ASCE Manuals and Reports on Engineering Practice No. 130

Waterfront Facilities Inspection and Assessment

Waterfront Facility Inspection Committee

Edited by
Ronald E. Heffron, P.E.

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Sponsored by
Technical Committee on Ports and Harbors of the
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MANUALS AND REPORTS ON ENGINEERING PRACTICE

(As developed by the ASCE Technical Procedures Committee, July 1930, and revised March 1935, February 1962, and April 1982)

A manual or report in this series consists of an orderly presentation of facts on a particular subject, supplemented by an analysis of limitations and applications of these facts. It contains information useful to the average engineer in his or her everyday work, rather than findings that may be useful only occasionally or rarely. It is not in any sense a "standard," however; nor is it so elementary or so conclusive as to provide a "rule of thumb" for nonengineers.

Furthermore, material in this series, in distinction from a paper (which expresses only one person's observations or opinions), is the work of a committee or group selected to assemble and express information on a specific topic. As often as practicable the committee is under the direction of one or more of the Technical Divisions and Councils, and the product evolved has been subjected to review by the Executive Committee of the Division or Council. As a step in the process of this review, proposed manuscripts are often brought before the members of the Technical Divisions and Councils for comment, which may serve as the basis for improvement. When published, each work shows the names of the committees by which it was compiled and indicates clearly the several processes through which it has passed in review, so that its merit may be definitely understood.

In February 1962 (and revised in April 1982), the Board of Direction voted to establish a series titled "Manuals and Reports on Engineering Practice," to include the Manuals published and authorized to date, future Manuals of Professional Practice, and Reports on Engineering Practice. All such Manual or Report material of the Society would have been refereed in a manner approved by the Board Committee on Publications and would be bound, with applicable discussion, in books similar to past Manuals. Numbering would be consecutive and would be a continuation of present Manual numbers. In some cases of joint committee reports, bypassing of Journal publications may be authorized.

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PREFACE

This manual provides guidelines and methodology for conducting engineering inspections and assessments of existing waterfront facilities constructed of materials including concrete, masonry, metals, composites, and wood; and located in near-shore, waterfront, and inland locations exposed to fresh or seawater. It also presents guidelines representing standards of practices, documentation and reporting, and administrative considerations for various inspection types, including routine, structural repair or upgrade design, new construction, baseline, due diligence, special, repair construction, and post-event inspections.

The extensive appendices provide guidelines for special considerations for specific structure types and systems, the types and causes of defects, specialized instruction techniques, inspection nomenclature, and an extensive glossary of key terms.

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CHAPTER 1
INTRODUCTION

1.1 INTENT OF THE MANUAL

The intent of this Manual of Practice is to provide guidelines and methodology for conducting engineering inspections and assessments of existing waterfront facilities constructed of materials including concrete, masonry, metals, composites, and wood; and located in near-shore, waterfront, and inland locations exposed to fresh or seawater. It includes, but is not limited to

- Piers (jetties),
- Wharves (quays),
- Dolphins,
- Bulkheads (quay walls),
- Seawalls,
- Relieving platforms,
- Gravity block walls,
- Caissons and cofferdams,
- Wave screens/attenuators,
- Marinas,
- Boat ramps,
- Marine railways,
- Floating structures,
- Single-point and multi-buoy moorings (SPMs, MBMs, etc.), and
- Slope protection.

The scope of the inspections covered in this manual includes fixed utilities, equipment, mooring hardware, topside paving and drainage, safety features, and appurtenances typically associated with waterfront assets and excludes specialty items such as container cranes and material offloading/conveyance equipment. The intent of the manual is to cover all aspects of waterfront structures in one document without the need to refer to multiple references.

For convenience, this manual will use the term "waterfront structures" to refer to any of the types of structures listed, where appropriate and not specifically limited. This manual is not concerned with bridges, dams, hydraulic structures, offshore (deep water) structures, offshore oil/gas platforms, or nuclear facilities. In addition, dry docks are excluded because they are covered comprehensively by ASCE Manual of Practice 121 "Safe Operation and Maintenance of Dry Dock Facilities" (2010).

A structural inspection and condition assessment of a waterfront facility can be undertaken for one or more purposes, including

- Determining the existing or baseline condition,
- Recommending and prioritizing maintenance and repair actions,
- Determining suitability and serviceability for specific uses and loads,
- Assessing life safety,
- Extending the useful service life,
- Preserving historic facilities,
- Establishing a baseline condition for change of ownership or legal purposes, and
- Identifying issues for a number of special purposes based on the specific structure and its current or proposed function.

One of the primary objectives of this manual is to provide guidance on various inspection types and how to match specific inspection types to project needs. Often inspections are conducted as part of a larger Asset Management Program by an owner. The primary reasons for establishing an asset management program include:

- Providing an effective tool to assist owners in prioritizing maintenance resources,
- Establishing a protocol to enhance the safety and integrity of assets,
- Ensuring tenants of a proactive plan for the maintenance of waterfront assets, and
- Responding to the mandates of insurance or regulatory requirements.

This manual presents guidelines for assessment procedures, including inspection, investigation, evaluation and testing methods, and a general format for an assessment report. Specific inspection techniques are beyond the scope of this manual, because the inspection personnel are presumed to possess the requisite knowledge based on their qualifications. Because condition assessments typically require "engineering judgment" and involve factors and circumstances too numerous to be readily defined and standardized, this manual is intended as a guide to be used by the professional engineer as part of a structural condition assessment. The adoption or use of some or all recommendations contained in this manual by personnel not experienced or qualified in the appropriate areas of waterfront structures is not an acceptable substitute for the use of qualified professional engineering services.

The scope of this manual is limited to the engineering and technical requirements for conducting above water and underwater facility assessments. Diving procedures and related safety issues are not within the scope of this manual; however, the very nature of the work, in addition to requiring technical competence, also requires proper training and preparation. This training is necessary to offset the inherent special hazards and to allow the safe operation of special underwater equipment and techniques, breathing apparatus, and special suits. Such special hazards may include differential pressures, high-velocity water flow, zero-visibility conditions, underwater entanglement hazards, confined space entries, equipment tag-out/lock-out procedures, penetration diving, contaminated water diving, and diving-related sickness/injury problems such as embolisms, the bends, nitrogen narcosis, physical exhaustion, etc. It is therefore imperative that applicable safety and training requirements be adhered to in conducting such work. The training requirements for commercial engineer-diver operations will be covered by a new ASCE standard that is under development.

1.2 IMPORTANCE OF INSPECTIONS

Inspections are a necessary part of effective waterfront facility maintenance management programs. They play an important role in protecting the public, providing reliable service, protecting the environment, and reducing maintenance and construction costs. Structural conditions above water that could lead to failure, loss of life, or property damage are often observed by engineers, maintenance workers, operations personnel, and sometimes the public. Similar structural conditions underwater are almost never observed by these same groups until the distress has progressed to the point that damage is evident above water. Failures of bridges due to deterioration have led to mandated requirements for periodic inspections of bridges in the United States. Similarly, many public and private organizations have adopted policies for inspection of waterfront facilities, recognizing the importance of these assets.

Inspections are also important in structure maintenance programs. All structures deteriorate and are subject to environmental and external physical forces. Not all distress is recognizable from above water, nor can the extent and severity necessarily be determined. An engineer cannot fully define the extent of distress nor design an appropriate repair without the benefit of an inspection, both above water and underwater.

1.3 HOW TO USE THIS MANUAL

Eight unique inspection types are defined in this manual. The owner or specifying entity must specify which inspection type is needed when initiating an inspection effort. Guidance is provided in Section 2.2.

In many instances, combining inspection types and conducting them simultaneously is desirable. For example, when a single waterfront facility is being inspected due to obvious significant deterioration, and the need for repairs is obvious and imminent, it may be desirable to combine the Routine Inspection and Structural Repair or Upgrade Design Inspection into one effort.

Once the inspection type is specified, the owner or specifying entity can simply request that the inspection be performed in accordance with this manual. Section 2.2 points out instances in which going beyond the basic scope of work and including additional scope items such as a global structural stability evaluation, load rating, service life extension study, or cost estimates for rehabilitation may be desirable.

The interval between inspections often differs for above water versus underwater inspections. In many cases it may be appropriate to conduct the above water and underwater inspections at the same frequency for convenience. It is typically advantageous for inspections of the above water and underwater portions of the structure to be performed by inspectors working with the same engineering team to make a meaningful assessment of components that are located both above and below water. Conducting the inspection of the above water and below water portions of the structure by the same team will generally be more cost effective as well. In any case, the owner or specifying entity should clearly indicate whether the inspection effort being requested should include above water, underwater, or both.

