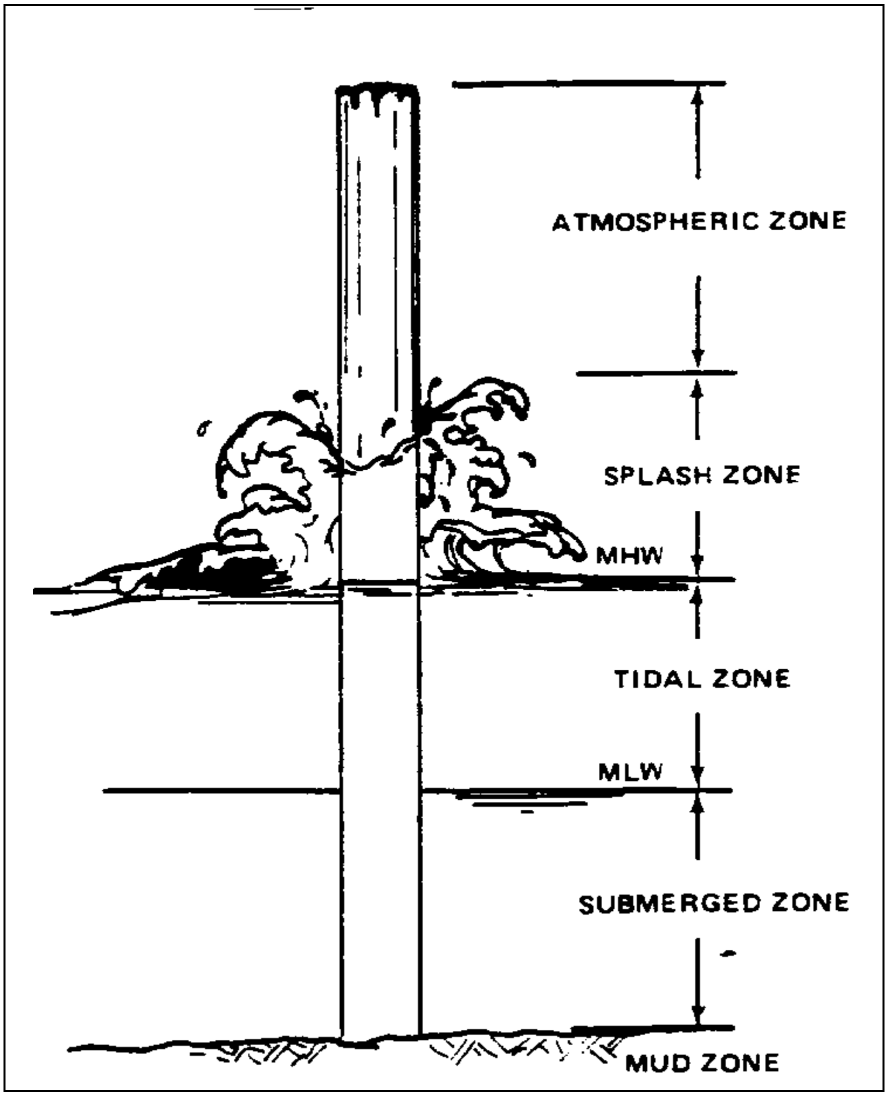


Figure 5-1. Various zones of influence on piling.

5.4 Documentation of Inspection

For the results of the inspection to be useful, they must be documented in a clear and concise manner and in accordance with generally understood terminology. Inspectors should maintain daily logs of inspection details including measurement data, locations of observation, and water depths, if relative. Inspection forms and reports should be completed as soon as possible after the inspection has been completed. Standard forms and report formats greatly facilitate the documentation procedure and are essential for comparing the results of the present inspection with past and future inspections. Figure 5-2 is a standard form for reporting the condition of piles; Figure 5-3 is an explanation of the condition ratings for concrete piles used on the form; and Figure 5-4 is an explanation of the condition ratings for timber piles. Steel pile inspection results are usually recorded in terms of remaining metal thickness. It should be noted, however, that the categorization of a defect, i.e., moderate, major, etc., will depend on the water depth. Piles in deeper water, with a long unsupported length, are susceptible to buckling, and loss in strength becomes more critical.

When appropriate, damaged areas should be documented with still photography and closed circuit television. Still photography provides the necessary high definition required for detailed analysis, while video, though having a less sharp image, provides a continuous view of events that can be monitored by surface engineers and recorded for later study. All photographs should be numbered, dated, and labeled with a brief description of the subject. A slate or other designation indicating the subject should appear in the photograph. When color photography is used, a color chart should be attached to the slate to indicate color distortions. Videotapes should be provided with a title and lead-in, describing what is on the tape. The description should include the method of inspection used, the nature and size of the structure being inspected, and any other pertinent information.

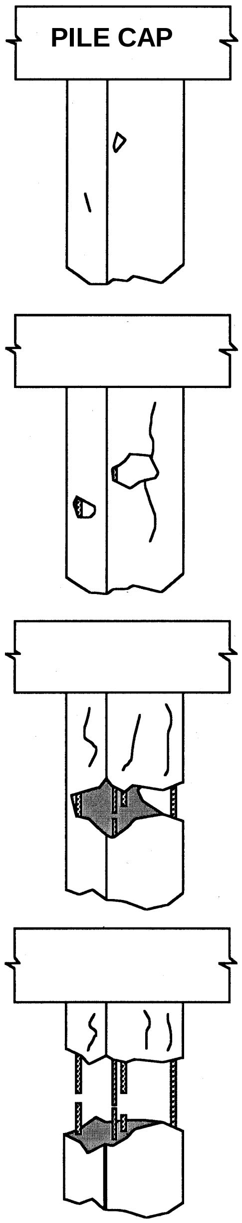
A debriefing with the activity personnel, with slides or photographs, should be conducted before leaving the site, and all questions should be resolved.

PILE INSPECTION RECORD

LOCATION		DATE	DIVERS
PIER NAME/NO.	PILE TYPE ☐ BEARING ☐ FENDER ☐ SHEET	PILE MATERIAL ☐ TIMBER ☐ STEEL ☐ REINFORCED CONCRETE	
WATER DEPTH	TIME OF DAY	TIDE	DEPTH OF DAMAGE FROM DATUM = GUAGE DEPTH - TIDE

BENT NO.	PILE NO.	NI	PILE CONDITION					TYPE DAMAGE			GAUGE DEPTH DAMAGE	DIMENSIONS OF DAMAGE			COMMENTS
			ND	MN	MD	MJ	SV	MECH.	BIO	FUNC.		HGT	WDTH	PENETR	

Figure 5-2. Standard Pile Inspection Report Form. (See Figure 5-3 and 5-4 for explanation of Ratings.)



CONCRETE PILE
<u>CONDITION RATING</u> <u>EXPLANATION</u>

NI NOT INSPECTED, INACCESSIBLE OR PASSED E

ND NO DEFECTS:
- hairline cracks
- good original surface, hard material

MN MINOR DEFECTS:
- good original surface
- minor cracks or pits
- small chips or popouts
- slight rust stains
- hard material, sound
- corrosion of the wires

MD MODERATE DEFECTS:
- limited spalling of concrete
- minor corrosion of exposed re-bar
- rust stains along re-bar
- softening of concrete
- reinforcing steel ties exposed
- popouts or impact damage

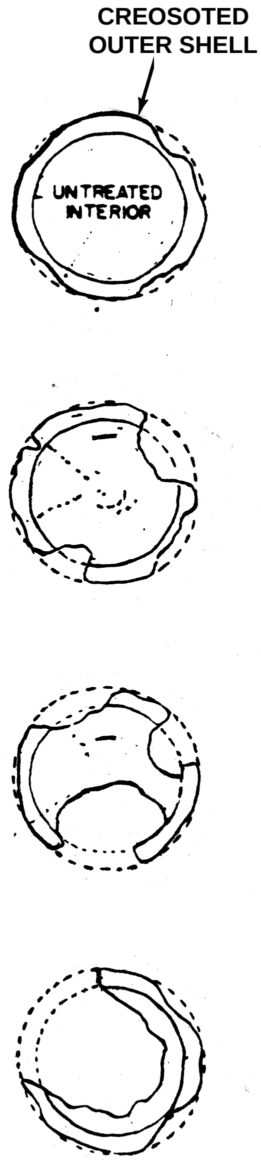
MJ MAJOR DEFECTS:
- spalling of concrete results in (10-15%) loss
- large spalls six inches or more in width or length
- deep wide cracks along re-bar
- major rust stains along rebar
- wide spread surface disintegration

SV SEVERE DEFECTS:
- exposed rebar with 50% loss of steel section are
- more than 15% loss of concrete

NOTE: Explanation of defect should be placed in the comments column.

Figure 5-3. Explanation of Pile Condition Ratings for Concrete Piles.

TIMBER PILE



CONDITION RATING	EXPLANATION
NI	NOT INSPECTED, INACCESSIBLE OR PASSED BY
ND	NO DEFECTS: - Less than 5% lost material - sound surface material - no evidence of borer damage
MN	MINOR DEFECTS: - 5% to 15% lost material - sound surface material - no evidence of borer damage - minor abrasion damage
MD	MODERATE DEFECTS: - 15% to 45% lost material - significant loss of outer shell material - evidence of borer damage - significant abrasion damage
MJ	MAJOR DEFECTS: - 45% to 75% lost material - significant loss of outer shell and interior material - evidence of severe borer damage - severe abrasion damage
SV	SEVERE DEFECTS: - more than 75% lost material - no remaining structural strength - severe borer damage

NOTE: Explanation of defect should be entered in the comments column.

Figure 5-4. Explanation of Pile Condition Ratings for Timber Piles.

5.5 Equipment and Tools

Following is a general discussion of tools required for the underwater inspection process. Each of the sections discussing the inspection of particular structure types will address the particular equipment and tools required to inspect that structure.

5.5.1 Surface Cleaning Tools. To perform a thorough inspection, the marine growth on the structure must be removed. This can be done by various means, depending on surface support. For small sample areas, wire brushes, probes, and scrapers may be adequate. For larger areas or more detailed inspections underwater, a hydraulic grinder with barnacle buster attachment, or high-pressure water jet gun, may be used. Exercise care to prevent damage to the preservative-treated layers of timber or deteriorating surfaces of concrete.

5.5.2 Inspection Tools. Inspection tools and equipment include:

(a) Hand-held tools such as portable flashlights, rulers, and tape measures for documenting areas; small or large hammers or pick-axes for performing soundings of the structural member; calipers and scales for determining thickness of steel flanges, webs, and plates, or diameters of piling; increment borer and T-handles for extracting core samples from timbers; and chipping tools for prodding the surface of the concrete to determine the depth of deterioration.

(b) Mechanical devices including a Schmidt test hammer for measuring concrete surface hardness and rotary coring equipment for taking core samples from concrete structures.

(c) Electrical equipment such as an underwater voltmeter for determining the level of cathodic protection on steel structures and underwater sonic and ultrasonic equipment for detecting voids in timbers or concrete and thickness of structural steel. Underwater magnetic particle testing to locate and define surface discontinuities in magnetic materials.

5.5.3 Recording Tools. Recording tools and equipment are required to provide a complete documentation of the condition of the structure. Simple tools such as clipboards, forms, and cassette recorders for above water inspections, or a Plexiglas slate and grease pencil for underwater inspection, provide the basic documentation tools. More in-depth documentation may be obtained with above-water or underwater photography using colored still-frame cameras or colored video, or closed-circuit television. The latter may be very valuable in expediting major underwater inspections. For underwater inspections in turbid water, a clear-water box may be fitted to the lens of the photographic or video equipment to improve visibility between the lens and surface to be inspected.

6.0 STEEL STRUCTURES

6.1 Types of Steel Structures

Structural steel is used in most metal waterfront structures because it is strong, readily available, easily fabricated into any shape, and not excessively costly. In marine applications, steel has many uses as a construction material. Steel piles, either H-piles or pipe piles, are used as support members for open piers, wharves, and other waterfront structures and facilities. Steel sheet piling is used primarily as a retaining wall structure for bulkheads used in the support of piers, wharves, drydocks, and quaywalls as well as near-water, earth-retaining structures. Fabricated structural steel members, whether tubular, plate, or other shapes, are used to construct undersea support towers for testing ranges, instrument arrays, and operation support platforms.

6.2 Deterioration of Steel Structures

There are six major types and causes of steel structure deterioration in the marine environment:

- Corrosion
- Abrasion
- Loosening of structural connections
- Fatigue
- Overloading
- Loss of foundation material

6.2.1 Corrosion. Corrosion is the principal cause of deterioration of steel waterfront structures. Corrosion of steel is an electrochemical process that converts the steel into iron oxides. These iron oxides are easily recognized by their reddish-brown color and are commonly called rust. The rust may remain in place in the form of an encrustation or may naturally fall away or be removed by wave action or abrasion. The corroded surfaces are usually irregular and in some cases the attack in localized areas will be much greater than in other areas resulting in pitting. Over a period of time, unchecked corrosion will reduce the structural integrity of steel components of waterfront structures

On bare unprotected steel pilings, corrosion is often most severe just above the high tide line, with another zone of severe attack just below the low tide line, as shown in Figure 6-1. Figures 6-2 and 6-3 illustrate typical corrosion on steel H-piling and sheet piling.

Submerged steel is also subject to galvanic corrosion. Galvanic corrosion occurs when two dissimilar metals are in electrical contact and both are submerged. An electrical current then flows between the two metals causing one of them to corrode rapidly. The composition of the metals, the exposed area, and the electrical conductivity of the liquid govern the speed of the attack. Salt water is an excellent electrical conductor, and galvanic corrosion resulting from dissimilar metals in contact is a significant problem on waterfront structures. The possibility of galvanic corrosion must be considered whenever dissimilar metals are used in marine structures.

An effect similar to galvanic corrosion can occur when there is a difference in environment between different areas on a single metal. When oxygen levels are limited, by reduced free access to freshly oxygenated water, in areas such as the threads of a bolt or between structural members, the difference in oxygen content can cause an electrical current to flow between the areas of high and low oxygen content. This electrical current results in accelerated corrosion. This effect is particularly severe on stainless steels and aluminum alloys. A difference in environment with resulting accelerated corrosion can also be created when a surface is partially covered by an electrically conductive material such as concrete.

Corrosion can also be accelerated by the action of bacteria. In the absence of oxygen, sulfate-reducing bacteria can grow, and the sulfides they produce can cause rapid attack on steel. Areas such as the inside of pipe piles that are not filled with concrete can become depleted in oxygen and are frequently the site of sulfate-reducing bacteria attack. Some bottom sediments are oxygen deficient and sulfate-reducing bacterial attack can occur on buried steel in such sediments. Sulfate-reducing bacteria attack is more likely to occur in polluted harbors but can occur whenever oxygen is depleted. The presence of sulfate-reducing bacteria can often be detected by the odor of rotten eggs produced by the bacteria. As sulfate-reducing bacteria attack usually occurs on the inside of pipe piles or below the mudline, it is especially difficult to locate and repair open end pipe piles which are not concrete filled and typically used on offshore and waterfront structures. Experience indicates, however, that the insides are generally not subject to corrosion.

Finally, corrosion can be initiated by the presence of stray currents, e.g., from nearby electrical power lines.

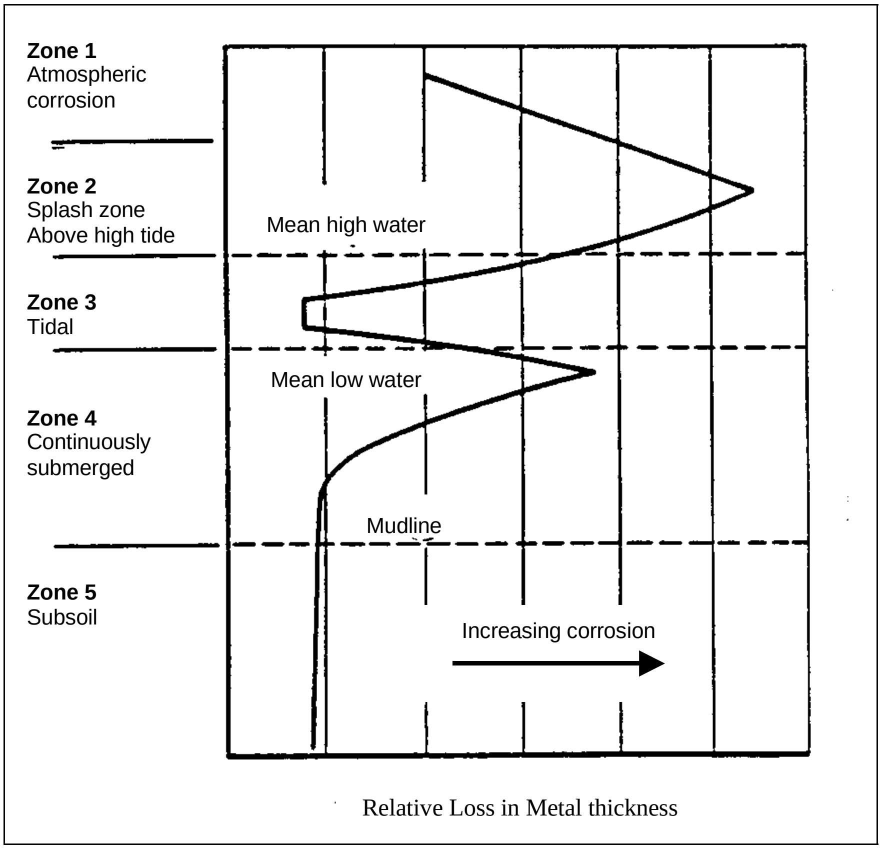


Figure 6-1. Severe Corrosion Cones, Just Above High Tide Line and Just Below Low Tide Line.