Unless otherwise specified, a typical inspection effort should include not only the structure but also any slope protection, scour, utilities, fixed topside mechanical/electrical equipment, mooring hardware, security barriers, safety features, cathodic protection systems, and topside paving and drainage.

1.4 LIMITATIONS OF RESPONSIBILITY

Waterfront facilities are subject to deterioration over time. An inspection of a waterfront facility should be considered a “snapshot” evaluation of the facility at a moment in time over the history of the asset. The validity of the inspection is thus limited in light of this continuum of ongoing deterioration. Accordingly, the manual provides guidance as to the frequency of Routine Inspections during the life cycle of the asset, with the frequency dependent on the Condition Assessment Rating from the previous inspection, the type of construction materials involved, and the nature of the service environment. The manual also provides guidance for quantitatively predicting the remaining service life of waterfront facilities, particularly for concrete, but with the implicit recognition that concrete structures require an additional level of investigation beyond the Routine Inspection scope of work.

Section 2.6.2, Condition Assessment Ratings, explains that Routine Inspections are intended to compare the current condition of the structure with its original, as-constructed condition. The fact that the structure was designed for loads that are less than the current standards for design shall have no influence on the ratings. Similarly, functional obsolescence is not considered when inspecting a facility, nor are the actual operational loads, because such information is generally not readily available to the inspection team.

1.5 SIGNIFICANT CHANGES AND OWNER'S RESPONSIBILITIES

Significant changes to a structure include reduction in design capacity due to damage or deterioration, increased loads, or upgrades that modify load paths. Increased loads may be a result of larger vessels (including increased sail or current area), increased live loads, or similar. In these situations, the owner may have certain responsibilities to ensure safety and to protect the environment.

When a waterfront structure is to be repaired or rehabilitated, with the goal of restoration to original design capacity, consideration should be given to the residual structural integrity relative to the structure's record drawings. Marine structures generally have some reserve load capacity and can tolerate minor deterioration. Unless the authority having jurisdiction (AHJ) dictates otherwise, where no significant deterioration or damage of individual components is observed that could significantly affect the original design capacity, the repair or rehabilitation may proceed without the requirement to perform a structural capacity evaluation, unless otherwise recommended by the engineer of record for the project.

The definition of "significant deterioration or damage" in this context should be based on the judgment of the inspector as a result of visual observation during the inspection and, when available, a review and understanding of the original design basis and criteria for the structure. This judgment should consider the severity of the deterioration or damage, as well as whether the deterioration is concentrated or distributed on the structure. Generally, deterioration that reduces the design capacity of primary members by 20% or more is considered potentially significant. Structures that are given a Structural Condition Assessment Rating of "poor" or below, as defined in Section 2.6, are generally considered to exhibit potentially significant damage.

If the deterioration or damage of individual components is deemed significant, the appropriate level of additional testing, structural assessment, or structural analysis should be determined by a registered professional engineer. Such additional evaluation may be localized to a component or group of components, or generalized to the global structural system, as determined appropriate by the engineer of record.

If the structure will be upgraded—defined as significantly increasing allowable loads on the structure or significantly changing load paths—the performance of the structural system must be ensured by the owner. The appropriate level of structural assessment or structural analysis should be determined by a registered professional engineer. The definition of "significantly increasing allowable loads" in this context should be when the demand-capacity ratio with the additional load considered is 10% or more greater than the demand-capacity ratio with the additional loads ignored.

If loads are significantly increased on a waterfront structure, or load paths are significantly modified as part of an upgrade project, an upgrade to comply with current code standards may also be required or desirable. This requirement is often dictated by the requirements of the AHJ but may also be a matter of prudence depending on the scope of the upgrades being implemented.

1.6 LIMITS OF INSPECTION

Routine Inspections are typically limited to accessible components. Buried components such as tie-backs, deadman anchors, or buried portions of piles are typically excluded from the scope of work in a Routine Inspection.

When inspecting a waterfront facility with the intent to upgrade, which involves adding load or changing load paths, exposing representative samples of buried or inaccessible components is typically necessary to verify their integrity. This exposure and inspection of inaccessible components may also be required in circumstances where evidence such as obvious deflection or settlement exists that indicates a potential or likely loss of integrity of such inaccessible components.

Underwater inspections should include all portions of structures that cannot be inspected from above water. In very shallow waters, an underwater inspection often can be accomplished by wading or by probing from above water. The depth of water for which such methods are appropriate is very shallow. In fast-moving waters, in waters with slippery or unstable bottoms, or in very turbid water, even a few feet of water may be too deep to permit a safe or satisfactory inspection from above water. The owner or specifying entity should determine if a realistic assessment of the condition of the structure can be achieved solely from an above water inspection; if not, an underwater inspection should be conducted.

For waterfront structures, except for those in shallow water as described, the underwater inspection should extend from the channel bottom or mudline to at least the high water level. High water level refers to high tide in tidal areas or high water elevation in rivers or lakes where water levels routinely fluctuate. It does not mean the high water mark associated with atypical flooding.

In some special circumstances, performing some limited underwater excavation at the structure/mudline interface may be necessary. Such excavation should be clarified in the scope of work and may require special environmental permits. For structures where inspecting some above water portions is difficult, such as the underside of a deck system, including above water portions with the underwater inspection may be necessary.

1.7 TERMINOLOGY

The following terms are used throughout this manual, and defining their meaning in the context of waterfront facilities is important:

- Preservation: The facility is not being repaired but is rather being treated, such as with coatings, sealants, or preservatives, to prevent or slow further deterioration.
- Sustainment: The facility has not exceeded its design life and is being repaired.
- Rehabilitation: The facility is being repaired or restored to its original, as-built condition. This is also referred to as "restoration" when the original design life is exceeded and is now being extended.
- Upgrade: The facility will have new or larger loads applied, or will be modified to alter load paths, thus necessitating the evaluation of the global structural system to determine if structural modifications are required.
- Inspection: The visual, tactile, and nondestructive testing associated with determining the physical condition of the structure, compared with the original as-built condition.
- Assessment: The evaluation of the inspection results to determine the significance of observed damage and deterioration on the design capacity of the structure.

1.8 ORGANIZATION

This Manual of Practice has been organized in chapters to provide both general and specific guidance. Chapter 2 provides an overview of the types of inspections, guidance on how to choose the appropriate inspection type, and general requirements for conducting waterfront facility inspections. It also includes guidelines for inspection frequencies. In addition, recommended qualifications of inspectors are presented along with assessment rating guidelines that are applicable to or can be readily adapted to most structures.

For each type of inspection, Chapter 3 defines the objectives and provides a detailed scope of work. Guidance is provided regarding methodology and how to make appropriate recommendations for any follow-on actions required.

Chapter 4 provides state-of-the-art guidance on quantitatively assessing the remaining useful life of a waterfront facility. Field inspection and testing requirements are provided, along with laboratory testing requirements and numerical modeling techniques.

Chapter 5 provides guidelines for preparation of a report for the Routine Inspection, often referred to as a Condition Assessment Inspection. It outlines the contents of a typical report, including background information, descriptions of inspection and testing methods, a description of the facilities inspected, reporting and documentation of inspection results, topics to be discussed in the assessment, and conclusions and recommendations.

Chapter 6 provides general guidelines for developing agreements between consultants and facility owners. It also presents an overview of the special requirements for insurance related to waterfront facility engineering assessments.

Appendices A through E include descriptions of approaches to specific types of structures and problem areas associated with those structures, descriptions of various mechanisms of deterioration that are applicable to the types of materials found in waterfront structures, an overview of specialized inspection and nondestructive testing techniques, an overview of inspection nomenclature, and references to other standards. A glossary of generally accepted standard terms related to waterfront structures is also included.

CHAPTER 2
STANDARDS OF PRACTICE

This section presents requirements for the above water and underwater inspection of waterfront structures. It describes recommended practices, which are designed to ensure that structures are adequately maintained for the protection of life, the environment, property, and equipment, and to maximize the longevity of the structure. These requirements include

- Type and frequency of inspections,
- Selection of the proper inspection method,
- Service life modeling or estimation,
- Minimum qualifications of inspection personnel,
- Element-level ratings,
- System ratings, and
- Recommended action guidelines.

2.1 TYPE AND FREQUENCY OF INSPECTIONS

2.1.1 General

This manual covers eight inspection types:

- Routine Inspection,
- Structural Repair or Upgrade Design Inspection,
- New Construction Inspection,
- Baseline Inspection,
- Due Diligence Inspection,
- Special Purpose Inspection,
- Repair Construction Inspection, and
- Post-Event Inspection.

Routine inspections, structural repair or upgrade design inspections, special purpose inspections, and repair construction inspections define routine maintenance activities. The routine inspection should be used as a screening mechanism to determine if and when other inspections may be conducted. Due diligence inspections are conducted when considering a change in ownership, an investment, insurance valuation, or negotiation of a lease. Finally, Post-event inspections are conducted only in response to a significant loading or environmental event.