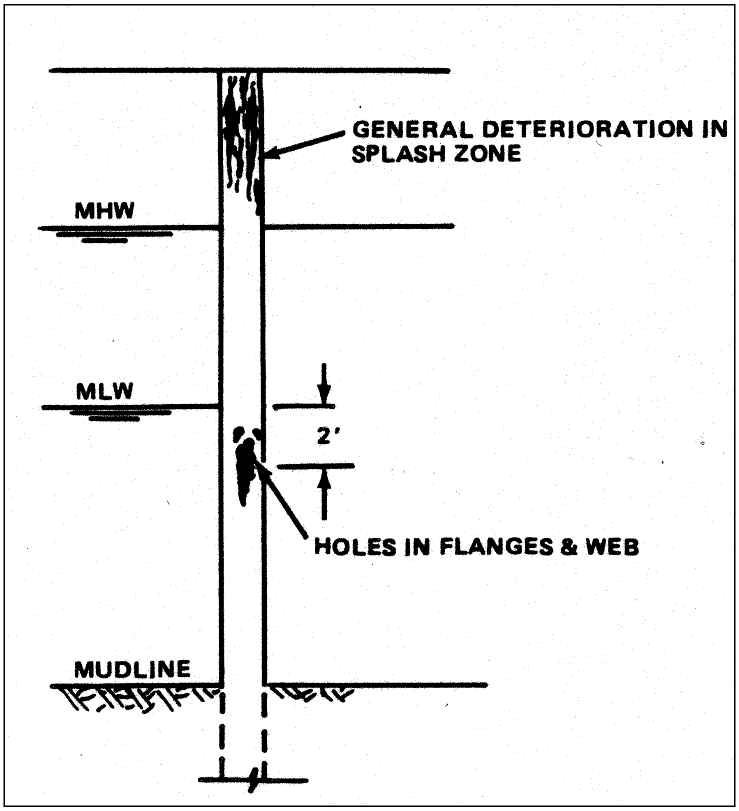


Figure 6-2. Typical Corrosion on Steel H-Piling.

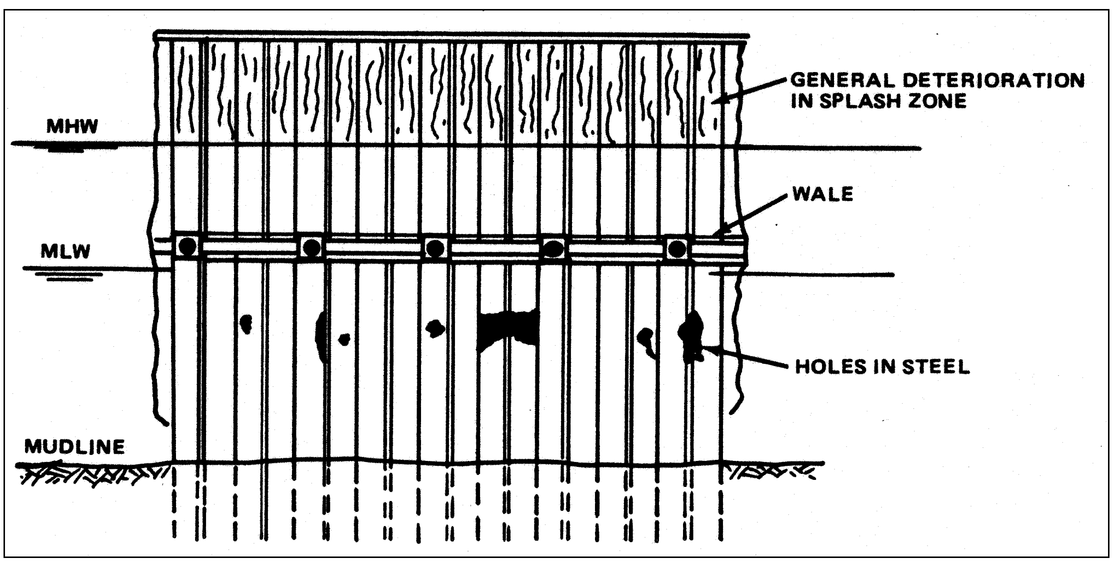


Figure 6-3. Typical Corrosion on Steel Sheet Piling.

6.2.2 Abrasion. Abrasion of steel structures can generally be recognized by a worn, smooth, polished appearance of the surface. Abrasion is caused by continual rubbing of adjacent moving steel surfaces, or by the exposure of structural components to wave action in areas of sandy bottom. Steel sheet piling and pile-supported structures are particularly susceptible to sand abrasion in exposed locations. Abrasion of steel structures is a problem because it removes both protective coatings and protective layers of corrosion products, thus accelerating corrosion.

6.2.3 Structural Connection Loosening. Structural connections joined together by rivets or bolts have a tendency to work loose over an extended period of time. Connection loosening can result from impact loading of the type imparted by a vessel striking a pier or wharf fender system. Wave action and reciprocating machinery mounted on or below pier or wharf decks are other sources of possible connection loosening. Corrosion of bolts, rivets, nuts, washers, and holes can also contribute to connection loosening. Loosening of connections will tend to produce misalignment in mating surfaces, which, in turn, can result in distortion and stress concentrations in framing members.

6.2.4 Fatigue Failure. Fatigue failure results in the fracture of structural members as a consequence of repeated high loading. Fatigue distress can be recognized by a series of small hairline fractures perpendicular to the line of stress in the member. Tubular connections of offshore platforms are particularly susceptible to fatigue failure. Fatigue cracks are difficult to locate. Since fatigue cracks represent an extremely dangerous condition in steel marine structures, extreme care must undertaken when inspecting structural members subjected to repetitive loading, particularly high wave loading.

6.2.5 Overloading. Steel structural elements are sensitive to impact damage from berthing vessels and other types of accidental overloading. Impact or collision damage can generally be recognized by the appearance of local distortion (deformation) of the damaged member. This damage is generally characterized by a sharp crimp or a warped surface as illustrated in Figure 6-4. Compression overloading damage of a steel pile is illustrated in Figure 6-5.

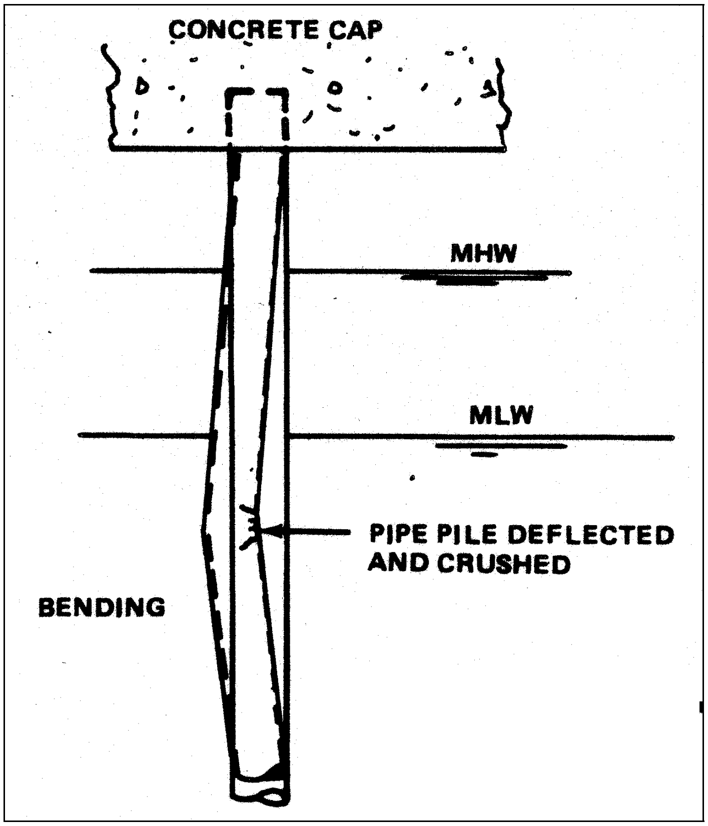


Figure 6-4. Overloading Damage Due to Impact or Collision.

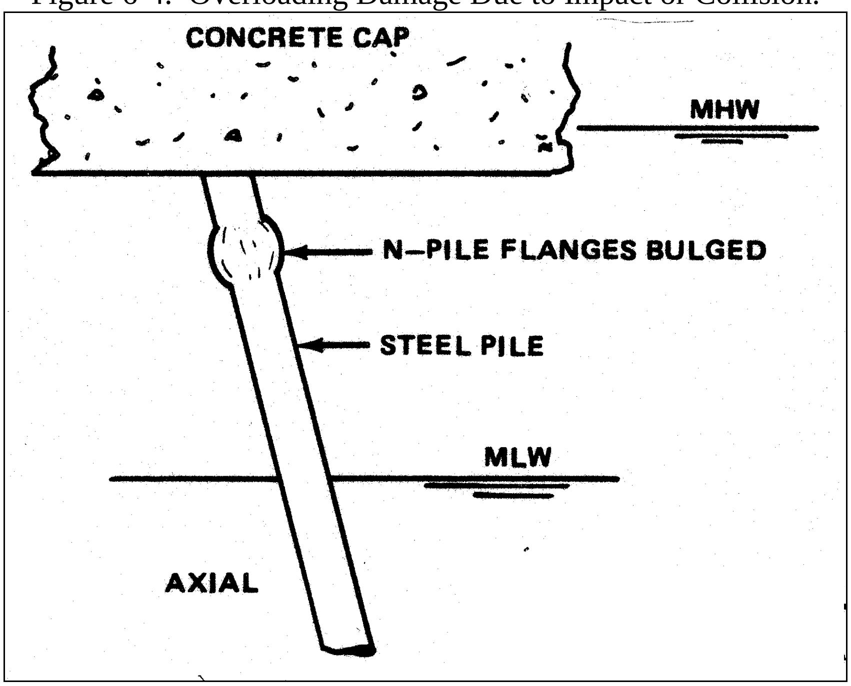


Figure 6-5. Overloading Damage Due to Compression.

6.2.6 Foundation Deterioration. Loss of foundation material from around steel piles leads to accelerated corrosion and loss of column strength of the piles. The loss of foundation material is usually caused by the scouring of material from around the piles. Scouring can be caused by an increase in the velocity of the water passing by the piles or a change in the current's direction. If the piles thus exposed are not protected, eventual collapse of the structure is possible. A loss of foundation material in front of a sheet pile bulkhead may cause kick-out of the toe of the wall and result in total failure.

6.3 Typical Inspection Procedure

6.3.1 Surface Inspections. Generally, visual inspections will allow detection and documentation of most forms of deterioration of steel structures. In the event that more detailed NDT techniques may be required under a Level III inspection, a plan and sampling techniques need to be developed and tailored to the specific areas of concern.

Some types of corrosion may not be detected by visual inspections. For example, inside steel pipe piling, anaerobic bacterial corrosion caused by sulfate-reducing bacteria is especially difficult to detect by visual inspection. Fatigue distress can be recognized by a series of small hairline fractures perpendicular to the line of stress but these are difficult to locate by visual inspection. This type of problem, however, is more prevalent to offshore platforms with welded structural connections than to standard piers and wharves.

Cathodic protection systems need to be closely monitored both visually and electrically for signs of loss of anodes, wear of anodes, disconnected wires, damaged anode suspension systems, and/or low voltage.

6.3.2 Underwater Inspection. Underwater Inspection of a steel waterfront structure should proceed as outlined in Table 6-1.

Table 6-1. Steel Structures Underwater Inspection Checklist.

Checkpoint	Description
1	Start the inspection at the splash/tidal zones and proceed to about 3 feet below the MLW. This is where most mechanical and corrosion damage is normally found.
2	Clean all marine growth from a 1-foot square section of pile (a larger areas, if inspecting sheeting) and visually inspect for rust, scale, and holes.
3	If the structure has a cathodic protection system, check the cleared underwater area with an underwater voltmeter, as shown in Figure 3-22, or use a portable reference electrode and portable reference cell, as shown in Figure 3-23, to determine the effectiveness of the cathodic protection system. Acceptance levels for cathodic protection are -0.80 to -0.90 volt when compared to a silver/silver chloride reference electrode.
4	Sound the surface with a hammer to detect any scaled steel or hollow areas.
5	Inspect holes in steel sheeting for loss of backfill material through the opening and subsidence of adjacent ground surface.
6	Descend, visually inspecting the structure and sounding with a hammer where there is minimal marine growth.
7	At the bottom, record the water depth, using a wrist gauge, on a Plexiglass slate with a grease pencil, or communicate the information to topside personnel.
8	Record other visual observations, such as coating condition (peeling, blistering, erosion). Closely inspect splices for loss of weld materials and looseness.
9	Record the condition of cathodic protection equipment (broken or corroded conduits, loose wires, consumed or lost anodes).
10	Record the extent and type of corrosion, structural damage, or any other significant observations, using calipers and scales to measure the thickness of steel flanges, webs, and plates, and ultrasonic meters to measure the thickness of steel pipe piles and sheet piling.
11	Return to the surface and immediately record the observation data in the inspection log, or communicate data to topside personnel.
12	Where more sophisticated means are required to evaluate the condition of steel piling: • Ultrasonic inspection is available for thickness measurements. Pay particular attention to ensure that the areas are clear of all marine growth and scale. Use of ultra-sonic equipment in areas with corrosion pitting can result in erroneous thickness measurements. • Magnetic particle inspection may be used, particularly on welded connections, to detect cracks and small defects.
Exposed Area Under Pier or Along Wharf	
1	Inspect for structural damage, rust, scale, and holes.
2	Sound the surface with a hammer to detect any scaled steel or hollow areas.
3	Inspect holes in steel sheeting for loss of backfill material through the opening and subsidence of adjacent ground surface.

6.4 Equipment and Tools Required

To ensure a thorough inspection, the area must be cleared of all marine growth. This can be done by various means, depending on surface support. A high-pressure water jet is the most effective method for clearing marine growth sufficiently for visual inspection. Hand tools, such as wire brushes and scrapers are sufficient for smaller jobs. Sounding of the structure can be done with a small hammer or pickax. Inspection of the structure requires some type of underwater data recording device, such as a grease pencil/slate, or hardwire communications with topside personnel. Calipers and scales are used to determine thicknesses of steel flanges, webs, and plates. A portable reference electrode or an underwater voltmeter is used to determine the effectiveness of cathodic protection on steel structures. Table 6-2 gives voltages measured by the underwater voltmeter for steel structures. Visual documentation may be desirable for illustrating problem areas to others who did not physically make the inspection dive. Using an underwater camera or television system can do this.

Table 6-2. Underwater Voltmeter Values for Steel Structures.

Voltage Measured (V)	Description
0.0 to –0.7	Steel is cathodically unprotected. The rate of corrosion depends on the effectiveness of paint or tar coatings, marine growth, and local water chemistry and water currents. On some structures, the hard layer of marine growth may provide some protection. The closer to 0 volts the more active is the corrosion potential. **Note**: -0.6 volt is the potential of bare, unprotected steel in seawater.
-0.7 to –0.82	The steel is partially protected.
-0.83 to –1.1	The steel is adequately protected. Cathodic protection systems are working effectively.
-1.1 or higher negative values	The steel is “overprotected.” **Note**: Under some circumstances, the metal surface can be made more brittle when overprotected. Surface coatings may be damaged or “lifted off” by the excess formation of hydrogen bubbles.

6.4.1 Ultrasonic Inspection. Ultrasonic thickness measurement equipment is available for inspecting steel structures. Thickness measurements are obtained because certain types of ultrasonic waves travel at a constant speed through a material, because they travel in straight lines, and because a portion of the wave is reflected when it meets an interface. The difference in time between the detection of the front surface and back surface echoes is correlated to the thickness of the material. Ultrasonic thickness measurements require a thorough removal of marine growth and scale and can be unreliable if the surface on which the instrument is placed is heavily pitted. Adequate training and experience are required to obtain readings and to evaluate the measurements made with this equipment.