New construction inspections are conducted only in association with a newly constructed structure or component. Baseline inspections are typically conducted near the completion of new construction, prior to owner acceptance but may also be conducted on existing structures coincident with the first routine inspection.

The typical flow and context of inspection activities associated with the eight inspection types are shown in Fig. 2-1. Although Fig. 2-1 represents a typical model of how inspection activities may flow, it is not the only way. In many cases, combining inspection types may be necessary or advantageous to avoid duplication of effort or minimize mobilization costs. Deviating from the typical flow of activities may also be necessary to tailor the inspection scope of work to the global project requirements. These inspection types include both above water and underwater efforts.

During the construction of new structures, above water and underwater inspections should be conducted to ensure proper quality control. This type of inspection is called a new construction inspection.

After a structure has been constructed, conducting a baseline inspection prior to acceptance of the structure is recommended practice. If not performed at the time of original construction, the baseline inspection should be performed coincident with the first routine inspection.

Routine inspections should be conducted with sufficient detail to evaluate the overall condition of the structure, determine if further maintenance attention to the structure is necessary, and determine the priority of such attention. Documentation of inspection results should be limited to the collection of data necessary to support these objectives to minimize the expenditure of maintenance resources. Structural repair or upgrade design inspections are conducted only when repairs must be performed, as determined from the routine inspection. Structural repair or upgrade design inspections may take more time to execute than routine inspections, because they require detailed documentation of all defects to be repaired. By using this two-tiered approach to the inspection process, inspection resources are utilized efficiently.

Routine inspection is not always necessary prior to conducting a structural repair or upgrade design inspection. In situations where the need for repairs is known or is obvious, or for small facilities, conducting the routine

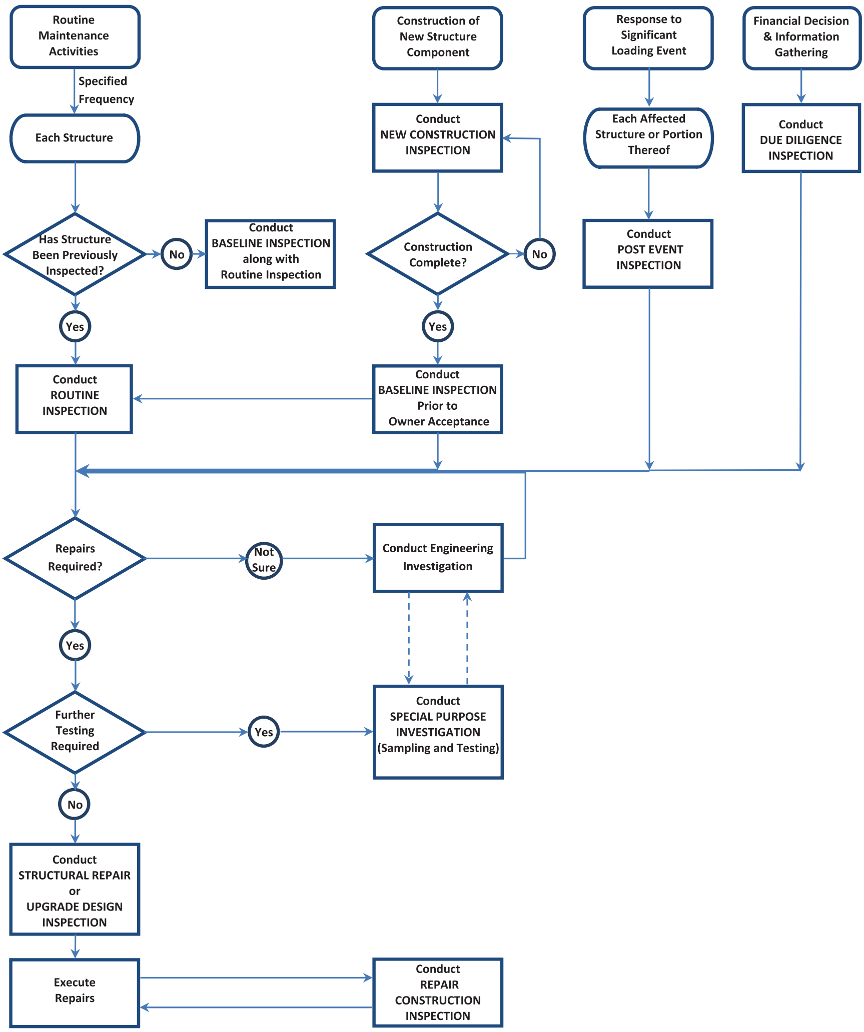

Fig. 2-1. Flow and context of inspection activities
Source: Courtesy of Moffatt & Nichol, Inc., reproduced with permission.

inspection and the structural repair or upgrade design inspection simultaneously may be advantageous.

A limited inspection of a structure may establish the general condition valuation; order-of-magnitude repair costs, repair methodology, and interval; and inspection costs and inspection intervals. This type of inspection is called a due diligence inspection.

In some cases, a more in-depth investigation involving various types of in situ and/or laboratory testing may be required. This type of inspection is called a special purpose inspection. Special purpose inspections are conducted when the cause of deterioration is unknown, or where multiple degradation mechanisms contribute to the deterioration.

In the course of implementing repairs, above water and underwater inspections should be conducted to ensure proper quality control and documentation and verify compliance with contract documents. This type of inspection is called a repair construction inspection.

In the event of earthquake, vessel impact, tsunami, fire, or flood, conducting a rapid inspection to verify damage and ensure the safety of personnel and equipment may be necessary. This type of inspection is called a post-event inspection.

Table 2-1 summarizes the purpose and frequency of inspection types. A description of each inspection type follows. Chapter 3 presents details of the scope of work for each inspection type.

2.1.2 Routine Inspections

2.1.2.1 Purpose and Frequency The purpose of a routine inspection is to assess the general condition of the structure, assign a Condition Assessment Rating, and make recommendations. Routine inspections should be performed on a cyclical basis and represent a proactive approach to maintenance.

The frequency with which routine inspections should be conducted is a function of several variables. The most important variables are material type, age of the structure, and service environment. The recommended frequency between inspections varies and is presented in Table 2-2. The frequencies represent maximum intervals between inspections and should be reduced as appropriate based on the extent of deterioration observed in a structure, the rate of further anticipated deterioration, and the importance of the structure.

Conducting routine assessments on a cyclical basis allows for the detection of deteriorated elements and provides the opportunity to repair before structural integrity is threatened. In addition, significant damage caused by impact from vessels or floating debris will be detected.

2.1.2.2 Scope of Work Overview The above water inspection includes a visual observation of the topside and above water components. The above water components are typically inspected from a boat; however, depending on circumstances, using divers may be necessary for low-clearance facilities or a snooper for high-clearance or open-ocean structures. The topside is typically inspected from the deck.

Underwater inspection is limited by poor visibility and the coverage of components by marine growth. A visual inspection of all submerged component surfaces during a routine inspection is impractical. For this reason, routine inspections focus on three levels of effort: visual and tactile

Table 2-1. Summary of Inspection Types

Inspection Type	Purpose	Frequency
Routine Inspection	To assess general condition, assign condition rating, and provide recommendations for future maintenance	As indicated in Table 2-2.
Structural Repair or Upgrade Design Inspection	To record relevant attributes of each defect to be repaired such that repair bid documents may be generated	Conducted only when designing repairs or upgrades
New Construction Inspection	To ensure proper ongoing quality of new construction in accordance with plans and specifications	During construction of new structures or components
Baseline Inspection	For new construction, to verify that construction plans have been followed and to ensure that construction is free of significant defects prior to owner acceptance. For existing structures, to verify dimensions and construction configuration details	Prior to owner acceptance of newly constructed structure or at the time of the first routine inspection on existing structures
Due Diligence Inspection	To form an engineering opinion of the general condition of a structure and estimate order-of-magnitude replacement costs and repair costs	Conducted as part of a financial, investment, or insurance valuation process
Special Purpose Inspection	To perform detailed testing or investigation of a structure required to understand the nature and/or extent of the deterioration prior to determining the need for and type of repairs required	Conducted only when deemed necessary as a result of a routine, or structural repair or upgrade design inspection

(Continued)

Table 2-1. Summary of Inspection Types *(Continued)*

Inspection Type	Purpose	Frequency
Repair Construction Inspection	To ensure proper quality of repairs, resolve field problems, and ensure proper documentation of payment quantities	During repair projects involving structures or components
Post-Event Inspection	To perform a rapid evaluation of a structure following an earthquake, storm, vessel impact, fire, tsunami, or similar event to determine if further attention to the structure is necessary as a result of the event	Following a significant potentially damage-causing event

inspection (Level I), partial marine growth removal of a representative sample (Level II), and nondestructive testing or partially destructive testing (Level III). The three levels are further defined in Chapter 3.

During the inspection, damage ratings are assigned to each element inspected to characterize the existing level of damage or deterioration. Upon completion of the inspection, a Condition Assessment Rating should be assigned to each element group or structure inspected, recommendations for additional follow-up activities should be provided as appropriate, and the recommended interval to the next routine inspection should be provided. If significant damage or deterioration is observed on the structure, a quantitative engineering assessment of the effect of the damage on the structural capacity of the structure should be recommended. The assessment is typically limited to an evaluation of the capacity of typical components relative to their original, as-built condition and does not consider the actual or anticipated loading (structural demand), because such information is typically not readily available to the inspectors at the time of the routine inspection. The results of such structural assessments should be used in assigning a Condition Assessment Rating. Should conditions warrant, an engineering evaluation should be recommended to evaluate the actual or anticipated loading against the reduced capacity determined as a result of the routine inspection.

Further details of the scope of work involved in conducting routine inspections are presented in Chapter 3, Scope of Inspection Work.

Table 2-2. Recommended Maximum Interval between Routine Inspections (Years)[a]

Condition Rating from Previous Inspection	CONSTRUCTION MATERIAL: Unwrapped Timber or Unprotected Steel (No Coating or Cathodic Protection)[d]		CONSTRUCTION MATERIAL: Concrete, Masonry, Wrapped Wood, Protected Steel, or Composite Materials[d]		Channel Bottom or Mudline Scour[e, f] (Soundings[g]/Direct Observation)	
	Benign[b] Environment	Aggressive[c] Environment	Benign[b] Environment	Aggressive[c] Environment	Benign[b] Environment	Aggressive[c] Environment
6 Good	6	4	6	5	6/6	2/5
5 Satisfactory	6	4	6	5	6/6	2/5
4 Fair	5	3	5	4	6/6	2/5
3 Poor	4	3	5	4	6/6	2/5
2 Serious	2	1	2	2	2/2	2/2
1 Critical	0.5	0.5	0.5	0.5	1/1	0.5/1

[a] The maximum interval between routine inspections may be reduced based on extent of deterioration, anticipated deterioration, and importance of the structure. Intervals may be increased for atypical cases where special construction materials are used. Regulations may dictate a maximum inspection interval.

[b] Benign environments include freshwater with low to moderate currents (current <0.75 knots).

[c] Aggressive environments include brackish water, seawater, polluted water, or waters with currents >0.75 knots. Facilities that handle chemicals containing elements detrimental to the structure's durability, such as chlorides, sulfates, or alkalis, are aggressive environments.

[d] The intervals indicate requirements for sounding timbers.

[e] The intervals indicate requirements for direct observation of the bottom for scour.

[f] Two maximum intervals are shown, one for the assessment of construction material (wood, concrete, steel, etc.) and one for scour (last two columns). The shorter interval should be used.

[g] Soundings may be performed at the time of the above water inspection.

2.1.3 Structural Repair or Upgrade Design Inspections

2.1.3.1 Purpose and Frequency The purpose of the structural repair or upgrade design inspection is to record defects to be repaired, including all relevant defect attributes, such that repair bid documents may be generated. Structural repair or upgrade design inspections should be conducted only when repairs are to be performed and should be conducted with as little interval as practicable between the time of the structural repair or upgrade design inspection and the execution of repairs; typically, one year has been accepted as a practical interval. A one-year interval typically provides sufficient time to develop the repair documents, bid and award the construction contract, and initiate construction without the design level inspection data changing sufficiently to cause significant change orders.

Typically, structural repair or upgrade design inspections result from a recommendation made following a routine inspection. However, when the need for repairs is obvious and the priority is clear, a structural repair or upgrade design inspection may be conducted without being preceded by a routine inspection or may be combined with a routine inspection.

2.1.3.2 Scope of Work Overview Prior to commencing a structural repair or upgrade design inspection, the criteria for what defects should be repaired should be established. In addition, determining the method(s) of repair for all typical situations on the structure may be beneficial. The structural repair or upgrade design inspection is then performed to document the location and size of defects to be repaired and to assign a method of repair, based on the preestablished criteria.

Estimating the size of each defect to be repaired is important to prepare reasonably accurate quantity and cost estimates for the repair project. Ideally, the structural repair or upgrade design inspection should be conducted only on the components identified to be in need of repair during the routine inspection. Therefore, if the components requiring repair are limited to a certain area of the structure or to specific component types, the scope of the structural repair or upgrade design inspection may be tailored to these specific areas to optimize resources and minimize costs.

The method of investigation used in a structural repair or upgrade design inspection must be tailored to the type and extent of deterioration observed. Details on the scope of structural repair or upgrade design inspection are presented in Chapter 3.

2.1.4 New Construction Inspections

2.1.4.1 Purpose and Frequency New construction inspections should be performed during the construction of new structures, or the construction of components, to ensure proper construction quality in accordance with the design plans and specifications.

2.1.4.2 Scope of Work Overview The scope of the new construction inspection should include quality control inspection of structures under construction for compliance with the construction documents and resolution of field problems. Details of the scope of new construction inspections are presented in Chapter 3.

2.1.5 Baseline Inspections

2.1.5.1 Purpose and Frequency The purpose of a baseline inspection is to verify that the structure was built according to the design drawings and to ensure that no significant defects exist on the structure prior to owner acceptance. Baseline inspections are typically conducted on newly constructed facilities prior to owner acceptance or final payment to the contractor. If the baseline inspection is not conducted at the time of original construction, it may be conducted simultaneously with the first routine inspection.

The purpose of conducting a baseline inspection on an existing structure is to verify that the structure was built according to the design drawings. Where no drawings exist, the purpose of the baseline inspection is to gather sufficient information to develop plan and section drawings of the structure.

2.1.5.2 Scope of Work Overview The scope of a baseline inspection typically includes confirmation of overall dimensions, pile plan, and other physical features. For new construction, the baseline inspection may also include confirmation of water depths or dredging, ensuring that construction is free of significant defects and that construction debris has been removed. For existing structures, the scope may include detailed measuring and testing to develop drawings of the structure where none exist. Details of the scope of a baseline inspection are presented in Chapter 3.

2.1.6 Due Diligence Inspections

2.1.6.1 Purpose and Frequency The purpose of the due diligence inspection is to provide the necessary information regarding the general condition of an existing facility; recommend repairs and determine their associated costs; and provide a projection of future repair, inspection, and maintenance costs. The inspection gathers only the limited information necessary for an engineer to form an opinion about the general condition of a structure; order-of-magnitude valuation; order-of-magnitude repair costs, repair methodology, and repair interval; and inspection costs and inspection interval recommendations.

2.1.6.2 Scope of Work Overview The scope of the due diligence inspection is a visual/tactile inspection to determine the general condition of the facility, identify significant damage requiring repairs, identify any maintenance repairs, and determine the ability of the facility to support the current or anticipated operations. The need and scope of a due diligence inspection is often dictated by financial or insurance considerations. Examples include the purchase of a marine terminal, negotiation or renegotiation of a lease, or consideration of a new insurance carrier.

The inspection and ratings should follow the guidelines of a routine inspection as described in Section 2.1.2. Documentation resulting from a due diligence inspection may not be as detailed as that of a routine inspection depending on the amount of time allowed to complete the inspection and report. Because due diligence inspections are performed as part of a financial transaction, the results are often required sooner than performing a routine inspection would allow. Should this be the case, the limited inspection effort and generalization of the observations should be stated explicitly and the inspection results qualified, as appropriate. Details of the scope of a due diligence inspection are presented in Chapter 3.

2.1.7 Special Purpose Inspections

2.1.7.1 Purpose and Frequency Special purpose inspections are conducted to collect more detailed information than normally collected during a routine or structural repair or upgrade design inspection. Such information may be necessary to understand the nature and/or extent of deterioration prior to determining the need for and type of repairs. Special purpose inspections may also be performed to estimate the remaining useful life of the structure. An example of the need for a special purpose inspection is a concrete structure with piles that are soft below the waterline. In such a case, the special purpose inspection would include coring and testing and analysis to determine if the cause of the softness is related to sulfate attack, alkali-silica reaction (ASR), or delayed ettringite formation (DEF). Another example of the need for a special purpose inspection is a concrete structure with cracking elements but limited corrosion. In such a case, the special purpose inspection would include coring and testing and analysis to determine if the cause of the cracking is related to chlorides, carbonation, sulfate attack, ASR, or DEF.