6.4.2 Underwater Magnetic Particle Testing. Underwater magnetic particle testing (UWMT) is a nondestructive method for locating and defining surface discontinuities (such as cracks) in magnetic materials underwater. Its principle of operation is that magnetic particles are attracted to flux leakages at the surface of magnetized materials and form indications of discontinuities located either at or just below the surface.

In operation, the magnetic material or item of interest is magnetized using an electromagnetic yoke specially designed for underwater use. Wherever surface discontinuities exist within the yoke's field of influence, magnetic flux will "leak" from the surface of the part. A slurry of magnetic particles are attracted to, and aligned with, the leaking magnetic flux. The particles are brightly colored and form a visible indication corresponding to the location of discontinuities at or very near the part's surface.

- **UWMT Applications** - Underwater magnetic particle testing is used primarily as a quality assurance tool to support underwater welding on ship structures. It can also be used to inspect hulls or other magnetic components for surface discontinuities such as cracks and lack of fusion in welds. UWMT can be used to define the true length (and locate the true ends) of discontinuities detected visually and to help determine where corrective measures (e.g., stop drilling) should be applied.

- **UWMT Limitations** - As with any inspection method, UWMT has some limitations. These include:

(1) Underwater magnetic particle testing has limited subsurface capability. It is considered to be strictly a method for detecting and measuring surface discontinuities. It is not an approved method for detection of subsurface discontinuities.

(2) The adequacy of inspection with UWMT (as with most nondestructive test methods) is largely a function of the operator's knowledge and skill. Inspections with UWMT are to be performed only by personnel trained and specifically certified in UWMT.

(3) UWMT is limited to ferromagnetic materials, which include most steels. For most applications, a simple check with a magnet is sufficient to determine suitability for UWMT.

- **Certification Requirements for UWMT** - Personnel performing UWMT require certification in UWMT. Certification can only be obtained by training and examination. Divers may be trained by a certified UWMT examiner. Training can be done at either the diver's activity or at the agent's facility.

- **Specific Preparation Requirements for UWMT** - Preparation for conducting UWMT entails assembling all necessary material and personnel required to safely satisfy the plan requirements. Divers must determine that the water current will not affect the application of magnetic particles where UWMT is to be conducted. Water currents greater than 1 knot make it difficult to perform UWMT. Divers must also determine that the underwater visibility is adequate for the interpretation of the test results.

The following paragraphs describe inspection equipment required to conduct UWMT. Inspection equipment specific to UWMT, along with general surface preparation and recording equipment are:

- **Inspection Equipment**

  Electronic yoke with power cable
  Ground fault interrupter (GFI)
  White light source
  U/W-1 magnetic particles with applicator
  Magnetic field indicator

- **Surface Preparation and Restoring Equipment**

  Diver staging (optional)
  Hydraulic or pneumatic hand-held grinder or high-pressure water jet
  Anti-corrosion coating (epoxy)

- **Recording Equipment**

  Stereo and/or still camera (optional)
  Video and monitor system (optional)
  Measuring devices (tape or rule)
  Plexiglas writing slate, grease pencil, arrow punch

UWMT equipment includes:

• **Electromagnetic Yoke** - An electromagnetic yoke is used to induce a magnetic field in the material. The articulation of the yoke's legs allows any pole spacing between 2 inches and 8 inches, and the yoke can accommodate plate offsets of up to 6 inches and joint angles from about 45 degrees to 270 degrees. To minimize the risk of electric shock, no controls are on the yoke. A topside operator energizes the yoke.

• **Power Cable** - A two-conductor power cable with a braided external ground and a protective jacket, delivers power to the electromagnetic yoke. Typical cables are 250 feet long to permit operation in the majority of locations accessible by a surface-supported diver. The external ground braid generates a ground fault whenever the cable is cut; the power conductors cannot be reached except by first penetrating the ground braid.

• **Ground Fault Interrupter (GFI)** - The diver's primary protection from electric shock is an approved isolation transformer/GFI device. The GFI interrupts power when it senses a drop in the resistance between the isolated system power leg and the power supply ground.

• **White Light Source** - A primary illumination source is a Remote Ocean Systems model TUBE-LIGHT.

• **Magnetic Particles** - Magnetic particles are finely divided ferromagnetic particles having a low magnetic retentivity and a high permeability. They are dyed pink to be visible under normal lighting. The particles are mixed with wetting agents and corrosion inhibitors to enhance their underwater performance.

- **Magnetic Particle Applicator** - The magnetic particle applicator is a reservoir of magnetic particles and water that the diver uses to deliver magnetic particles to the surface of the inspection area. A simple and effective magnetic particle applicator is a plastic squeeze bottle that contains a marble-sized object to aid in mixing.

- **Magnetic Field Indicator** - The magnetic field indicator is a small device with crack-like discontinuities on its face. The indicator is used to determine if the inspection site has adequate magnetic flux. The diver places the indicator at the inspection site, topside energizes the yoke, and the diver delivers the particles. A clearly visible accumulation of particles (indications) should then form along the crack-like discontinuities on the pie-shaped magnetic field indicator. In the pie-shaped gauge, the crack-like discontinuities are furnace-brazed joints between adjacent steel wedges. Though a simple test to measure the magnetic field strength inside the material being inspected is unknown, it is assumed that an adequate field just outside the material signifies an adequate field inside as well.

7.0 COMPLIANT MOORINGS

7.1 Types of Compliant Moorings

Compliant moorings allow ships to maintain either a fixed or semi-fixed position. A compliant mooring in common use is the riser free-swinging mooring as shown in Figure 7-1. This type of mooring achieves its holding power through anchors embedded in the seafloor. These anchors are connected to ground leg chains that meet at the ground ring which, in turn, is connected to a riser-type buoy by a riser chain.

Another compliant mooring is the nonriser free-swinging mooring, illustrated in Figure 7-2. This configuration uses anchors embedded in the seafloor that are individually connected to a telephone buoy. Both riser and nonriser moorings require a good deal of unobstructed water surface to allow the ship to rotate around the mooring according to changes in wind and current direction.

A spread mooring eliminates the tendency for the buoy to rotate. This type of mooring uses two or more mooring buoys, usually in conjunction with the ship's anchors, to hold the ship in a fixed position. The most commonly used types of buoys are illustrated in 7-3.

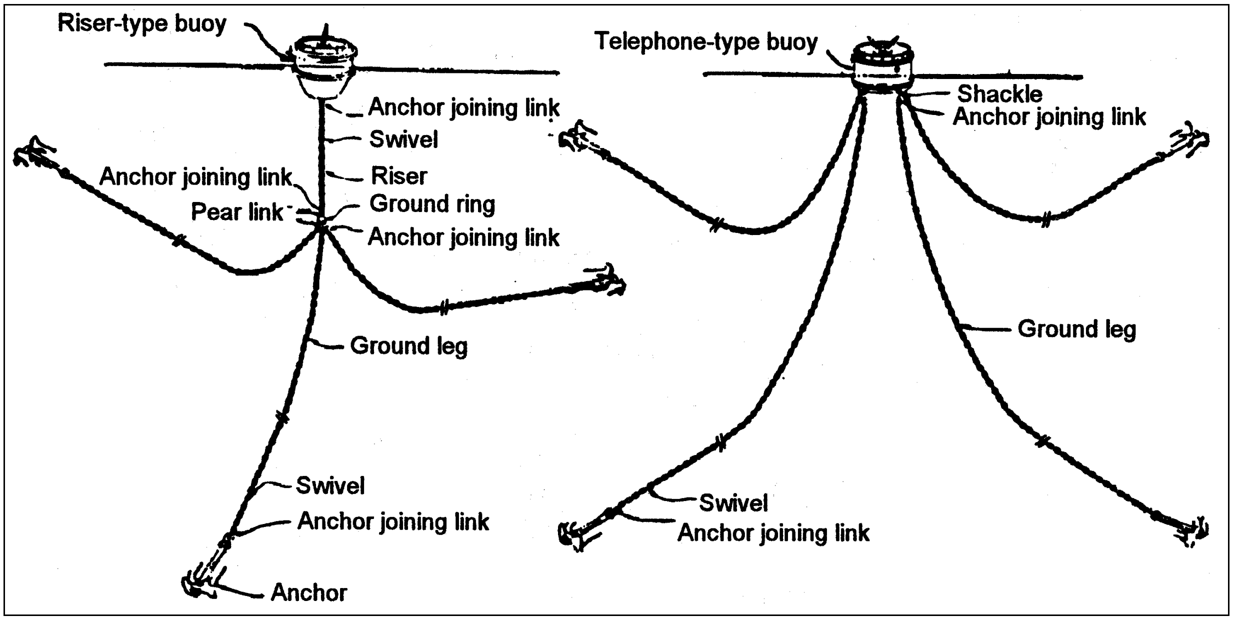


Figure 7-1. Free Swinging Mooring. Figure 7-2. Non-riser Free Swinging Mooring.

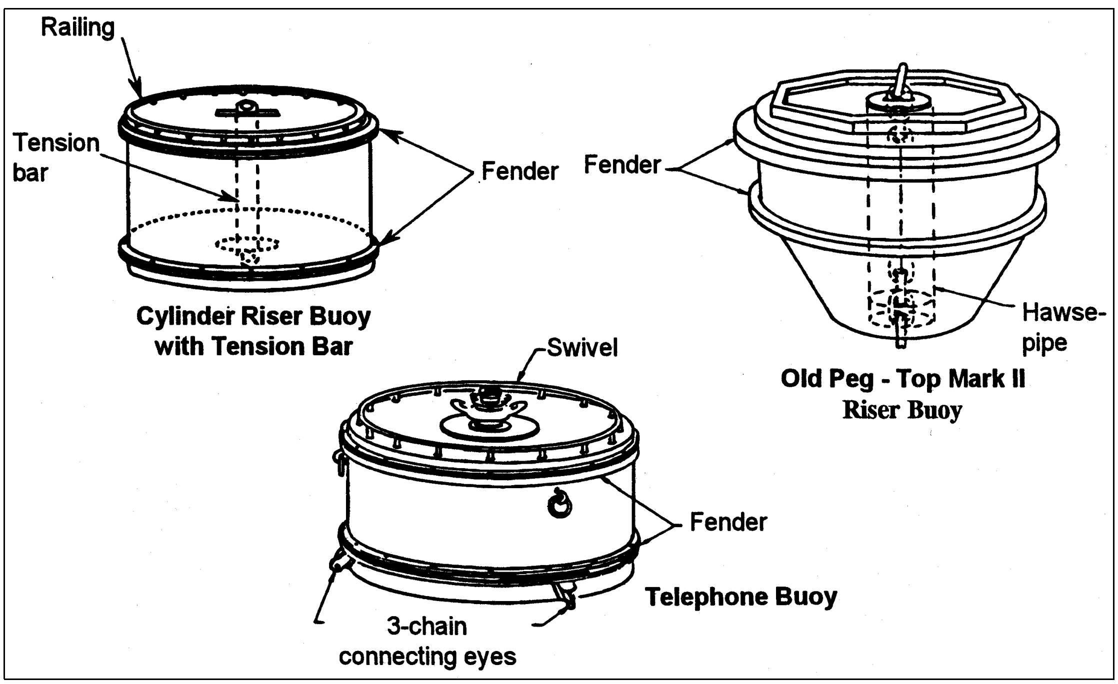


Figure 7.3. Commonly Used Buoys.

7.2 Compliant Mooring Anchors

Not being able to comment on typical mooring anchors that may be found in marine terminal facilities, some common types of anchors used in Navy compliant moorings are:

- **Drag Embedment Anchors**. Of the common drag embedment anchor types found in Navy moorings, the NAVMOOR anchor is typically found in high capacity moorings (Class C -

100,000 pounds and above); while the stabilized Stockless anchor is used in moderate to low capacity moorings (Class C or below). Stockless anchor flukes will be fixed in the fully opened position for mud soil applications.

When mooring load in a ground leg exceeds the capacity of a single anchor, multiple anchors are used side by side or in tandem (piggyback). In mud seafloors, the piggyback and connecting chain will be buried. However, in hard clay and sand seafloors, the connecting chain and hardware will be exposed and available for inspection.

- **Wedge Anchor (Pearl Harbor Anchor)**. This inexpensive anchor may be found in low capacity and short-scope moorings in single and multiple anchor ground legs. Both primary and tandem chain connections and tandem chain often are exposed on the bottom and thus are available for inspection. For rock seafloors, this anchor may be fitted with steel digging plates on the front anchor face, which may be worn or damaged and should be inspected.

- **Direct Embedment Anchors**. Two direct embedment anchor types, which are characterized by their method of installation, are used in Navy compliant moorings. They are the propellant-embedded anchor (PEA) and the pile-driven plate anchor (PDP). The PEA with a wire downhaul cable is fired into the seafloor from a gun (harpoon-like). The wire cable is particularly susceptible to wear at the soil, coral, or rock interface. The PDP is driven into the seafloor by a pile driver and follower assembly. A chain or chain and wire combination can be used with the PDP, but the chain segment always occurs at the soil or coral interface to reduce wear potential. The seafloor interface segment of wire or chain connected to all direct embedment anchors should be inspected.

- **Pile Anchors**. This anchor is used often with bow ground legs of Mediterranean moorings. Its use should be limited in the future due to expanded use of driven plate anchors. The pile anchor to chain connection is usually located below the mudline. Inspection of this connection can be accomplished using a suction dredge to uncover the connection. Inspection is only necessary if severe chain wear/corrosion is evident at the mudline.

7.3 Deterioration of Compliant Moorings

Deterioration of compliant moorings is primarily due to corrosion and wear losses on the mooring chains, fittings, and anchors. Compliant moorings are affected by loss of buoyancy due to accumulations of fouling organisms. Compliant moorings are also affected by both electrochemical corrosion and a form of corrosion known as fretting. Fretting is the combined effect of corrosion and ordinary wear. Fretting and ordinary wear is caused by the relative movement between interconnecting links and fittings under the influence of waves, currents, tidal variations and action from the motion of the buoys. Corrosion and wear of metal components is observed as pitting, holes, cracks, fissures, loose or missing bolts or rivets, and reduction of chain wire diameter. Reduction of chain wire diameter is often greatest at interlink connections.

7.3.1 Chain-Link Measurements. One significant parameter used to evaluate the condition of a mooring is the chain wire diameter. A selective sampling of wire diameter of chain links and connecting hardware is taken to determine the amount of deterioration due to corrosion and wear.

- “Single-link” measurements are taken where chain is slack.

- “Double-link” measurements are taken where two links connect under tension.

Chain links and other chain components that measure greater than 90 percent of original wire diameter are considered to be in “good” condition. Measurement between 80 and 90 percent of original diameter is considered “fair” condition and is cause for the mooring to be downgraded in classification. Measurement less than 80 percent is considered an indication of “poor” condition and is cause for the mooring to be declared unsatisfactory for use.

7.4 Typical Inspection Procedure

Inspecting a compliant mooring should be in accordance with the following checklist. The information should be recorded on a standard compliant mooring underwater inspection report.

7.4.1 Inspection Checklist

1. BUOY UPPER PORTION

a. Overall Condition

- Record buoy type (drum, peg top, etc.).

- Measure and record buoy diameter and freeboard (waterline to top of buoy).

- Buoy overall condition: report any visible damage or listing. If the buoy is listing, determine which inner compartment has water in it.

- Report the color and markings. Ensure that the identification number on the buoy is the same as that depicted on navigation charts; if not, report it.

b. Fiberglass Coating

- Report hull dents or separation of the fiberglass from the buoy. The metal could be indented and the fiberglass could look undamaged.

- Report peeling or loose seams or edges. Fiberglass will often fail there first.

- Report any rust bleeding. This indicates trapped moisture between the fiberglass and the buoy’s hull.

- Report blisters, bubbles, cracks, checking, or glazing that may be hidden under paint.

c. Painted Surfaces

- Report spalling, cracking, peeling, and blisters.

- Report lack of full paint coverage of the buoy or paint discoloration due to chemical reactions or rust bleeding.

MOORING NO. ____________ CLASS. ____________ LOCATION ______________ LAT. ______________ LONG. ______________

ANCHOR TYPES/SIZE: ______________ BUOY TYPE: __________ BUOY DIAM: __________ BUOY COLOR/MARKINGS: ____________

BOTTOM TYPE: ☐ SAND ☐ MUD ☐ CLAY ☐ CORAL ☐ ROCK VISIBILITY __________ D = DEPTH NI = NOT INSPECTED, INACCESSIBLE

COMPONENTS		NI	NEW	CONDITION: SINGLE LINK (%) 90+	SINGLE LINK (%) 80+	SINGLE LINK (%) 80-	DOUBLE LINK (%) 90+	DOUBLE LINK (%) 80+	DOUBLE LINK (%) 80-	D	COMMENT/DESCRIPTION
Chain Measurements											
Riser	Near Buoy										
	Middle										
	Near Grd Rg										
Ground Ring											
Ground Leg No. A	Upper End										
	Middle										
	Enters Bottom										
Ground Leg No. B	Upper End										
	Middle										
	Enters Bottom										
Ground Leg No. C	Upper End										
	Middle										
	Enters Bottom										
Ground Leg No. D	Upper End										
	Middle										
	Enters Bottom										

Component	Condition	Comments/Description
Overall Buoy Condition		
Buoy Fiberglass Coatings		
Paint Condition		

Date: ______________ Engineer in Charge: ______________ Divers: ______________

(Continued on back)

Figure 7-4. Standard mooring inspection report form.