Special purpose inspections are typically performed on a case-by-case basis as a result of a recommendation made following a routine inspection. However, a special purpose inspection may also be performed concurrently with a routine inspection or structural repair or upgrade design inspection where appropriate.

2.1.7.2 Scope of Work Overview The scope of a special purpose inspection may vary widely depending on the objectives of the inspection and the nature of the deterioration. Examples of common special purpose inspection techniques follow. Some of these techniques may also be used in conducting routine or structural repair or upgrade design inspections in some circumstances.

- Concrete coring for physical testing and/or laboratory analysis (strength testing, composition analysis, dynamic modulus of elasticity testing, static modulus of elasticity testing, specific gravity and absorption testing, petrographic analysis, scanning electron microscopy, differential thermal analysis, etc.);
- Concrete chloride content evaluation;
- Half-cell potential measurements;
- Ultrasonic remaining thickness measurements;
- Rebound hammer testing;
- Penetration resistance testing;
- Pulse velocity and pulse echo testing;
- Crack monitoring;
- Settlement monitoring;
- Ground-penetrating radar investigations;
- Sub-bottom profiling;
- Side scan or multibeam sonar investigations;
- Wood preservative retention testing;
- Timber component removal and dissection;
- Dissolved oxygen (DO) testing;
- Marine borer investigation;
- Fluorometer dye/leak detection testing;
- Scour analysis or soil particle size analysis;
- Magnetic particle inspection;
- Coating thickness or continuity inspection;
- Coupon sampling and metallurgical analysis; and
- Postmarine growth removal inspection.

The requester of the services must specify the type of inspection or testing technique, which may typically be based on a recommendation made following a routine inspection. Details on the scope of a special purpose inspection are presented in Chapter 3.

2.1.8 Repair Construction Inspections

2.1.8.1 Purpose and Frequency Repair construction inspections should be performed during the execution of repair projects to ensure proper quality of repairs, resolve field problems, and ensure impartial documentation of payment quantities. The onsite inspector, while evaluating work against the contract specifications, may also evaluate contractor claims for progress payments or additional work. Repair quantities and specified repair methods are only estimates based on the best judgment of the inspection engineer during the structural repair or upgrade design inspection. Widespread removal of unsound materials may reveal differing conditions. The need for attentive inspection during the execution of repairs is important to protect the interests of the owner. This is particularly true where payment for repair work will be based on unit pricing.

2.1.8.2 Scope of Work Overview The scope of the repair construction inspection should include quality control inspection of repairs for compliance with the specifications and may also include resolution of field problems, evaluation of contractor claims, and determination that repair quantities are properly recorded where necessary. Details of the scope of repair construction inspections are presented in Chapter 3.

2.1.9 Post-Event Inspections

2.1.9.1 Purpose and Frequency Post-Event Inspections should be conducted following a significant, potentially damage-causing event such as a flood, earthquake, storm, vessel impact, or tsunami. The primary purpose of a Post-Event Inspection is to rapidly assess the structural stability of the structure and/or to determine if further attention to the structure is necessary as a result of the event.

2.1.9.2 Scope of Work Overview Post-Event Inspections are intended to be somewhat rapid visual/tactile inspections to determine if the event resulted in any significant damage requiring repairs or load restrictions. The need for and scope of a Post-Event Inspection is generally dictated by the type and severity of the event. For example, a major flood may result in scour conditions that necessitate an underwater inspection. However, an earthquake or vessel impact often results in damage above the waterline as well as below; therefore, an underwater inspection may be triggered only where above water damage is visible. If a Post-Event Inspection is required, the amount of marine growth removal required for the inspection should be based on the type of damage that may have occurred. Whereas gross breakages or channel bottom evaluations may require no time-consuming marine growth removal, potential overstressing cracks on concrete piles may dictate higher levels of growth removal.

Documentation resulting from a Post-Event Inspection may be minimal. A simple rating system is used to indicate if further attention is required and how urgent such attention should be. The rating system used for a Post-Event Inspection should be different from the rating system used during a routine inspection, because the post-event rating should focus on event-related damage only. However, general observations of significant damage not related to the event, such as significant corrosion damage or other deterioration, should be mentioned as appropriate. Details of the scope of a Post-Event Inspection are presented in Chapter 3.

2.2 SELECTION OF THE PROPER INSPECTION TYPE

Each of the eight inspection types defined herein has a distinct purpose; however, these inspection types are not necessarily exclusive. Inspection types may be combined freely to meet the global objectives of a project.

Table 2-3 lists the most common inspection objectives and provides guidance on choosing the inspection type or types that meet the needs of the project. Guidance is also provided in Table 2-3 to indicate whether the inspection objective is included in the standard scope of work for an inspection type, or whether the objective is nonstandard. Nonstandard objectives must be specifically stated when defining the scope of work for an inspection or repair project.

2.3 SERVICE LIFE MODELING: PURPOSE AND VALUE

The use of the inspection data, engineering assessments, and cost data for planning, budgeting, and management of facilities often necessitates an estimate of the predicted remaining service life. Typically, this estimate of remaining service life is based on the assessing engineer's experience and judgment. In most cases, this is reasonable and acceptable. However, in cases where quantitative information is wanted, such as critical facilities, or in cases that may be adversarial or controversial, an impartial tool to predict service life of materials can be valuable. Service life modeling uses site-specific materials and boundary conditions to predict the service life of the concrete (defined in more detail in Chapter 4). Situations in which such service life modeling would be valuable include

- Performance specifications: When specifying the service life of concrete, having a quantitative tool to measure the predicted service life of the various alternatives under consideration is desirable. For example, when considering various cements, pozzolans, admixtures, aggregate, sand, water/cementitious ratios, concrete cover, and reinforcing types, optimizing the concrete mixture to meet the specified service life may be beneficial to a contractor.
- Existing structures: When assessing an existing structure and its various elements that have not reached the corrosion threshold (average critical chloride content at the initiation of corrosion for a specific material), determining the remaining service life can be beneficial for the planning and future management of a facility. Being able to quantitatively measure the impact of various alternatives or options on the remaining service life of the various elements of a structure can aid in managing and planning the maintenance of a facility. For example, when considering when or how to repair a facility, knowing

Table 2-3. Matching Inspection Objectives with the Eight Inspection Types

Objective	Inspection Type	Included in Standard Scope of Work	Addition to the Standard Scope of Work
Ensure quality control during new construction	New Construction Inspection	✓	
Verify installed quantities for contractor payment	New Construction Inspection	✓	
Respond to field questions and problems during new construction	New Construction Inspection	✓	
Verify that structure is built in general compliance with the design drawings, if available	Baseline Inspection	✓	
Ensure that new structure has no significant defects prior to owner acceptance	Baseline Inspection	✓	
Generate design drawings where no drawings exist	Baseline Inspection		✓
Assess and rate the overall condition of an existing structure	Routine Inspection	✓	
Determine what future maintenance activities are necessary on a structure	Routine Inspection	✓	
Quantitatively evaluate the local loss of structural capacity of typical components as a result of damage or deterioration	Routine Inspection	✓	

Table 2-3. Matching Inspection Objectives with the Eight Inspection Types *(Continued)*

Objective	Inspection Type	Included in Standard Scope of Work	Addition to the Standard Scope of Work
Quantitatively evaluate the global structural integrity relative to actual loads on the structure, considering observed damage or deterioration	Routine Inspection		✓ (Engineering evaluation)
Estimate the remaining useful life of the structure	Routine Inspection		✓ (May require special purpose inspection)
Develop order-of-magnitude estimates of probable costs for rehabilitation work	Routine Inspection		✓
Assess the general condition of an existing facility	Due Diligence Inspection	✓	
Develop order-of-magnitude valuation of the facility	Due Diligence Inspection	✓	
Develop order-of-magnitude rehabilitation costs, including future maintenance and inspections	Due Diligence Inspection	✓	
Provide an opinion of the facility's ability to support present and/or anticipated operations	Due Diligence Inspection	✓	

(Continued)

Table 2-3. Matching Inspection Objectives with the Eight Inspection Types *(Continued)*

Objective	Inspection Type	Included in Standard Scope of Work	Addition to the Standard Scope of Work
Document details of defects and components to be repaired	Structural Repair or Upgrade Design Inspection	✓	
Develop detailed quantity estimates for rehabilitation work	Structural Repair or Upgrade Design Inspection	✓	
Develop detailed repair plans (bid documents), including drawings and specifications	Structural Repair or Upgrade Design Inspection		✓
Determine the cause of observed deterioration to fix or prevent it in the future, where such cause is not readily apparent	Special Purpose Inspection[a]		✓
Quantify the extent of observed deterioration	Special Purpose Inspection[a]		✓
Determine the structural significance of observed damage	Special Purpose Inspection[a]		✓
Determine the significance of observed damage on future durability	Special Purpose Inspection[a]		✓
Ensure quality control of repairs during construction	Repair Construction Inspection	✓	

Table 2-3. Matching Inspection Objectives with the Eight Inspection Types *(Continued)*

Objective	Inspection Type	Included in Standard Scope of Work	Addition to the Standard Scope of Work
Respond to field questions and problems during construction of repairs	Repair Construction Inspection	✓	
Ensure impartial documentation of repair quantities during construction of repairs	Repair Construction Inspection	✓	
Assess and rate structural integrity following a significant loading or environmental event	Post-Event Inspection	✓	
Determine if additional remedial attention is necessary on a structure as a result of a significant loading or environmental event	Post-Event Inspection	✓	

[a]Note that special purpose inspections have no "standard" scope of work. Each Special Purpose Inspection should be conducted for a predefined purpose and such purposes may vary considerably.

the impact on the remaining service of the elements is essential in determining the most economical solution to reach the desired service life goals.

- Construction variances: When assessing the impact a variance has on the service life of a structure or an element, having a tool to quantitatively measure the remaining service life is valuable in determining the difference in service life between the as-designed condition and the as-built condition. For example, if concrete is placed with a lower water/cementitious ratio but with less cover than designed, does it have the same, more, or less service life than that designed? If it is less, various alternatives could be modeled to determine which alternative would achieve the desired service life.

2.4 MINIMUM QUALIFICATIONS OF INSPECTION PERSONNEL

2.4.1 General

The inspection of waterfront structures requires a specialized understanding of the engineering applications and technologies unique to waterfront structures and the complex marine environment. It is critical that the inspections be carried out by professionals with the appropriate level of education, experience, and expertise. All personnel should have the qualifications, including education and practical experience, required to perform the inspection or specific technical task assigned if working as part of a team. The entire process, from scoping to reporting, and all inspection types should be performed under the direction of a registered professional engineer qualified in the appropriate discipline.

A properly executed inspection goes well beyond the mere logging of observed defects. The nature of on-site inspection work necessitates that engineering judgment be applied to decisions made throughout the inspection process. The minimum qualifications for on-site personnel are to ensure that they have the necessary training and experience to observe, assess, and exercise sound judgment. Specific reasons for such judgment include

- Assigning Condition Assessment Ratings to a structure requires an understanding of load paths and the structural significance of observed damage. For example, assessing the significance of a deteriorated wood cross brace versus a deteriorated timber pile requires an understanding of structural redundancies and alternate load paths and an understanding of where the section loss occurs on the member relative to the point of maximum bending moment or shear.
- Quantifying and evaluating the structural significance of damage requires first-hand knowledge of the deterioration and the judgment to know what specific data should be collected to support the structural analysis. For example, corroded steel piles may require corrosion profiling of representative members to evaluate section loss against axial forces and bending moments at various points along the piles.
- Estimating the remaining useful life of a structure requires a detailed understanding of the deterioration mechanism(s) and rates. For example, the rate of chloride intrusion into a particular concrete structure may be determined and compared with the corrosion threshold to estimate the remaining useful life of the structure.
- Determining the most appropriate method of conducting a structural repair or upgrade design inspection requires a detailed understanding of which repair methods will be cost effective and economical. For example, piles that will be jacketed may not require the same level of

inspection effort as piles on which each defect will be repaired individually.

- Determining the proper method of repair for each defect requires an understanding of the deterioration process. For example, distinguishing an overstressing crack from a corrosion crack is important because, whereas an overstressing crack may be repaired by epoxy injection, such a repair on a corrosion crack would be inappropriate as a long-term repair solution.

This section defines the recommended minimum qualifications of the project manager, team leader, and team members for both above water and underwater inspections. The number of members of the inspection team and the qualifications and expertise of the individual members should be evaluated in consideration of the engineering requirements of the task and the requirements of the facility owner and regulatory agencies involved. Although safety considerations are not covered in this manual, the safety-related qualifications should be evaluated separately, and all inspection personnel should also be trained or certified and experienced in the applicable safety practices necessary to conduct the inspections.

The minimum qualifications for personnel performing underwater inspections should be equivalent to those performing above water inspections. All underwater inspections and diving operations should be conducted in accordance with applicable regulations. In the United States, diving is generally performed in accordance with the requirements of the federal Commercial Diving Standards of the Occupational Safety and Health Administration (OSHA) and state OSHA requirements, as applicable.

2.4.2 Project Manager

The inspection team should be under the direction and supervision of a project manager who understands the overall goals and objectives of the inspection. The project manager should be a registered professional engineer specializing in civil, structural, or ocean engineering with at least 10 years of experience in a responsible capacity for the inspection, design, and construction of waterfront structures.

2.4.3 Team Leader

The inspection team should be led by and be under the direct on-site supervision of a team leader. The team leader should be a registered professional engineer and should have a minimum of five years of experience performing similar waterfront inspections. The team leader should be at the site for the duration of the field inspection and should personally direct the inspection team to ensure that each element is inspected and that its condition is properly documented. When unusual conditions, significant structural deficiencies, or unusual construction is encountered, the team leader should personally observe and evaluate the condition. The team leader should periodically communicate with the project manager to report the inspection findings and receive instruction. For underwater inspections, the team leader should also be a trained commercial diver and should actively participate in the inspection by personally conducting the underwater inspection of a minimum of 25% of the structure.

2.4.4 Team Members

Team members involved in inspection and note taking or documentation work shall be trained inspectors who are graduates of a four-year engineering curriculum and certified as an engineer-in-training (EIT), or technicians who have relevant certifications for bridge or related inspections by the National Society of Professional Engineers' (NSPE) program for National Institute for Certification in Engineering Technologies (NICET) or Federal Highway Administration–approved comprehensive inspection training courses. (Outside of the United States, comparable evidence of minimum competence may be substituted.) Other personnel performing manual tasks, such as removing marine growth, or supporting diving operations, but not conducting or reporting inspections, may have lesser qualifications. In addition, other technicians and/or divers with special knowledge, skills, or experience may be part of the team as required to support the objective. Team members involved in underwater inspections should also be trained commercial divers.

2.5 ELEMENT-LEVEL DAMAGE RATING

A damage rating is assigned to each element inspected during an investigation. The rating reflects the condition of the individual element only and is independent of the element's structural importance and the type of inspection being conducted.

Element-level damage ratings are standardized to provide a qualitative description of an element's condition based on a quantified level of damage. By using a quantified scale, objectivity is maintained throughout the inspection.

The following sections present damage ratings typically used for timber, steel, reinforced concrete, and prestressed concrete elements.

2.5.1 Timber Elements

Typical damage ratings used for timber elements are described in Table 2-4 and depicted in Fig. 2-2.

Table 2-4. Damage Ratings for Timber Elements

Damage Rating		Existing Damage[a]	Exclusions [Defects Requiring Elevation to the Next Higher Damage Rating(s)]
NI	Not Inspected	• Not inspected, inaccessible, or passed by[b]	
ND	No Defects	• Sound surface material	
MN	Minor	• Checks, splits, and gouges less than 0.5 in. wide • Evidence of marine borers or fungal decay	Minor damage not appropriate if • Loss of cross section • Marine borer infestation • Displacements, loss of bearing, or connections
MD	Moderate	• Remaining diameter loss up to 15% • Checks and splits wider than 0.5 in. • Cross-section area loss up to 25% • Corroded hardware • Evidence of marine borers or fungal decay, with loss of section	Moderate damage not appropriate if • Displacements, loss of bearing or connections

(Continued)

Table 2-4. Damage Ratings for Timber Elements *(Continued)*

Damage Rating		Existing Damage[a]	Exclusions [Defects Requiring Elevation to the Next Higher Damage Rating(s)]
MJ	Major	• Remaining diameter loss 15 to 30% • Checks and splits through full depth of cross section • Cross-section area loss 25 to 50%; heavily corroded hardware • Displacement and misalignments at connections	Major damage not appropriate if • Partial or complete breakage
SV	Severe	• Remaining diameter loss more than 30% • Cross-section area loss more than 50% • Loss of connections and/or fully nonbearing condition • Partial or complete breakage	

[a] Any defect listed is sufficient to identify relevant damage grade.
[b] If not inspected due to inaccessibility or passed by, note as such.