Component	Condition	Comments/Description
Hull Condition		
Top Jewelery		
Top Fenders/Chaffing Strips		
Top Manhole		
Top Tension Bar		
Top Hawsepipe		
Lower Fender		
Lower Hull		
Lower Hawsepipe		
Bottom Jewelery		
Buoy Cathodic Protection		
Bottom Tension Bar		
Joining Hardware		
Swivel		
Top Riser Joint Hardware		
Bottom Riser Joint Hardware		
Ground Ring		
Ground Leg A Joint Hardware		
Ground Leg B Joint Hardware		
Ground Leg C Joint Hardware		
Ground Leg D Joint Hardware		
Ground Leg Swivels		
Chain Anodes		
Visible Anchors		
Anchor Hardware		

Figure 7-4. Standard mooring inspection report form (continued).

d. Top Jewelry

- Identify each component and prepare a sketch depicting the location of each within the top jewelry.

- Report any wear or corrosion of jewelry components.

e. Fenders/Chafing Strips

- Record the number and location of each.

- Record the method of fender/chafing strip attachment.

- Check for and report any loose, rusted, or broken attachments or bolts.

- Check the welds securing the fender/chafing strip mounting brackets to the buoy hull and report any cracks or separation of the welding material from the parent metal.

- Ensure that drainage holes through the chafing strips are open and not clogged with debris.

(1) Timber

- Report any splintering, dry rot, worm/borer holes, or broken sections.

- Record paint type and condition.

(2) Rubber

- Check for and report any rubber brittleness or cracking.

- Record any tears, rips, or missing sections.

(3) Steel Pipe Chafing Rail

- Record pipe rail diameter and height above the deck.

- Check for rust and a secure attachment at the base of the stanchions and rust on the underside of each horizontal rail.

- Record any damage, i.e, dents, fractures, or loose parts on which a line may foul.

f. Manhole Covers

- Report the number, size, and location of each manhole.

- Report rusting of the covers or bolts. The edges of the covers may show a "delamination" of the steel.

- Check for and report any loose or missing bolts.

- On fiberglass-coated buoys, report whether the manhole covers are fiberglassed or not.

g. Tension Bar

- Check eye for wear and measure its diameter with calipers.

- Measure steel bar thickness.

- Check base plate for cracks, warping, or other damage.

- Record plate thickness.

h. Hawsepipe

- Measure and record wire diameter and condition of chain held in place by the retaining plate.

- Check for and report bell mouth rusting or wear.

2. BUOY LOWER PORTION (UNDERWATER)

a. Lower Fender

- Record fender material.

- If timber, report any splintering or broken/missing sections.

- If rubber, report any tears, rips, or missing sections.

- If visible, record fender attachment method.

- Check for and report any rusted, loose, or broken attachments or bolts.

b. Buoy Bottom

- Record marine growth thickness.

- If there is no appreciable marine growth, check and record the type and condition of the protective coating (paint or fiberglass).

- Report any dents or other bottom hull damage.

c. Tension Bar

- Check lower tension bar eye for wear and measure its wire diameter with calipers.

- Check retaining plate and report any observed wear or warping.

d. Hawsepipe

- Measure and record chain wire diameter at the bottom of the hawsepipe.

- Check and report rubbing casting wear. If the rubbing casting is missing, then check for rusting and wear of the bell mouth.

- Ensure that chain is securely attached to rubbing casting.

e. Bottom Jewelry

- Identify and report each type of chain component between lower tension bar eye and riser chain.

- Measure and record component length and wire diameter.

- Report any observed wear or corrosion.

f. Cathodic Protection System on Buoy

- Record number, size, and location of installed anodes.

- Ensure that each anode is securely attached to buoy.

- Use an underwater voltmeter or portable voltmeter and silver/silver chloride reference electrode as described in Section 6.4, measure the potential of the bottom of the buoy in at least three locations and record the potentials. The guidelines for interpretation of the potentials given in Table 7-1 also apply to steel buoy bottoms.

Table 7-1. Underwater Voltmeter Values for Steel Structures.

Voltage Measured (V)	Description
0.0 to –0.7	Steel is cathodically unprotected. The rate of corrosion depends on the effectiveness of paint or tar coatings, marine growth, and local water chemistry and water currents. On some structures, the hard layer of marine growth may provide some protection. The closer to 0 volts the more active the corrosion potential. Note: -0.6 volt is the potential of bare, unprotected steel in seawater.
-0.7 to –0.82	The steel is partially protected.
-0.83 to –1.1	The steel is adequately protected. Cathodic protection systems are working effectively.
-1.1 or higher negative values	The steel is "overprotected." Note: Under some circumstances, the metal surface can be made more brittle when overprotected. Surface coatings may be damaged or "lifted off" by the excess formation of hydrogen bubbles.

3. RISER CHAIN SUBASSEMBLY

a. Links

- Record chain type (cast, forged, Dilok).

- Using appropriate tools, clean the following components for measurements:

  (1) First three links below bottom jewelry.
  (2) Three links just above ground ring.
  (3) Three links about halfway in between these two areas.
  (4) If the riser contains more than one shot of chain, clean links and take measurements at both ends and near the center of each shot.

- In a nonriser-type mooring clean:

  (1) First three links of each leg just below buoy's padeyes.
  (2) Three links just above mudline.
  (3) Three links about halfway in-between.

- Take and record double-link measurements of cleaned links.

- Record length of one of the links cleaned at each area.

- Check for and record manufacturer's markings.

- Check for pitting, measure diameter and depth of any pits found, and record results.

- Record water depth below buoy where each measurement is taken.

b. Connecting Hardware

- If visible, identify and record type of each (shackle, detachable link, anchor joining, etc.). Detachable links should be found on either side of the shackle and at the top and bottom of each chain shot.

- Record component's overall length and wire diameter.

- Report any loose, broken, or missing parts. If visible, note condition of tapered locking pin in a detachable link.

- Record water depth below buoy of each connecting component.

- Record any manufacturer's markings.

Past experience has indicated that the most severe wear occurs at the shackle connecting the mooring buoy padeye with the top link of chain. Special attention is required to inspect this shackle:

- Measure the least diameter of the shackle pin.

- Inspect whether the pin exhibits any outward movement.

- Check and record the condition of locking wire or pin at the end of the shackle pin.

c. Swivel

- Each riser subassembly should contain a swivel. Record swivel depth.

- Check swivel for marine growth.

- Record any manufacturer's markings.

4. GROUND RING SUBASSEMBLY

- Three typical types of ground ring assemblies are:

  (1) A ground ring with four pear links attached.
  (2) A ground ring with four anchor joining links.
  (3) A ground ring with four shackles.

- Record type of ground ring assembly observed.

- Measure and record inside diameter (ID) of ring.

- Check and report any distortion of ring from circular that would indicate overstressing.

- Record height of assembly above bottom, or if the water is too deep, record depth below buoy.

- Using calipers, measure wire diameters of links attached to the ground ring and record results.

- Record any manufacturer's markings.

5. GROUND LEG SUBASSEMBLY

a. Links

- Record chain type installed (cast, forged, Dilok).

- Using appropriate tools, clean the following for measurements:

  (1) First three links of each leg below the ground ring.
  (2) Three links above mudline.
  (3) Three links about halfway in-between these two areas.

- Measure and record double-link measurements of the cleaned links. If one or more legs should extend considerable distances before entering the bottom, clean links and take measurements at both ends and near the center of each visible shot. If chain is not in tension, single-link measurements should be taken and recorded.

- Record length of one of the links at each area.

- Check for and record manufacturer's markings.

- Check for pitting, measure diameter and depth of any pits found, and record results.

- Record each anchor leg length from ground ring to bottom and from where it touches bottom to the point it becomes buried.

- Using a compass, note and record the relative bearing of each leg from the ground ring.

- Repeat above steps for three links at each end of tandem anchor connecting chain (if visible).

b. Connecting Hardware

- Identify and record component type (shackle, detachable link, anchor joining, etc.).

- Record component’s overall length and wire diameter.

- Report any loose, broken, or missing parts.

- Record any manufacturer’s markings.

- Record position of each connecting component by leg number and number of feet from ground ring.

c. Swivel

- Each anchor leg subassembly may contain a swivel. If located, record position by its leg number.

- Record any manufacturer’s markings.

6. ANCHOR ASSEMBLY (if visible)

a. Anchor

- Identify and record type. Note whether or not anchor has stabilizers.

- Attach a pop float and record its bearing from the buoy using a compass.

- Determine and record anchor’s orientation (i.e., flukes buried, flukes up, anchor on its side, anchor facing the wrong direction, etc.).

b. Repeat all of the above for the tandem anchor.

c. Connecting Hardware

- Identify and record component type and location.

- Record component’s overall length and wire diameter.

- Report loose, broken, or missing components.

7. PROPELLANT- EMBEDMENT ANCHORS (if visible)

a. Swage Fittings

- Check for any loose, broken, or missing pins or parts.

- Check for fraying of the wire rope pendant where it enters the swage fitting and report any noted.

b. Pendant/Downhaul Cable

- Measure and record the wire diameter.

- Check for fraying, kinking, “birdcag-ing,” or rusting of the cable and report any noted. Look for a “necking down” of the wire that may indicate the existence of a corrosion cell.

- Record the amount (in feet) of wire pendant visible between the anchor leg and the point that the pendant enters the bottom.

- Report any evidence of pendant cable movement on the bottom.

- Inspect and record any sign of wire rope pullout at the terminations.

8. EQUALIZER (SPIDER)

- Check for rust and wear.

- Note the amount of marine growth located within the equalizer.

9. CHAIN CATHODIC PROTECTION SYSTEM

a. Anodes

- Record anode size and location on the chain.

- Observe and record anode condition and determine whether or not its consumption is uniform.

- Record the color and estimate the thickness of the oxidation coating.

- Ensure secure attachment to the chain and the continuity wire.

- Using an underwater voltmeter, measure and record the chain’s electrical potential.

b. Electrical Continuity- Cables/Clips

- Check and record cable’s secure connection to the chain.

- Probe chain every 15 feet until anchor is reached or chain disappears into the bottom and record the potentials.

- The risers of mooring buoys are commonly protected from corrosion using sacrificial anodes. These anodes are consumed by galvanic action while providing protection for the chain. In order to be effective, electrical continuity between the anode and all chain links must be provided. For the ground legs that are often slack, a connecting wire attached to the chain provides this continuity. The tension in riser chain is normally sufficient to maintain electrical continuity.

7.4.2 Cathodic Protection Inspection. The most common method of cathodically protecting compliant moorings involves the use of 150- to 500-pound zinc anodes attached to buoy hulls and each shot of chain. Underwater voltmeters are used to determine the effectiveness of the system by measuring relative electrical potentials of the buoy and chain at certain distances from the anode. The electrical potential of the metal is the charge of the metal compared to a standard reference electrode, typically silver/silver chloride. Steel that is adequately protected from corrosion should have electrical potentials that fall between -0.80 and -0.90 volts (Table7-1).

A portable voltmeter and portable reference electrode can be used to measure the potential on buoy hulls, but due to water depth and questionable electrical continuity, an underwater voltmeter is required for inspection of the cathodic protection system on chain.

A greater potential indicates that the anode is overworking and serious damage could occur to the metal, while a lesser potential indicates that the system is not operating effectively and corrosion may be occurring.

Compliant mooring inspection divers will normally use a self-contained voltmeter, which consists of a digital display, surface readout facility, and rechargeable battery. Underwater voltmeter readings must be taken at 20-foot intervals on the chain, on each side of each anode, at each end at the continuity cable, and on each side of each swivel. Whenever readings are taken, potentials, depth, and element measured should be recorded. Note that a moored vessel can affect the cathodic protection system on the mooring buoy and chain and cause the readings to be either higher or lower than normal.

7.5 Equipment and Tools Required

Chain measurements are best made with precut “go-no go” gauges, calibrated at 90 and 80 percent of original wire diameter. Calipers (24-inch minimum) are also required, with the measurements taken off a ruler attached to a Plexiglas slate. A 100-foot tape and scales 1, 2, and 3 feet long with large numbers suitable for photo documentation will be required. A diver’s compass and accurate depth gauge, as well as survey buoys, will also be required.

The effectiveness of cathodic protection systems is measured as follows:

- On mooring buoys - either an underwater voltmeter or a portable voltmeter and portable reference electrode can be used.

- On chain - an underwater voltmeter is used.

To record any findings underwater, a grease pencil and Plexiglas slate are required. An underwater camera is required for photographic documentation, and a video recording system may be required. An inclinometer is required for obtaining the angles of mooring chains in nonriser-type moorings and spread moorings. Marker tags are used to relocate or mark links or accessories. Transits and targets are required for locating buoy positions. Because divers need high mobility, and because of the depth of water in which they will be working, the cleaning operations to be performed for inspection work generally require only hand tools, such as wire brushes and scrapers.

At times ROVs may be used to supplement mooring inspections.

8.0 CONCRETE STRUCTURES

8.1 Types of Marine Concrete Structures

Concrete is widely used in the marine environment as a construction material because of its many desirable properties. In its plastic state, concrete is easily mixed, handled, transported, and placed into forms. The strength of concrete can be regulated by adjusting the quantities of cement, aggregate, water, admixtures, and, in particular, the water-to-cement ratio. This ratio is one of the prime considerations in concrete mix design not only to provide adequate concrete strength, but, equally important, to provide long term durability of concrete in the harsh marine environment.

The performance of a concrete structure is most affected by the care taken in its construction and installation. Properly made concrete is highly durable in marine applications, exhibiting resistance to corrosion of reinforcing steel, chemical deterioration, weathering, erosion, and structural damage. Concrete is relatively strong under compressive loading, and with steel reinforcing resists bending and tensile forces. Concrete can be cast in place at the job site, precast into the required shape at a concrete plant and shipped to the site, or prestressed before installation to accept additional loading. With proper procedures, concrete can be rapidly placed underwater where it will harden into good quality concrete.

Circular or square concrete piles (Figure 4-2) are widely used to support piers, wharves, and other structures. Concrete is used as a decking material for many waterfront facilities and in retaining wall structures, such as those needed for closed piers and wharves, bulkheads, quaywalls, dry-docks, and seawalls. It is also used in pavements, bridge foundations, boat loadings and ramps, breakwaters, undersea cable and pipeline stabilization, and offshore structures.

8.2 Deterioration of Marine Concrete

The most common damage resulting from the premature deterioration of concrete structures in or near seawater is cracking and loss of material (or cross section). Softening of the concrete due to chemical action is another form of damage but less common than cracking. As shown in Table 8-1, the damage to concrete is generally most severe in the splash and tidal zones, but does occur in all zones. The different exposure zones are shown in Figure 5-1.

Deterioration of concrete waterfront structures is caused primarily by:

- Corrosion of steel reinforcement
- Repetitive freezing and thawing of moist concrete
- Abrasion
- Chemical deterioration from saltwater
- Structural overloading
- Shrinkage
- Swelling

Concrete damage is found by walking the pier deck, by inspecting below the pier deck with a small boat or barge, and by underwater inspections. The primary method of inspecting concrete is by visual observation. Most durability problems will be detected visually using hand tools such as pick and hammer. Only after problems are detected should other inspection methods such as probes, coring or sonic test equipment be considered.

Table 8-1. Types of Damage in Marine Concrete.

Description of Damage	Zone (Location)[a]		Common Causes of Damage					
	Observed	Most Severe	Corrosion of Reinforcement	Freeze-Thaw	Abrasion	Sulfate Attack	Chemical Reaction of Aggregates	Structural Overload
Cracking	All	T	X[b]	X			X	X
Loss of material-[c] Exposed Rein-forcment and/or Aggregate	All	S, T	X	X	X	X	X	X
Material	S, T, Su	S, T				X		

[a]A = Atmospheric zone: S = Splash zone; T = Tidal zone; Su = Submerged zone; M = Mud zone (see Figure 3-11).
[b]Rust stains on the concrete surface are generally a symptom of corrosion of the reinforcement.
[c]Loss of material from spalling, scaling, disintegration.

The three most common visual signs of concrete deterioration in marine structures are: cracking, disintegration, and spalling. Disintegration is defined as an overall decay of the concrete involving loss of strength of the cement and sand paste and subsequent loosening or loss of coarse aggregate particles. Spalling is defined as a localized area or fragment of concrete falling away from the structure. Both disintegration and spalling can expose reinforcing steel.

The causes for each symptom of deterioration are many and varied, and in most cases of progressing deterioration, they occur simultaneously. Much concrete deterioration in the marine environment starts as a result of poor construction techniques and inadequate inspection and quality control during construction. To develop a suitable and adequate concrete repair procedure, the cause of deterioration must be determined. Causes of concrete deterioration are described.

8.2.1 Corrosion of Reinforcing Steel. With the exception of mass gravity structures, most marine concrete structures use steel reinforcement. This reinforcement, to be most effective, is nearly always located within a few inches of the concrete surface, making the steel susceptible to corrosion if it does not have adequate cover of good quality concrete. Corrosion is more likely to occur if the concrete is overly porous or if cracking is initiated by some action.

The reinforcing steel corrosion products (rust) can increase the volume of the rusted area up to eight times. This leads to cracking of the concrete cover in lines parallel to the reinforcing steel. Eventually spalling results, and in cases of close reinforcement spacing, a complete delamination of the concrete surface can occur.

All concrete is porous to some extent. The degree of porosity is dependent primarily on the water/cement (w/c) ratio of the concrete mix and on good construction practices. The lower the w/c ratio, the more dense (less porous) the concrete which limits the rate at which water, dissolved oxygen, and chloride ions reach the reinforcing steel, and lengthens the time for corrosion of the rebar to damage the concrete.

For example, reinforced marine concrete made with a w/c ratio of 0.6 to 0.7 (7 or 8 gallons of water per 94-pound sack of cement) will show rebar corrosion, cracking, and spalling in a few years, whereas well made concrete with a w/c of 0.4 (about 4-1/2 gallons of water per sack of cement) will likely serve several decades or more before serious deterioration occurs.

8.2.2 Freeze/Thaw Deterioration. Freeze/thaw deterioration is the freezing of absorbed moisture or water in porous concrete exposed to subfreezing temperatures. This is one of the most common causes of concrete deterioration in the tidal and splash zones. Upon freezing, this entrapped water expands and cracks the concrete. Upon thawing, the cracked surface disintegrates. Repeated cycles of freezing and thawing can lead to partial or even total loss of the concrete cross section, thus exposing the reinforcing steel which then rapidly corrodes as illustrated in Figure 8-1. The best prevention of freeze/thaw damage is to use air-entrained concrete with a rich cement content and a low water/cement ratio.

Precast concrete piles may have a cast-in-place jet pipe that was not filled with concrete after the pile was driven. When the water in the pipe freezes, it can cause longitudinal cracks in the pile, as illustrated in Figure 8-2.

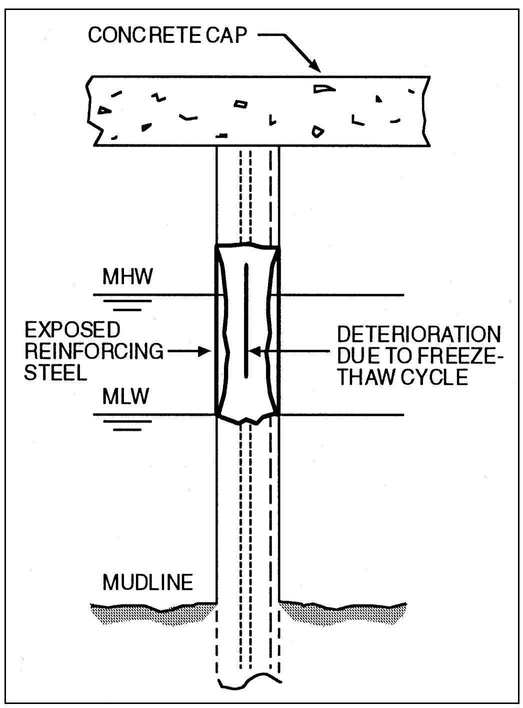


Figure 8-1. Loss of Concrete Cross Section Due to Freeze/Thaw Cycle.

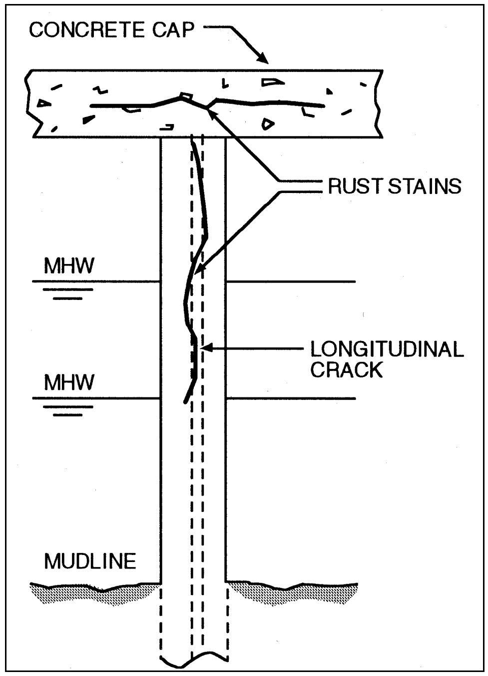


Figure 8-2. Longitudinal Cracks in Precast Concrete Pile from Freezing of Cast-in-Place Jet Pipe.

8.2.3 Abrasion Wear. Abrasion is defined as erosion of a concrete surface by the physical action (impact and rubbing) of external loadings or abrading agents. Deck slabs are subject to abrasion by vehicular traffic and loading equipment. Deck edges and wharf faces at berthing spaces without adequate fendering are abraded by moored vessels. Frequently, concrete piles and walls are abraded in the tidal zone by floating debris moved by currents, waves, propeller wash, and tide changes. Less frequently, submerged concrete, especially at the mudline, is abraded by silt, sand, and debris churned up by moving water. Figure 8-3 illustrates the effects of abrasion on a concrete pile.

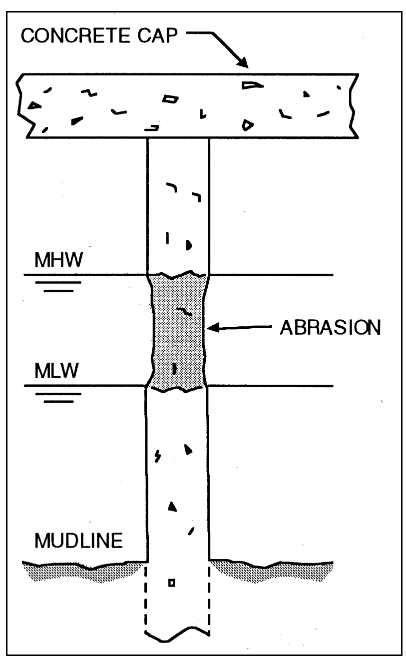


Figure 8-3. Abrasion Effects on a Concrete Pile.

8.2.4 Chemical Deterioration. The most significant and serious saltwater chemical reaction to hardened concrete is the combining of sulfates in seawater with chemicals in the cement paste, referred to as sulphate attack. This reaction can produce internal expansion and cause cracking. More commonly, however, the hydrate cement paste looses strength and becomes soft. Aggregate particles become exposed or fall from the concrete mass because of the weak cement paste.

8.2.5 Axial Overloading. Deterioration of concrete piles from axial overloading can be a cause of eventual failure of the pile. Overloading can result from superimposed "dead" and "live" loads exceeding the bearing capacity of the pile, and also from overstressing at the time of pile driving. Pile driving overloading often results in hairline cracks at the top of the pile or circumferential cracks at other locations along the pile that are difficult to see, as illustrated in Figure 8-4. As marine growth covers the pile, the cracks become extremely difficult to detect.

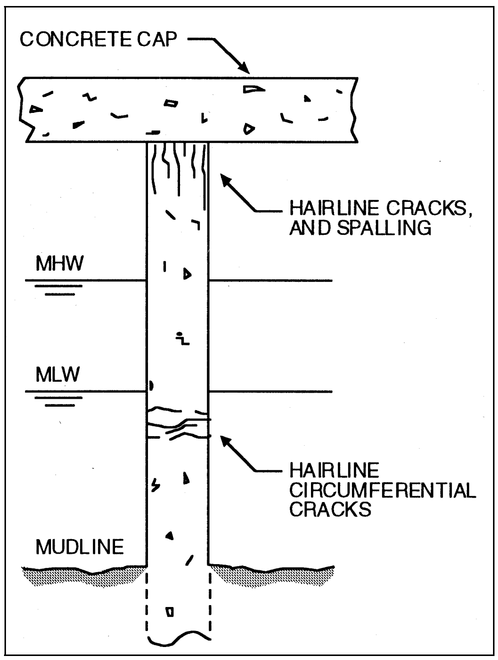


Figure 8-4. Pile Driving Overloading Effects.

8.2.6 Shrinkage. Shrinkage or contraction can occur from moisture or temperature changes. Hardened concrete that looses internal water due to evaporation will shrink. Any temperature decrease of the concrete will cause contraction. The major cause of microcracks within concrete is from high temperatures generated from the normal hydration of cement. The concrete hardens at a high temperature and later cools to ambient temperatures. Precast concrete members that have been steam cured are particularly susceptible to microcrack formation. If the shrinkage or contraction is restrained, internal stresses may develop in sufficient magnitude to cause significant cracks in the structure.

Variations in atmospheric temperature cause a change in temperature of a hardened concrete mass, which results in volumetric changes. Provisions must be made to permit this expansion and contraction process to take place. Failure to do so will result in contraction stresses (tension), which may cause cracking, or expansion stresses (compression), which may lead to spalling.

8.2.7 Swelling. Concrete that increases in moisture content by absorbing water or increases in temperature will swell or expand. Typically, swelling by water absorption is not a concern unless precast dry-concrete members are used. Temperature increases from daily and seasonal changes may cause cracking in some concrete members.

8.2.8 Other Deterioration Factors. The proceeding has discussed deterioration in concrete caused by improper selection or proportioning of concrete materials, faulty construction methods and procedures, and attack by environmental forces. Of equal importance, and a major cause of much concrete deterioration, is poor design of concrete structural details.

A few examples of poor design and construction details that contribute to concrete failure and deterioration are:

- Congestion of reinforcing steel
- Lack of adequate cover for reinforcing steel
- Abrupt change in size of section
- Reentrant corners
- Lack of chamfers and fillets at corners
- Rigid joints between precast units
- Construction joint leakage
- Poorly designed scuppers, drips, and curb slots
- Inadequate drainage
- Too little gap at expansion joints
- Incompatibility of materials or sections

8.3 Concrete Inspection Procedure

8.3.1 Surface Inspections. The areas below should be inspected to ensure a thorough inspection of concrete structures and their attachments above water. Include annual load testing of the pier decking if heavy equipment or vehicles are to be driven onto the pier. Areas where the inspector should be particularly watchful for signs of deterioration include:

(1) Inside corners and areas where radical changes occur in size of deck sections.

(2) Deck expansion joints where insufficient gap is allowed, rigid joints between precast units, and construction joints in general.

(3) Poorly designed scuppers, drips, and curb slots, and other areas where inadequate drainage exists.

(4) Joints between the deck and pile cap, expansion joints where insufficient gap is allowed, and rigid joints between precast piles and cast-in-place pile caps.

The inspector should be alert for any change in appearance of the concrete surface and any change in sound from the hammer. Chemical attack will be indicated by erosion of surface material or by cracking on the surface. Freeze-thaw deterioration will appear as erosion of surface material. A hammer or gad (sharp pointed tool), should be used to chip or probe the surface to detect the depth of deterioration.

Corrosion of reinforcement materials can be detected from rust stains on the surface. More advanced stages of corrosion are indicated by cracks that run parallel to the steel reinforcing bars. At times, corrosion is hidden from view, but will be indicated by a hollow sound from the hammer. This can occur on heavily reinforced slabs, such as pier decks, where the reinforcement has corroded enough to spall a layer of concrete at the level of the reinforcing mat.

Cracks found on the surface of a concrete structure should be given careful attention. Sketches should be made to show the length and direction of the cracks. Overall cracking patterns and changes in crack length, width and direction with time are meaningful data to a structural engineer. Photographs are helpful, but only as a supplement to the sketches.

If there is evidence of significant deterioration, more detailed NDT techniques may be employed in a scheduled Level III inspection. Refer to the Level III Test Procedures for Concrete Inspection for mechanical and electrical test methods. The plan and sampling techniques shall be tailored to the specific areas of concern.

8.3.2 Underwater Inspection

8.3.2.1 Visual Inspection. Levels I and II visual inspection of concrete waterfront structures should proceed as shown in Table 8-2.

Table 8-2. Concrete Structure Underwater Inspection Checklist.

Checkpoint	Description
1	Inspect the structure beginning in the splash/tidal zone. This is where most mechanical and biological damage is normally found.
2	Clear a section about 18 to 24 inches in length of all marine growth.
3	Visually inspect this area for cracks, abraided surface spalling, or mechanical damage, and exposed reinforcing steel.
4	Sound the cleaned area with a hammer to detect any loose layers of concrete hollow spots in the pile, structure, or soft concrete. A sharp ringing noise indicates sound concrete. A soft surface will be detected, not only by a sound change, but also by a change in the rebound, or feel, of the hammer. A thud or hollow sound indicates a delaminated layer of concrete, most likely from corrosion of steel reinforcement.
5	Descend, visually inspecting the pile or structure where marine growth is minimal, and sound with a hammer.
6	Inspect in greater detail the base of mass structures, such as foundations, quaywalls, breakwaters, or bridge piers. These types of structures are prone to undermining by wave and current action, which, if not rectified, could lead to failure of the structure.
7	At the bottom, record the water depth along with any observations of damage on a Plexiglas slated.
8	After returning to the surface, immediately record all information into the inspection log. NOTE: If signs of deteriorations are found, then a Level III inspection, involving either nondestructive or destructive tests, may be required. Refer to the Level III Test Procedures for Concrete Inspection for mechanical and electrical test methods.
Exposed Area Under Pier or Along Wharf or Dolphin Assembly	
9	Check pile caps and bearing, batter, and fender piles for damaged or broken members, cracks, and spalling of concrete, rust stains, and exposed reinforcing steel.
10	Sound the piling or structure with a hammer to detect any loose layers of concrete or hollow spots. A sharp ringing noise indicates sound concrete. A soft surface will be detected, not only by a sound change, but also by a change in the rebound, or feel, of the hammer. A thud or hollow sound indicates a delaminated layer of concrete, most likely from corrosion of steel reinforcement. **NOTE**: If signs of deterioration are found, then a Level III inspection, involving either nondestructive or destructive tests, may be required. Refer to the Level III Test Procedures for Concrete Inspection for mechanical and electrical test methods.

8.3.2.2 Level III Nondestructive Inspection of Concrete. The qualitative data obtained from visual inspections are sometimes inadequate to accurately assess the condition of the structure. In these instances, quantitative data obtained from nondestructive testing instruments can assist the facilities engineer in determining the condition of the structure. Three specialized instruments have been developed for underwater inspection of concrete structures. These instruments are the:

- **Magnetic rebar locator** - used to determine the location and orientation of rebar in concrete structures and to measure the amount of concrete cover over the rebar.

- **Rebound hammer** - used to evaluate the surface hardness of the concrete and obtain a general condition assessment.

- **Ultrasonic system -** used to obtain a general condition rating and indication of overall strength of the concrete based on sound velocity measurements through a large volume of the structural element.

Each instrument consists of an underwater sensor connected to a topside deck unit through an umbilical cable. The deck unit contains the signal conditioning electronics and data acquisition system. To operate the instruments, the diver has to position the underwater sensor on a previously cleaned portion of the structure surface and a person topside must operate the data acquisition system in order to collect and store the data. Each instrument is independently operated and provides unique information to help assess the condition of the concrete structure.

8.4 Equipment and Tools Required

To perform a thorough inspection, the marine growth on the structure must be removed. A "Barnacle Buster" or pneumatic chipping gun is an efficient method of removing marine growth from concrete surfaces. Various types of high-pressure water jet cleaning systems are also effective. Exercise care in the use of these methods because they may further damage a deteriorating concrete structure. If minimal marine growth is found in the splash/tidal area, small hand tools, such as wire brushes and scrapers, are sufficient. A hammer for sounding and an accurate water-depth gauge will be required. Record observations on a Plexiglas slate with a grease pencil. Use underwater video cameras for permanent visual documentation.

8.4.1 Magnetic Rebar Locator. The magnetic rebar locator is an instrument that detects the disturbances in a magnetic flux field caused by the presence of magnetic material. The magnitude of this disturbance is used to determine the location and orientation of rebar in concrete structures and to measure the amount of concrete cover over the rebar. The system consists of an underwater test probe, an umbilical cable, and a topside data acquisition unit (DAU) including printer.

The test probe consists of two coils mounted on a U-shaped magnetic core. A magnetic field is produced in one coil and the disturbance-induced magnetic field in the rebar is measured in the other coil. The magnitude of the induced current is affected by both the diameter of the rebar and its distance from the coils. Therefore, if either of the parameters is known, the other can be determined. By scanning with the probe until a peak reading is obtained, the location of the rebar can also be determined. A maximum deflection of the meter needle will occur when the axis of the probe poles are parallel to and directly over the axis of a reinforcing bar, thus indicating orientation.