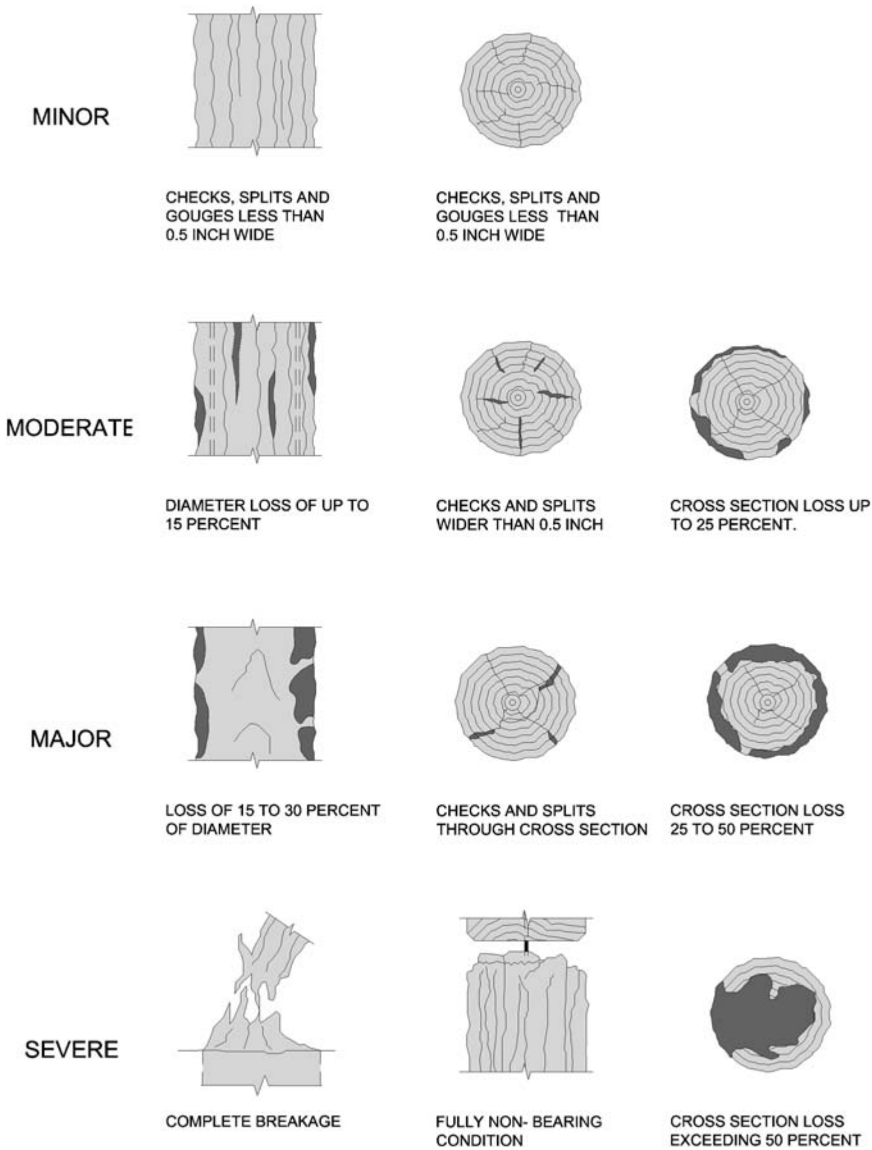

Fig. 2-2. Condition ratings for timber elements
Source: Courtesy of CH2M HILL, Inc. and Ben C. Gerwick, Inc., reproduced with permission.

2.5.2 Steel Elements

Typical damage ratings used for steel elements are described in Table 2-5 and depicted in Fig. 2-3.

2.5.3 Reinforced Concrete Elements

Typical damage ratings for reinforced concrete elements are described in Table 2-6 and depicted in Fig. 2-4.

2.5.4 Prestressed Concrete Elements

Typical damage ratings for prestressed concrete elements are described in Table 2-7 and depicted in Fig. 2-5.

2.5.5 Mooring System Elements

Typical damage ratings for mooring systems are described in Table 2-8 and Table 2-9 and depicted in Fig. 2-6 through Fig. 2-8.

2.5.6 Fender System Elements

Typical damage ratings for fender system elements are described in Table 2-10 through Table 2-13 and depicted in Fig. 2-9 through Fig. 2-14.

2.5.7 Utility Systems

Damage ratings of waterfront utility systems provide a means of identifying the importance and severity of deficiencies observed during inspection. Inspection of the utilities is limited to the observed condition of the utility lines, risers, hangars, brackets, and accessories. The intent of the inspection is to ensure, to the extent possible, that the utility line and supports are structurally sound. The remaining thickness and interior condition of the utility piping, valves, and other system elements are typically not part of a waterfront inspection. The typical rating system described in Section 2.6.2 was used as a basis for the damage ratings used for these systems. Utility lines, brackets, and accessories are rated based on the degree of observed damage or deterioration and corresponding urgency of repair. The severity of the rating indicates a condition that requires replacement, repair, or a more detailed inspection to determine remaining material thickness or internal condition.

The results of the condition inspection may be represented on a plan using a minimum scale of 1 in. = 30 ft. The utility lines are color coded to indicate observed conditions, the degree of damage, and corresponding urgency of

Table 2-5. Damage Ratings for Steel Elements

Damage Rating		Existing Damage[a]	Exclusions [Defects Requiring Elevation to the Next Higher Damage Rating(s)]
NI	Not Inspected	• Not inspected, inaccessible, or passed by[b]	
ND	No Defects	• Protective coating or wrap intact • Light surface rust • No apparent loss of material	
MN	Minor	• Protective coating or wrap damaged and loss of thickness up to 15% of nominal at any location • Less than 50% of perimeter or circumference affected by corrosion at any elevation or cross section • Loss of thickness up to 15% of nominal at any location	Minor damage not appropriate if • Changes in straight line configuration or local buckling • Corrosion loss exceeding fabrication tolerances (at any location)
MD	Moderate	• Protective coating or wrap damaged and loss of thickness 15 to 30% of nominal at any location • More than 50% of perimeter or circumference affected by corrosion at any elevation or cross section • Loss of thickness 15 to 30% of nominal at any location	Moderate damage not appropriate if • Changes in straight line configuration or local buckling • Loss of thickness exceeding 30% of nominal at any location

(Continued)

Table 2-5. Damage Ratings for Steel Elements *(Continued)*

Damage Rating		Existing Damage[a]	Exclusions [Defects Requiring Elevation to the Next Higher Damage Rating(s)]
MJ	Major	• Protective coating or wrap damaged and loss of nominal thickness 30 to 50% at any location • Partial loss of flange edges or visible reduction of wall thickness on pipe piles • Loss of nominal thickness 30 to 50% at any location	Major damage not appropriate if • Changes in straight line configuration or local buckling • Perforations or loss of wall thickness exceeding 50% of nominal
SV	Severe	• Protective coating or wrap damaged and loss of wall thickness exceeding 50% of nominal at any location • Structural bends or buckling, breakage and displacement at supports, loose or lost connections • Loss of wall thickness exceeding 50% of nominal at any location	

[a] Any defect listed is sufficient to identify relevant damage grade.
[b] If not inspected due to inaccessibility or passed by, note as such.