The underwater rebar locator is calibrated for rebar that varies from No. 3 to No. 16 in size. The meter can be used to measure the depth of concrete cover over rebar in the range of l/4 to 8 inches thick, or conversely, it can measure the diameter of the rebar. The best accuracy (±10 percent) is obtained for concrete cover less than 4 inches thick.

- **System Limitations**. The presence of other metallic objects in the vicinity where the measurements are being made can affect the operation of the rebar locator. For example, in heavily reinforced structures, the effect of nearby rebar cannot be eliminated and accurate depth readings are difficult or impossible. If the separation of two parallel rebars is at least three times the thickness of the concrete cover, this effect can be neglected. The presence of rebar perpendicular to the axis of the underwater probe has less effect on the measurement of concrete cover than that of parallel rebar, and in most instances it can be ignored.

8.4.2 Rebound Hammer. The underwater rebound hammer system, is a surface hardness tester that can be used to obtain a general condition assessment of concrete. The system consists of an underwater rebound hammer, an umbilical cable, and a topside data acquisition unit (DAU) including printer. The rebound hammer is mounted in a waterproof housing which contains an electrical pickup to sense the position of the rebound mechanism. The umbilical connects the underwater rebound hammer to the DAU that contains the signal conditioning electronics and data acquisition system.

The rebound hammer correlates the rebound height of a spring-driven mass after it impacts the surface of the concrete with the compressive strength of the concrete under test. The spring-driven mass slides on a guide rod within the tubular housing. When the impact plunger is pressed firmly against the concrete surface, a trigger releases the spring-loaded mass causing it to impact the plunger and transfers the energy to the concrete surface. The mass then rebounds and the rebound height is correlated to the surface hardness of the concrete.

A general calibration chart relates the rebound number to cube compressive strength for the underwater rebound hammer. The pressure housing has a depth rating of 190 feet and it is pressure compensated at 5 psi over the ambient pressure. Air is supplied to the rebound hammer from a scuba tank through the umbilical cable via an external pressure regulator to maintain the positive pressure differential inside the housing.

- **System Limitations**. The following characteristics of concrete can affect the correlation of the rebound number with the actual surface hardness and should be understood before using the instrument:

(1) Higher rebound numbers are generally obtained from smoother surfaces and the scatter in the data tends to be less. Minimizing the data scatter increases the confidence in the test results. Therefore, underwater concrete surfaces must be thoroughly cleaned and smoothed with a carborundum stone (or similar abrasive) before measurements are taken.

(2) Water-saturated concrete tends to show rebound readings approximately 5 points lower than for the same concrete tested dry. This affects the comparison of data taken above and below the waterline.

(3) Type of aggregate and cement affects the correlation of the rebound numbers with actual compressive strength of the concrete under test. A calibration curve is required for each particular concrete mix to assure accuracy. Since this is not practical for most situations, the data should only be used for making comparative measurements from one location to another within a uniform concrete structure.

Because of these limitations, the estimation of concrete compressive strength obtained with a rebound hammer is only accurate to about ±25 percent. This applies to concrete specimens cast, cured, and tested under the identical conditions as those from which the calibration curves were established. The rebound hammer is primarily useful for checking surface compressive strength or surface hardness and uniformity of concrete within a structure. It can also be used to compare one concrete structure against another if they are known to be reasonably similar.

8.4.3 Ultrasonic System. The ultrasonic system is used to obtain a general condition rating and indication of overall strength of the concrete based on sound velocity measurements through a large volume of the structural element. It is recommended that the underwater ultrasonic system be used primarily for checking the uniformity of concrete from one test location to another in a given structure. If the data consistently indicate poor or very poor quality concrete, core samples must be taken and standard compression tests performed to confirm the results.

The system consists of two different underwater transducer holders for direct and indirect sound velocity measurements. An umbilical cable connects either the direct or indirect transducer holder to the topside DAU. The DAU contains most of the signal conditioning electronics and data acquisition system.

Ultrasonic techniques use the transit time of high-frequency sound waves through concrete to assess its condition. Ultrasonic testing procedures for concrete have been standardized by ASTM Standard C597 and test equipment is available from commercial sources for in-air testing. Measuring sound velocity in concrete requires using a separate transmit and receive transducer to avoid energy scattering and reflection problems. Sound velocity is calculated by measuring the time required to transmit over a known path length. The average sound velocity obtained should only be used as an indicator of concrete quality and not as a measurement of compressive strength. Table 8-3 presents some suggested condition ratings for concrete based on sound velocity measurements.

Table 8-3. General Condition Rating Based on Sound Velocity.

Condition Rating	Sound Velocity (ft/sec)
Excellent	> 15,000
Good	12,000 – 15,000
Questionable	10,000 – 12,000
Poor	7,000 – 10,000
Very Poor	<7,000

The two methods used to measure sound velocity in concrete are direct and indirect. The most preferred method is direct transmission where the transducers are positioned on opposite sides of the test specimen and the waves propagate directly toward the receiver. This method provides maximum sensitivity with a well-defined path length.

Indirect transmission is used when only one surface of the concrete is accessible, such as a concrete retaining wall: both transducers are placed on the same side of the concrete. With this method, energy scattered by discontinuities within the concrete is detected by the receive transducer.

- **Transducer Holders**. Two types of transducer holders are provided with the ultrasonic system. The direct transducer holder is used to examine structures with accessible opposing surfaces; for example, concrete piles. The indirect transducer holder is used to examine structures with only one accessible surface; for example, concrete bulkheads.

The direct transducer holder framework can be adjusted to accommodate concrete pile sections that range from 8 inches to 24 inches thick. The digital display of sound wave transit time provides feedback to help the diver position the transducer holder for optimum results.

The indirect transducer holder is very similar to the direct transducer holder in operation except for the path length measurement that is fixed at 12 inches. A suction cup was added to the indirect holder to force the transmit transducer firmly against the concrete surface under test and provide a reaction force for the diver. A small suction pump is used to pump water from the cup to provide a holding force of about 25 pounds depending on the surface condition of the concrete.

- **System Limitations**. Results obtained with the ultrasonic test system are affected by the following factors which influence the quality of the data:

(1) **Concrete Surface Finish** - The smoothness of the surface under test is important for maintaining good acoustical coupling between the transmit transducer and the surface of the concrete. A coupling agent, such as silicone grease, must be placed between the transmit transducer and the concrete surface to transfer maximum energy. If a coupling agent is not used, the transmitted signal will be severely attenuated which results in large errors in the measurement of the transit time.

(2) **Reinforcing Steel** - Sound velocity measurements taken near steel reinforcing bars may be higher because the sound velocity in steel is from 1.2 to 1.9 times the velocity in concrete. The effect is small when the axis of the rebar is perpendicular to the direction of sound propagation and the correction factors are on the order of 1 to 4 percent depending on the quality of the concrete. If the axes of the rebar are parallel to the direction of sound propagation, reliable corrections are difficult. Therefore, it is recommended that sound transmission paths be chosen that avoid the influence of the rebar.

(3) **Signal Detection Threshold** - The signal detection threshold of the ultrasonic system can cause erroneous transit time data to be recorded. This happens when the amplitude of the first peak of the received signal is below the threshold triggering level of the system. When the instrument detects a following peak, this causes an apparent transit time increase of one-half wavelength or more.

9.0 TIMBER STRUCTURES

9.1 Types of Timber Structures

Timber is used in marine applications as a construction material chiefly because of its low initial cost and the ease with which it can be procured, transported, and constructed into required shapes. Timber has a wide range of uses in marine construction. It can be used as pile material for waterfront structures such as piers and wharves; as decking and framing material for the upper portion of waterfront structures, fender piles, and dolphins; and as construction material for bulkheads and retaining walls. Softwood timber, such as fir and pine, must be pressure treated with an appropriate preservative before it is used in the marine environment. Hardwoods, such as oak and greenhart, which are often used in fender systems, are not treated.

9.2 Deterioration of Timber Structures

Timber structures are subject to deterioration from decay or rot, attack by marine borers and insects, splitting and checking brought about by drying shrinkage or by the alternate wetting and drying cycle within the splash zone, overloading, corrosion of connections, abrasion, and ice heaving. Waterfront deterioration and damage is found by walking the pier, by inspecting dolphins and below pier decks in a small boat or barge, and by underwater inspections.

When inspecting above the water surface, the inspector should take maximum advantage of low tide conditions to visually observe the overall condition of the piling. This may lead to the determination that an underwater inspection is necessary. The underwater inspection should, on the other hand, take maximum advantage of high water conditions in order to compile the most comprehensive field data on existing conditions.

9.2.1 Fungi and Rot Damage. Several species of fungi exist by feeding on timber, causing a breakdown within the cellular structure of timber under attack. In the early stages, fungi attack is evident by a discoloration and softening of the wood accompanied by a fluffy or cottony appearance. Advanced attack will cause destruction of the wood cells and the appearance of fruiting bodies, such as mushrooms. Figure 9-1 illustrates the effect of timber rot. The rapidity of decay is dependent upon the fungi species, variety of wood, exposure, and climate. To live, fungi must have air, food (the wood), favorable temperature, and a moisture content of over 20 percent, which is generally higher than that of typical air-dried wood. Submerged timber will not rot because of a lack of air. Fungi growth takes place in all saltwater environments within the temperature range of 50 to 90°F. As the temperature level drops to freezing, fungi growth becomes dormant, but will reactivate when the temperature increases.

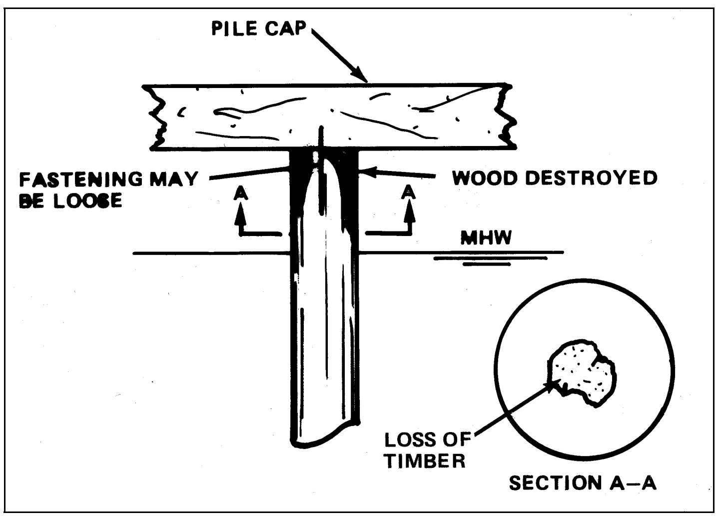


Figure 9-1. Effects of Timber Rot.

9.2.2 Marine Borer and Insect Attack. Marine borer attack is a very serious problem for timber structures in the splash and submerged zones. The ravaging effects of two large groups of marine invertebrates, the Teredo (commonly called shipworms) and the Limnoria (commonly called woodgribbles), are well-documented.

Shipworms are mollusks and are distantly related to the oyster and the clam, even though the adult form is worm-like in appearance. Shipworm species are found in nearly all saltwater harbors and oceans of the world, except for the colder waters of the Arctic and Antarctic regions.

Adult shipworms eject their young into the water at birth. These miniature animals are driven by tides and currents until they settle on firm surfaces or die. Should they settle on submerged timber during the first 48 hours of their life, they begin to change in physical appearance, with the body beginning to elongate, while two clam-like shells begin to auger into the wood. The original hole in the timber surface created by the infant shipworm is no larger than the diameter of a pinhead.

As the shipworm continues to burrow and grow, it becomes more worm-like in appearance, with its body increasing in diameter to completely fill its burrow. In time, the animal orients its body parallel to the grains of the timber member. A calcium-like white excretion is left behind on the walls of the burrow track. As the exterior timber deteriorates via other means, these white trails become an obvious indication of shipworm presence. Eventually, the interior of a timber pile or beam under shipworm attack will become completely riddled with burrows, although externally no evidence of attack is apparent.

In tropical climates, shipworms have been known to grow to 6 feet in length and as much as 3 inches in diameter. In temperate climates, such as North America, shipworms generally range between 6 to 8 inches in length and about 1/2 inch in diameter. Figure 9-2 illustrates the damage caused by shipworms.

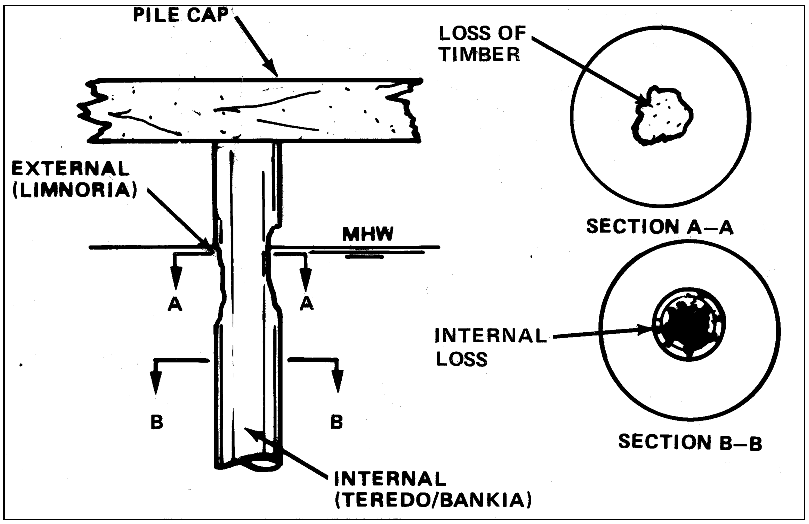


Figure 9-2. Damage to Timber Pile Caused by Shipworms.

Woodgribbles are crustaceans related distantly to the crab and shrimp family. They are quite small, averaging only 1/8 to 1/4 inch in length. This tiny organism is a voracious wood chewer, with its appendages and mouth developed for rasping and biting.

At birth, the woodgribble mother retains the young within a pouch until they develop sufficiently to fend for themselves. She then releases them within her furrow and they proceed to dig side furrows. Ordinarily woodgribbles do not burow deeply into the timber surface but limit their attack to shallow surface trenches. In timber piling, this results in a slow but continual reduction in pile diameter. Damage is most frequently found at the waterline or mudline, where the woodgribble population is the greatest. Severe attack will produce an hourglass appearance in piling, as illustrated in Figure 9-3, reducing the outside diameter of untreated pine or Douglas fir by up to 6 inches in 1 year.

Termites are the most destructive type of insect life to attack above-water and onshore timbers. They feed on the cellulose matter contained in timber. If termite damage is suspected, an ice pick makes an ideal tool to determine their presence, as a serious attack will eat away large interior portions of the wood just below the surface of the timber. Timbers most subject to attack are curbs and blocking on bulkhead fills.

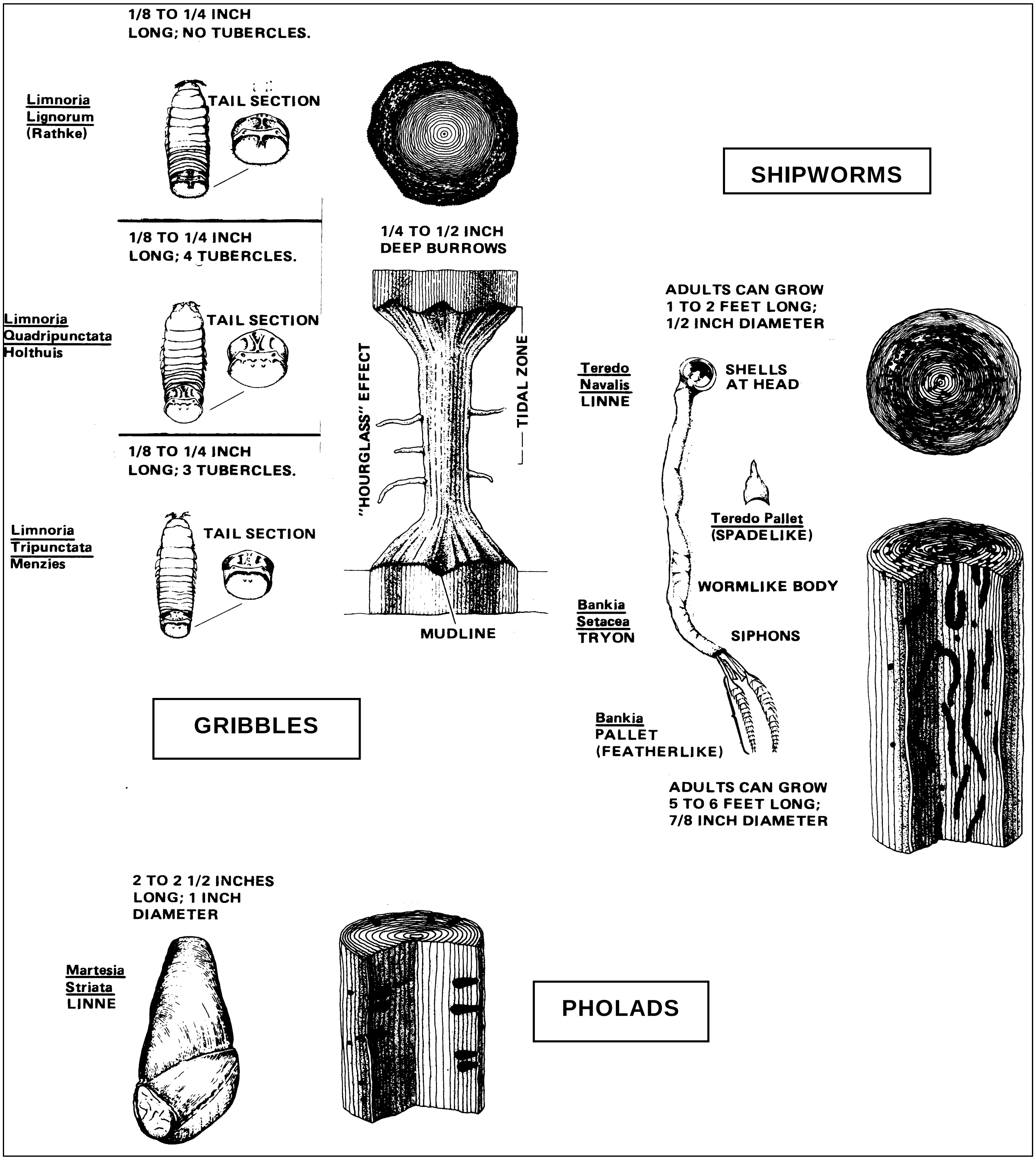


Figure 9-3. Marine Borers---Shipworms, Gribbles, and Pholads.

9.2.3 Shrinkage Damage. Drying causes timber to shrink. After installation this drying process continues, especially in hot dry climates, and the timber members split and check. This shrinkage also causes bolts to loosen in connections which, in turn, causes slippage and deflections in timber members and even distortion and weakening of the entire assembly. Ordinarily, splitting or checking is not serious and is allowed for in standard timber design specifications. However, splits and checks in excess of those allowed by the standard grading rules are potential troublemakers and should be closed.

Splitting and checking create an opening in the timber face or end that is an ideal means of access for insects and borers. These openings also tend to accumulate moisture and dirt, which can also easily lead to decay and rot. Should excessive moisture freeze, the split or check will widen.

9.2.4 Overloading. Axial and bending overloading of piles may be due to a continuous source of loading or to an infrequent type of loading. Material stored in a warehouse on a pier is a form of continuous loading. Short-time loading is exemplified by the impact of a vessel striking a pier or heavy vehicles passing over the deck of the pier. Timber fender faces are particularly subject to bending overloading during ship impact. Failure of one pile requires the adjacent piling to carry not only its own but also part of the damaged pile's load. Continual overloading will cause failure of the adjacent piling, leading to the eventual collapse of the entire structure. Figures 9-4 and 9-5 illustrate the effect of compression and bending overloading, respectively.

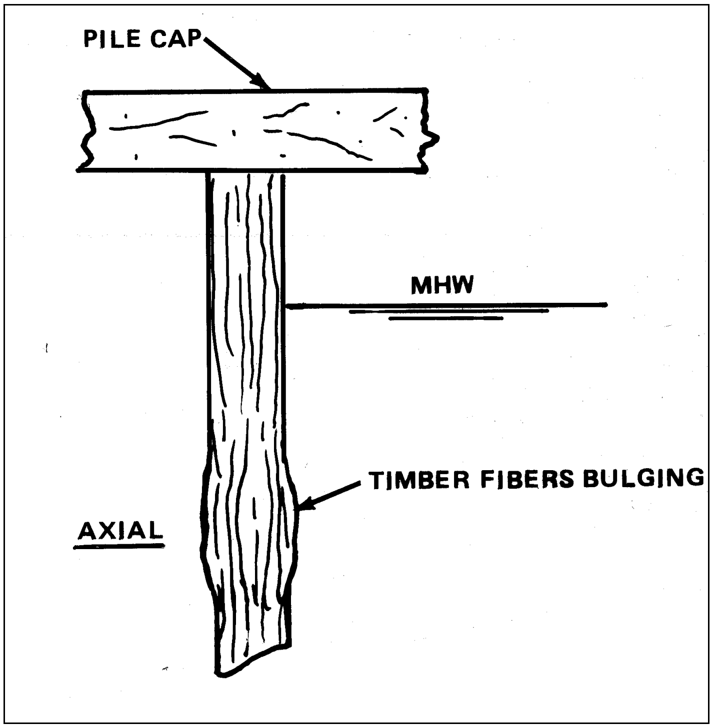


Figure 9-4. Compression Overloading of Timber Pile.

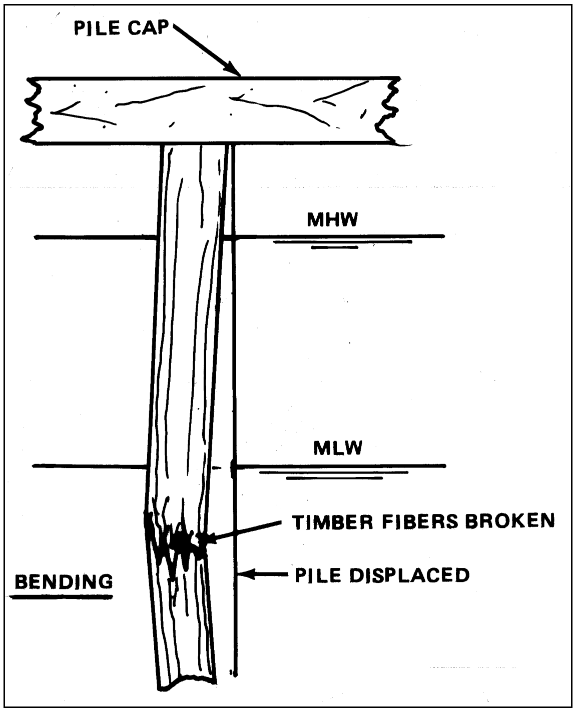


Figure 9-5. Bending Overloading of Timber Pile.

9.2.5 Structural Connection Corrosion. The weak link in marine timber construction is the connecting hardware, since this steel hardware is subject to corrosion. Figure 9-6 illustrates one consequence of one type of hardware failure. Of prime importance to structure integrity are the proper sizing of pins and bolts and the use of Ogee washers in place of thin, flat plate steel washers. The pins and bolts are subject to corrosion, which is very difficult to prevent; therefore, all pins and bolts should be galvanized and oversized to provide a corrosion allowance, with a minimum diameter of 1-inch being supplied. More importantly, Ogee washers should be used. These tapered washers are made of corrosion-resistant wrought or cast iron and are equal in thickness to the bolt diameter. The outside diameter of Ogee washers is considerably greater than that of flat plate steel washers, making them far less subject to loosening under load because their greater bearing area prevents timber crushing.

Bolts on timber fender faces are always countersunk. It is important to provide sufficient clearance for timber abrasion and wear between the top of the bolt and the timber face. These recesses should always be plugged with timber discs or filled with pitch or mastic to protect the steel components from corrosion. Oversized and empty hardware holes are ideal access ports for insects and marine borers. These areas should be closely inspected to ensure the piles are not being bored into.

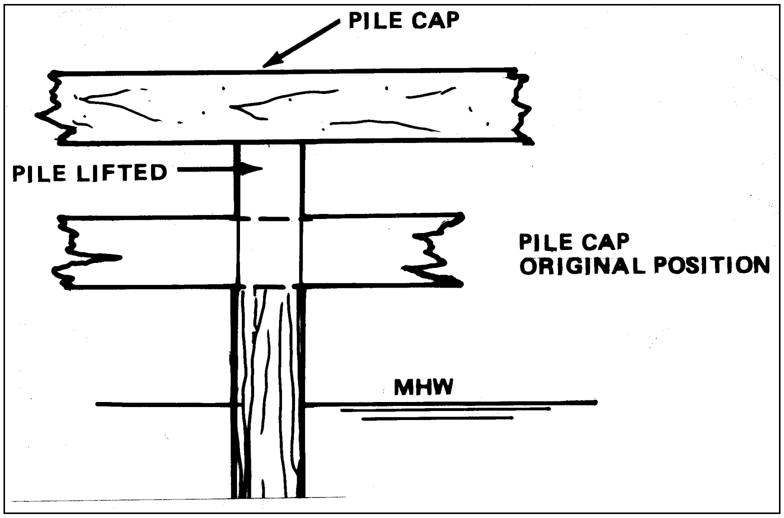


Figure 9-6. One Potential Consequence of Steel Connecting hardware failure in timber Construction.

9.2.6 Abrasion Damage. Abrasion from suspended sand or silt and from ice during winter months will continually decrease the diameter of piles, as shown in Figure 9-7, unless some means of protecting the piles is used. The rate at which the pile is destroyed by abrasion depends on the amount of debris in the harbor, whether or not there is ice in the harbor, the activity of marine borers, and the velocity of the water moving past the pile.

Timber fender faces are subject to constant abrasion while a ship is in berth. The constant ranging of the vessel fore and aft and up and down will, in time, wear away the outer timber fibers, tending to expose the connecting hardware to contact with the vessel.

Attack by woodgribbles accelerates the rate of destruction of a pile by rendering surface fibers susceptible to removal by abrasion. Abrasion can usually be distinguished from woodgribble attack because abrasion is usually concentrated on one side of the pile while woodgribble destruction is uniformly distributed around the pile. Also, abrasion usually leaves the surface fibers of timber piles rough and protruding from the surface of the sound timber.

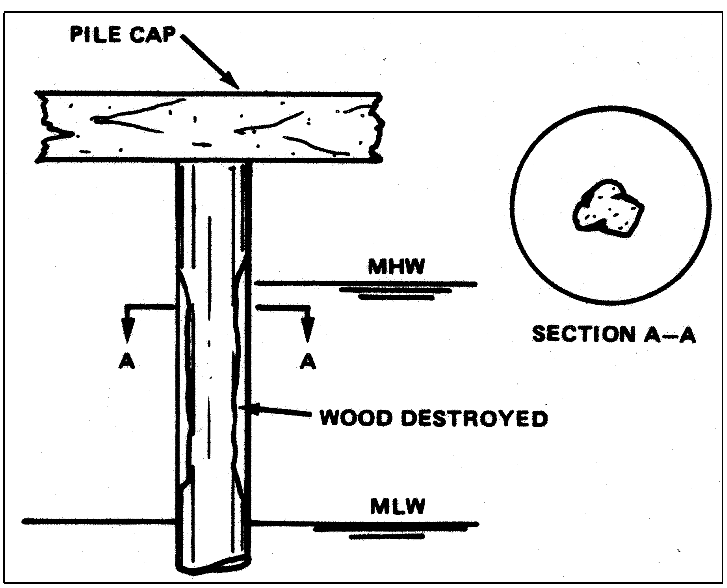


Figure 9-7. Reduction in pile diameter due to abrasion.

9.3 Typical Inspection Procedure

9.3.1 Surface Inspections. A thorough inspection of all timber structures and their attachments above water should occur. Include annual load testing of the pier decking if heavy equipment or vehicles are to be driven onto the pier. The inspector should be alert, specifically in the areas of stringers, pile caps and top of piles, for signs of discoloration and softening of the wood, accompanied by a fluffy or cotton appearance. This may be an early sign of fungi damage. More advanced deterioration may take on the appearance of fruiting bodies, such as mushrooms. Further down the pile, the inspector should look for burrows or hollows in the wood, surface trenches in the outer layers of the pile, and loss of pile diameter. This may be evidence of marine borer attack.

9.3.2 Underwater Inspections. Underwater inspection of a timber waterfront structure should proceed as outlined in Table 9-1.

Table 9-1. Timber Structure Underwater Inspection Checklist.

Checkpoint	Description
1	Start at the splash/tidal zones. **Note**: A Level I inspection should be done first to identify areas of mechanical damage, repair, and new construction.
2	Clear a section of the structure of all marine growth and visually inspect if for surface deterioration. Do spot locations rather than cleaning entire structure.
3	Sound the cleaned area with a hammer and carefully probe with a thin-pointed tool, such as an ice pick.
4	Descend down the pile, sounding the structure with a hammer wherever there is minimal marine growth, as well as probing carefully with an ice pick.
5	At the bottom, note and record the depth of the water.
6	Record visual observations, such as presence of marine borers, losses of cross-sectional area, organism-caused deterioration, location and extent of damage, alignment problems, and condition of fastenings. Use calipers and scales as required.
7	Where internal damage from marine borers is suspected, ultrasonic techniques are available to support the underwater inspection program. The ultrasonic equipment is only available as a contractor service at this time.
8	After finishing the underwork, return to the surface and immediately transcribe all observation data into the inspection log.
Exposed Area Under Pier or Along Wharf or Dolphin Assembly	
9	Check wood stringers, pile caps, bearing, and batter and fender piles for missing or broken members. Check dolphins for broken, worn, or corroded cables and cable connectors; and corroded, loose, broken, or missing wedge block, chafing strips and bands, or chock bolt hangers.
10	Visually examine piling for rot, fungi, and marine borer damage.
11	Sound the pile areas with a hammer and carefully probe with a thin-pointed tool such as an ice pick.
12	If an area is in question, take a small boring for laboratory analysis using an increment borer. Once the core is extracted, seal the hole with a creosote-treated plug to prevent easy access of borers to the interior of the pile. **NOTE**: An engineer should be present whenever underwater inspections are made to explain to the diver exactly what he should look for: number and size of piles, type and depth of bulkheads, location of tiebacks, and cross bracing. .The engineer shall evaluate the diver's observations and

	determine the degree of hazard.

9.4 Equipment and Tools Required

To ensure a thorough inspection, the area must be cleared of all marine growth. This can be done using a "Barnacle Buster" or other types of high-pressure waterblasters. However, when using this equipment, great care must be exercised to prevent damage to the preservative-treated layer of timber.

- Clean small areas with wire brushes and scrapers.

- Sounding of the structure can be performed using a 3-pound sledge hammer.

- An ice pick or pick hammer is required for probing and an increment borer is required if cores are to be taken.

- Timber element dimensions can be checked using a ruler or tape measure.

- A simple fabricated or purchased caliper, is very effective for measuring the diameter of piles.

Inspection data can be recorded underwater using a Plexiglas slate with a grease pencil. Permanent documentation can be achieved through the use of underwater photography, either still photo or television.

10.0 STONE MASONRY STRUCTURES

10.1 Types of Stone Masonry Structures

Although very few waterfront structures built today are constructed from stone masonry, it is still necessary to be familiar with the inspection of this type of structure. Throughout the 19th century, stone masonry was generally used in constructing graving docks, bridge piers, quaywalls, and wharves. Typically, the quarried stone used was granite set into lime mortar or portland cement mortar.

10.2 Deterioration of Stone Masonry Structures

Stone masonry structures typically develop problems at the joints between pieces of stone. Failures of these types of structures usually occur as a result of washout of the joints. In addition, increased earth or hydrostatic pressure causes joints to crack and stones to fall out. Scouring at the base of the structure because of wave and current action and loss of fill from behind the structure are two common types of damage that can lead to serious structural failure.

10.3 Typical Inspection Procedure

Stone masonry retaining walls, such as those found on quaywalls and wharves, generally require only a very simple inspection, as follows:

- Begin the inspection at the waterline, checking for excessive weathering and abrasion deterioration, and loss of mortar from the joints.

- Inspect below the waterline, taking note of the general condition of the wall, and paying particular attention to the joints between each stone.

- If there are significant gaps between stones or stones are missing, note the location, depth, and length of missing stone.

- Continue to the bottom of the structure and note any undermining or scouring of the material under the wall structure.

- At any missing stone or undermining, probe the cavity to estimate the extent of the void (if any) behind or below the wall.

- Record the depth of the water at the base of the wall.

- After returning to the surface, immediately transcribe all information into the inspection log if information has not been communicated via hardwire. Also, record in the log the general condition of the wall above the waterline, especially noting all joints from which mortar has washed out.

10.4 Equipment and Tools Required

Since the underwater inspection of stone masonry structures involves only a cursory inspection of the joints between stones and the general condition of the wall and its foundation, only a few tools are required. A ruler is used to determine the width and depth of cracks and open joints, as well as the size of missing stones or pieces of stone. It is also useful for quantifying the amount of scouring that has occurred. A length of small-diameter rebar or other suitable probe can be used to check for voids in the fill behind or below the wall. A Plexiglas slate and a grease pencil are used underwater to record any pertinent information, or the information is communicated to topside personnel via hardwire. Small hand tools, such as wire brushes and scrapers, are also useful to clear off cracks and joints.

11.0 COASTAL PROTECTION STRUCTURES

Structures designed to reduce the erosive effects of wave action, or to protect harbors from excessive wave action and the formation of sandbars, are classified protection structures. The common coastal protection structures are seawalls, groins, jetties, and breakwaters. NAVFAC Mil-Hdbk-1025/4, “Seawalls, Bulkheads, and Quaywalls” and NAVFAC DM-26.02, “Coastal Protection,” provide additional information on the design and configuration of coastal protection structures.

11.1 Seawalls

Seawalls are massive coastal structures built along the shoreline to protect coastal areas from erosion caused by waves and flooding during heavy seas. Seawalls are constructed of a variety of materials including rubble-mounds, granite masonry, or reinforced concrete elements. They are usually supplemented by steel or concrete sheet pile driven into the soil and are strengthened by wales and brace-type piles. Figure 11-1 shows three seawall configurations.

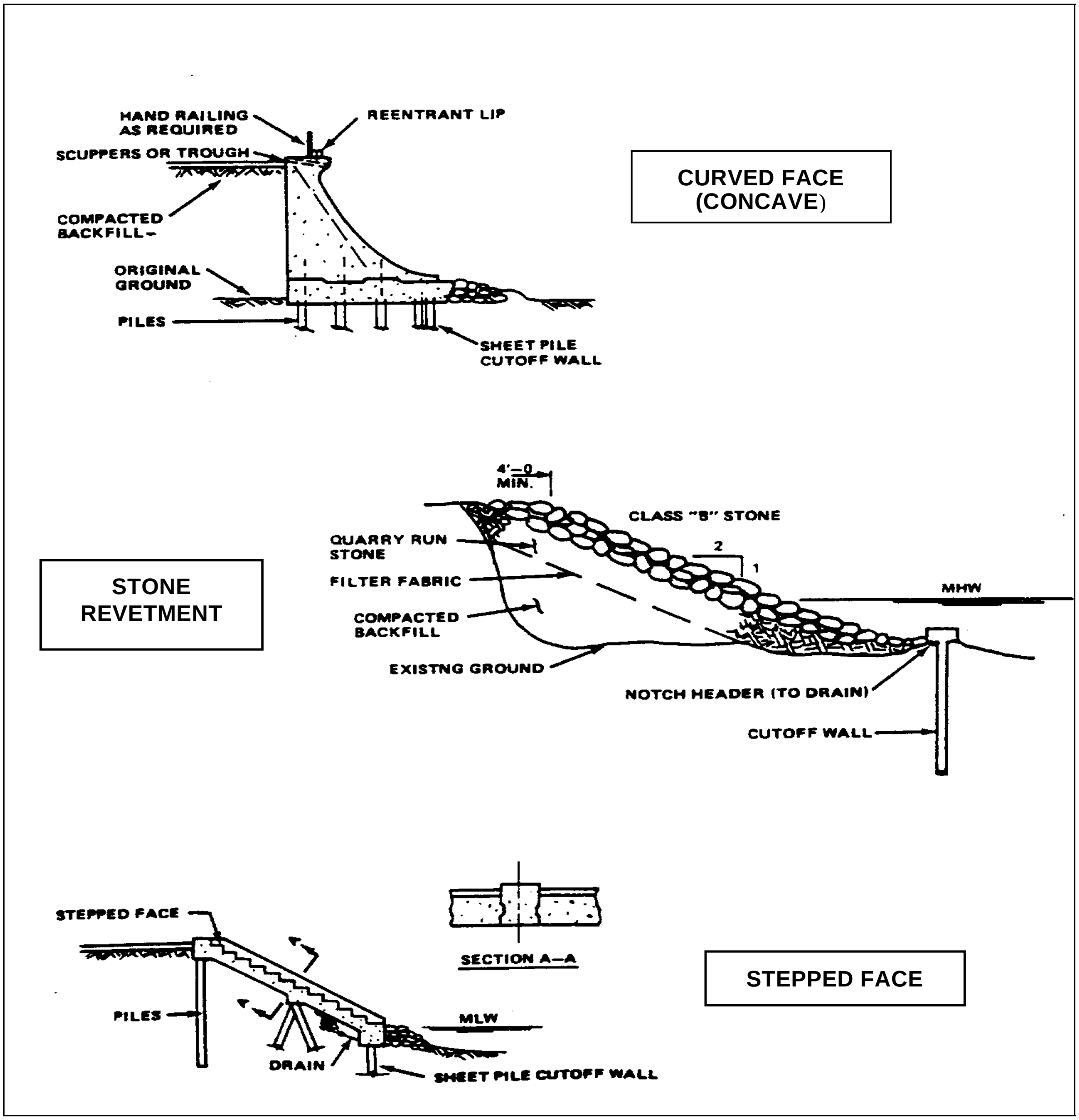


Figure 11-1. Curved Face, Stone Revetment, and Stepped Face Seawall Configurations.

11.2 Groins

Groins are structures designed to control the rate of shifting sand by influencing offshore currents and waves so that erosion of the shoreline is minimized. Groins project outward, perpendicular to the shoreline, and are constructed of large rocks, precast concrete units, reinforced or prestressed concrete piles, steel sheet piles, or timber cribbing filled with rock.

11.3 Jetties

Jetties are structures that extend from the shore into deeper water to prevent the formation of sandbars and to direct and confine the flow of water due to currents and tides. These structures are normally located at the entrance to a harbor or a river estuary. Jetties are usually constructed of mounds of large rubble to a height several feet above the high tide mark.

11.4 Breakwaters

Breakwaters are large rubble-mound structures located outside of a harbor, anchorage, or coastline to protect the inner waters and shoreline from the effects of heavy seas. These barriers help to ensure safe mooring, operating, loading, or unloading of ships within the harbor. Breakwaters may be connected to the shore or detached from the shore. There are three general types of breakwaters, depending on the type of exposed face. The exposed face may be vertical, partly vertical, and partly inclined, or inclined.

11.5 Rubble-Mound Structures

Rubble-mound structures (Figure 11-2) are constructed on the seabed by dumping stones of various sizes from scows and barges until the mound emerges a certain distance above mean sea level. The outer layers of the mound are covered with armor consisting either of large stone or precast concrete units of a number of possible shapes. Rubble is irregularly shaped rough stones, ranging in size up to 1,000 ft3 each and weigh up to 90 tons each. Cobble, also used in rubble-mound structures, is rounded gravel or gravel fragments between 2-1/2 and 10 inches in diameter. Rubble-mound structures are used extensively, chiefly because they are adaptable to almost any depth of water in the vicinity of harbors and can be repaired readily.

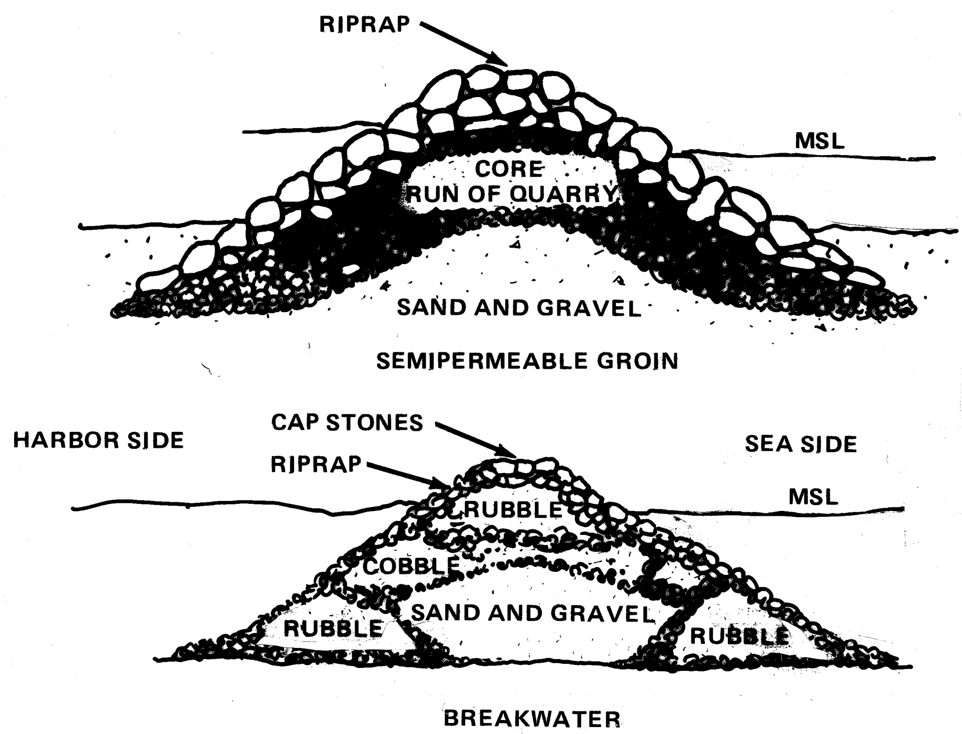


Figure 11-2. Rubble Mound Structures.

11.6 Deterioration of Rubble-Mound Structures

The four principal types of deterioration in rubble-mound waterfront structures are:

- Sloughing of side slope
- Slippage of base material as a result of scour by currents
- Dislodgment of stones by wave action
- Excessive settlement of the seabed supporting the structure

During the inspection of seawalls, breakwaters, groins, and jetties, similar to those shown in Figure 11-2, the inspector should check for horizontal and vertical alignment. He should also be particularly watchful for signs of breakage or displacement of large stones or concrete armor elements, and washing out of substrate under the larger stones or concrete elements, particularly at the toe of the structure. These losses can be early signs of eminent structural failures if corrective action is not taken.

Inspection of rubble-mound structures should include:

- Erosion of core material by wave action.
- Erosion of small stones in riprap.
- Stability of armor stones or blocks.
- Breakage and displacement of concrete armor elements.
- Washing out of substrate at the toe of the structures.
- Undermining of foundation.
- High water mark; overtopping.
- Settling of structures.

11.7 Typical Inspection Procedure

Inspection of a rubble-mound structure should proceed as outlined in Table 11-1.

Table 11-1. Rubble-Mound Structure Surface and Underwater Inspection Checklist.

Checklist	Description
1	Swim around the base of the structure looking for beginning weaknesses in the base, such as washout of small stones and core material.
2	Note signs of detrimental wave action, such as scouring and sloughing.
3	Record all pertinent information on a Plexiglas slate. After returning to the surface, transfer the information into the inspection log.
4	Record the result of the above-water inspection, include a description of the alignment and general condition of the mound, such as dislodgement of stones, gaps, and other weaknesses.

11.8 Equipment and Tools Required

Inspecting rubble-mound structures requires that divers be equipped with recording devices, such as a Plexiglas slate, grease pencil, and cameras.

12.0 SYNTHETIC MATERIALS AND COMPONENTS

Inspection of synthetic materials and components is subdivided into the following three categories:

12.1 Structural Members

Structural members should be inspected annually when the regular pier inspection is accomplished. The inspection is intended to detect and document:

(1) Cracked, worn, brittle or deformed plastic railings, stanchions, gratings, light standards, or piping; loose or damaged fittings and connections; and exposed fiberglass.

(2) Cracked, worn, or deformed rubber resilient fender components, and/or loose or damaged fittings and connections.

Basic inspection procedures are the same as those outlined for timber or concrete structures.

12.2 Coatings, Patches and Jackets

Coatings, patches, and jackets should be inspected annually, or more frequently, depending upon the failure rate of the application. The objective of the inspection is to detect and document:

(1) Pits, cracks, scars or abrasions in coatings.

(2) Cracked, loose or dislodged epoxy patches.

(3) Punctures, embrittlement, tears, rips, or abrasions in fabric, or unlocking of fabric seams in pile jackets.

Basic inspection procedures are the same as those outlined for timber, concrete and steel structures.

12.3 Foam-Filled Fenders

Inspection will be done by walking the pier and by use of a small boat. Inspection of foam-filled fenders should be performed more frequently than normal pier inspections and should cover:

(1) Condition of the fender-to-pier connection hardware. Check for operability and signs of corrosion. Check to ensure that the fender is constrained horizontally so that it contacts the bearing surface for its full length. Ensure that the fender is free to float with the tide vertically and rotate around its long axis.

(2) Condition of the fender chain and tire net for net fenders. Check to see that the chain is symmetrical on the fender and that the end fittings are in good working order. Ensure that the chains are protected from the ship hull by the tires, and that the net is not loose.

(3) Condition of end fittings on netless fenders. Check to see that the fittings are in good working order, and corrosion is minimal. Check to see that the fender shell is not cracked or separated around end fittings.

(4) Condition of the fender elastomer shell. Check for cuts, tears, and punctures. Record the size and location of damage on a sketch.

(5) Measure or estimate the diameter of the fender at its smallest point to record permanent set.

Record keeping for foam-filled fenders is very important. In this regard, the fenders should be treated as an item of high-cost equipment rather than an appurtenance to a fixed facility. Each fender should have a unique identification number with a history record that includes date of procurement, manufacturer, date of installation or when fender was put into service, and berth location if permanently installed.

13.0 QUAYWALLS

Quaywalls are an integral part of wharves and should be included when other pier components are inspected.

Deterioration of quaywalls is indicated by:

(1) Shifts in horizontal and vertical alignment of sheet piling
(2) Damage or deterioration of the wood, concrete, or steel sheet piling
(3) Wash-out of substrate under the sheet piling, particularly at the toe of the structure.

Item 1 can be detected by visual observation. A complete description of shifts and any apparent cause should be provided. Item 2 is covered by Chapters 6, 8, and 9. Item 3 may be detected by visual inspection in clear water at low tide. If not, then an underwater inspection is required. The following checklist is a useful guide.

Table 13.1 Quaywall Surface And Underwater Inspection Checklist.

☐ Swim around the base of the structure looking for beginning weaknesses, such as washout of small stones and core material.
☐ Note signs of detrimental wave action, such as scouring and sloughing.
☐ Record all pertinent information on a Plexiglas slate and, upon return to the surface, transfer the information into the inspection log.
☐ Record the result of the above-water inspection, which should include a description of the alignment, and general condition of the seawall.

14.0 THE INSPECTION REPORT

For each inspection, a report is prepared. The report includes facility plans with updated descriptions such as size and pile arrangement, an evaluation of the assessed conditions, and recommendations for further action. The report should provide sufficient technical detail to support the assessments and recommendations. Since underwater inspections are specialized, a report format such as the one presented in Table 14-1 is recommended. The recommended format is for each report to first present the Front Information (as defined below) followed by three major sections and the Appendices. This format is used by the NFESC, East Coast Detachment, when conducting underwater inspections and assessments at Naval waterfront facilities.

Table 14-1. Format for Waterfront Inspection Reports.

Front Information:

Report Cover

↳**Title Page**

↳**Executive Summary**

↳**Executive Summary Table**

↳**Table of Contents**

↳ **List of Figures**

↳ **List of Photographs**

↳ **List of Tables**

Report Body:

Section 1		Introduction
1.1		Background/ Objectives
1.2		Inspection Exit Briefing
Section 2		Activity Description (Information that affects inspection, repair, rate of deterioration, etc.)
2.1		Location
2.2		Existing Waterfront Facilities at Activity
2.3		Waterfront Facilities Inspected
Section 3		Inspected Facilities
3.1		Name of Facility
	3.1.1	Description of Facility
	3.1.2	Observed Inspected Condition
	3.1.3	Structural Condition Assessment
	3.1.4	Recommendations
		Repeat the above as necessary for each facility
Appendices		
A		Key Personnel
B		Inspection Procedure/ Level
C		Structural Data
D		Pertinent Background Information
E		Calculations for Structural Assessment
F		Backup Data for Cost Estimates
G		Cost Estimate Summary
H		References

The objective of the report guideline is to facilitate the writing of comprehensive, standardized, and usable reports. The guideline is the result of many years of experience involving underwater inspections of hundreds of waterfront facilities. The guidelines will assist the inspecting party in preparing the report by pointing out specific information and formats to be incorporated, and by identifying recurrent errors to avoid.

A major objective of underwater inspection report is to provide facility managers with an assessment of the condition of their inspected waterfront facilities. The report shall provide the detailed information needed to substantiate requests for funding to maintain and repair the waterfront facilities. The report shall include the following:

Identification and description of all major damage and deterioration of the facility.

Estimate of the extent of minor damage and deterioration.

Assessment of the general physical condition.

Recommendations for types of maintenance and repair required.

Identification of any problems associated with mobilization of equipment, personnel, and materials to accomplish maintenance and repairs.

Budgetary estimates of costs for recommended maintenance and repairs.

Estimate of expected life of each facility, with and without recommended repairs.

Recommendations for types and frequencies of future underwater inspections.

Updated facility drawings, both hard copy, and electronically-stored versions (which may differ significantly from the drawings available at the activity).

Documentation of the type and extent (light, moderate, heavy) of marine growth, to help in the planning of future inspections.

Water depths at each facility.

Water visibility, tidal range, water current, and any other pertinent environmental conditions.

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