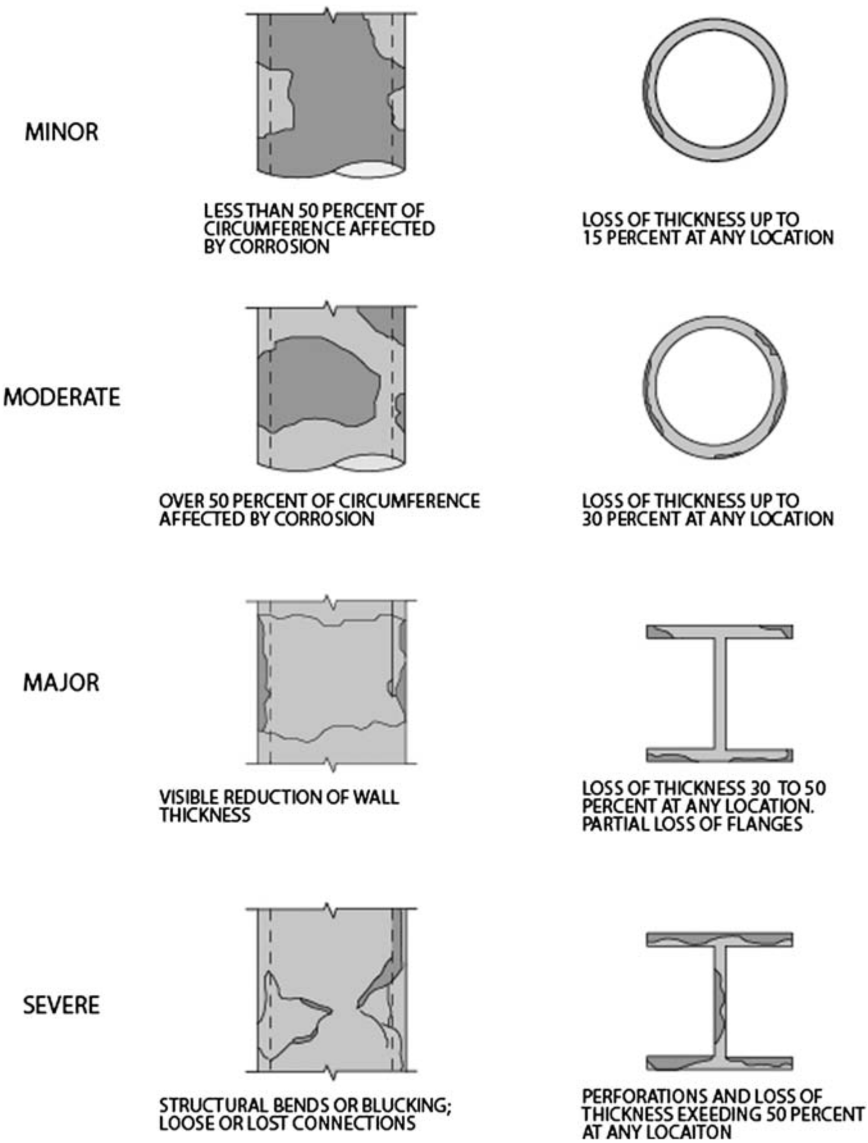

Fig. 2-3. Damage ratings for steel elements
Source: Courtesy of CH2M HILL, Inc. and COWI, Inc., reproduced with permission.

Table 2-6. Damage Ratings for Reinforced Concrete Elements

Damage Rating		Existing Damage[a]	Exclusions [Defects Requiring Elevation to the Next Higher Damage Rating(s)]
NI	Not Inspected	• Not inspected, inaccessible, or passed by[b]	
ND	No Defects	• Good original hard surface, hard material, sound	
MN	Minor	• Mechanical abrasion or impact spalls up to 1 in. in depth • Occasional corrosion stains or small pop-out corrosion spalls • General cracks up to 1/16 in. in width	Minor damage not appropriate if • Structural damage • Corrosion cracks • Chemical deterioration[c]
MD	Moderate	• Structural cracks up to 1/16 in. in width • Corrosion cracks up to 1/4 in. in width • Chemical deterioration: Random cracks up to 1/16 in. in width; "Soft" concrete and/or rounding of corners up to 1 in. deep • Mechanical abrasion or impact spalls greater than 1 in. in depth	Moderate damage not appropriate if • Structural breakage and/or spalls • Exposed reinforcement • Loss of cross section due to chemical deterioration beyond rounding of corner edges

MJ	Major	• Structural cracks 1/16 in. to 1/4 in. in width and partial breakage (through section cracking with structural spalls) • Corrosion cracks wider than 1/4 in. and open or closed corrosion spalls (excluding pop-outs) • Multiple cracks and disintegration of surface layer due to chemical deterioration • Mechanical abrasion or impact spalls exposing the reinforcing	Major damage not appropriate if • Loss of cross section exceeding 30% due to any cause
SV	Severe	• Structural cracks wider than 1/4 in. or complete breakage • Complete loss of concrete cover due to corrosion of reinforcing steel with more than 30% of diameter loss for any main reinforcing bar • Loss of bearing and displacement at connections • Loss of concrete cover (exposed steel) due to chemical deterioration • Loss of more 30% of cross section due to any cause	

[a] Any defect listed is sufficient to identify relevant damage grade.
[b] If not inspected due to inaccessibility or passed by, note as such.
[c] Chemical deterioration: Sulfate attack, alkali-silica reaction, alkali-aggregate reaction, alkali-carbonate reaction ettringite distress, or other chemical/concrete deterioration.

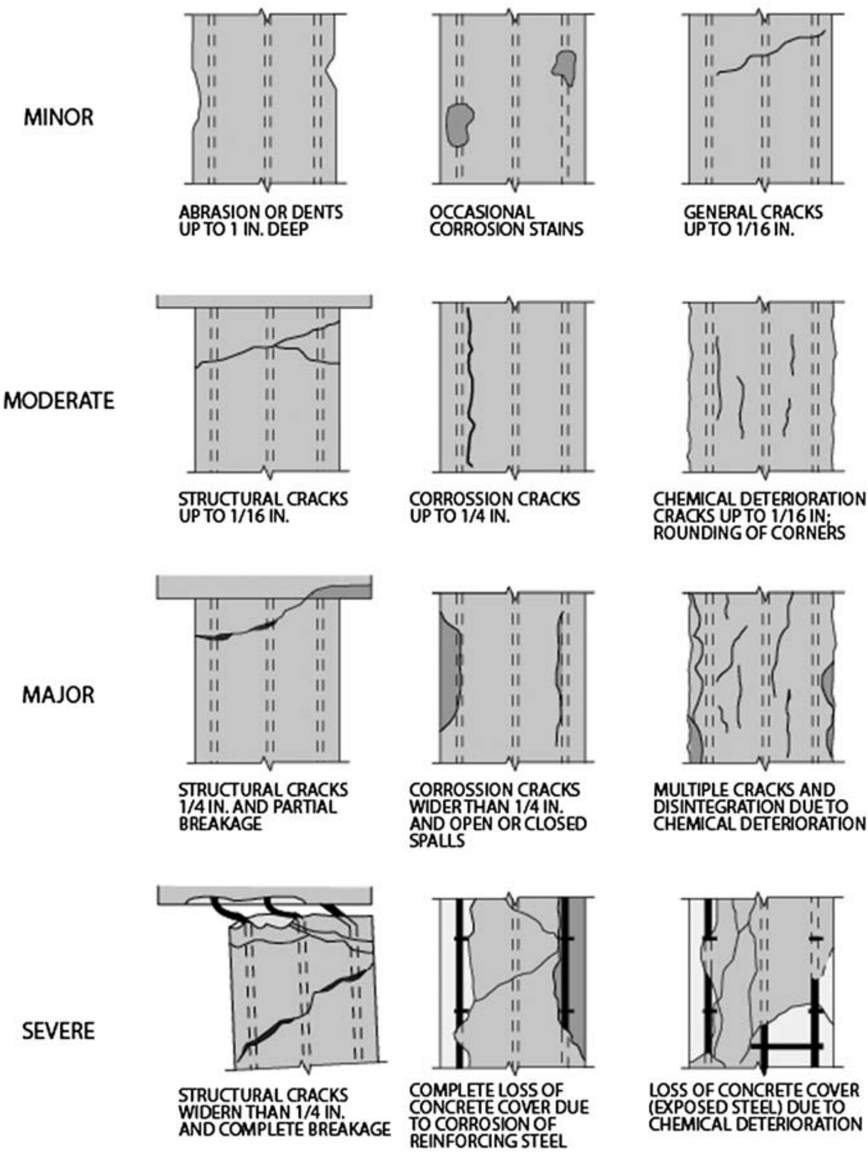

Fig. 2-4. Damage ratings for reinforced concrete elements
Source: Courtesy of CH2M HILL, Inc. and COWI, Inc., reproduced with permission.

Table 2-7. Damage Ratings for Prestressed Concrete Elements

Damage Rating		Existing Damage[a]	Exclusions [Defects Requiring Elevation to the Next Higher Damage Rating(s)]
NI	Not Inspected	• Not inspected, inaccessible, or passed by[b]	
ND	No Defects	• Good original hard surface, hard material, sound	
MN	Minor	• Minor mechanical or impact spalls up to 0.5 in. deep	Minor damage not appropriate if • Structural damage • Corrosion damage • Chemical deterioration[c] • Cracks of any type or size
MD	Moderate	• Structural cracks up to 1/32 in. in width • Chemical deterioration: Random cracks up to 1/32 in. in width	Moderate damage not appropriate if • Structural breakage and/or spalls • Corrosion cracks • Loss of cross section in any form • "Softening" of concrete

(Continued)

Table 2-7. Damage Ratings for Prestressed Concrete Elements *(Continued)*

Damage Rating		Existing Damage[a]	Exclusions [Defects Requiring Elevation to the Next Higher Damage Rating(s)]
MJ	Major	• Structural cracks 1/32 in. to 1/8 in. in width • Any corrosion cracks generated by strands or cables • Chemical deterioration: cracks wider than 1/8 in. • "Softening" of concrete up to 1 in. deep	Major damage not appropriate if • Exposed prestressing steel
SV	Severe	• Structural cracks wider than 1/8 in. and at least partial breakage or loss of bearing • Corrosion spalls over any prestressing steel • Partial spalling and loss of cross section due to chemical deterioration	

[a] Any defect listed is sufficient to identify relevant damage grade.
[b] If not inspected due to inaccessibility or passed by, note as such.
[c] Chemical deterioration: Sulfate attack, alkali-silica reaction, alkali-aggregate reaction, alkali-carbonate reaction ettringite distress, or other chemical/concrete deterioration.

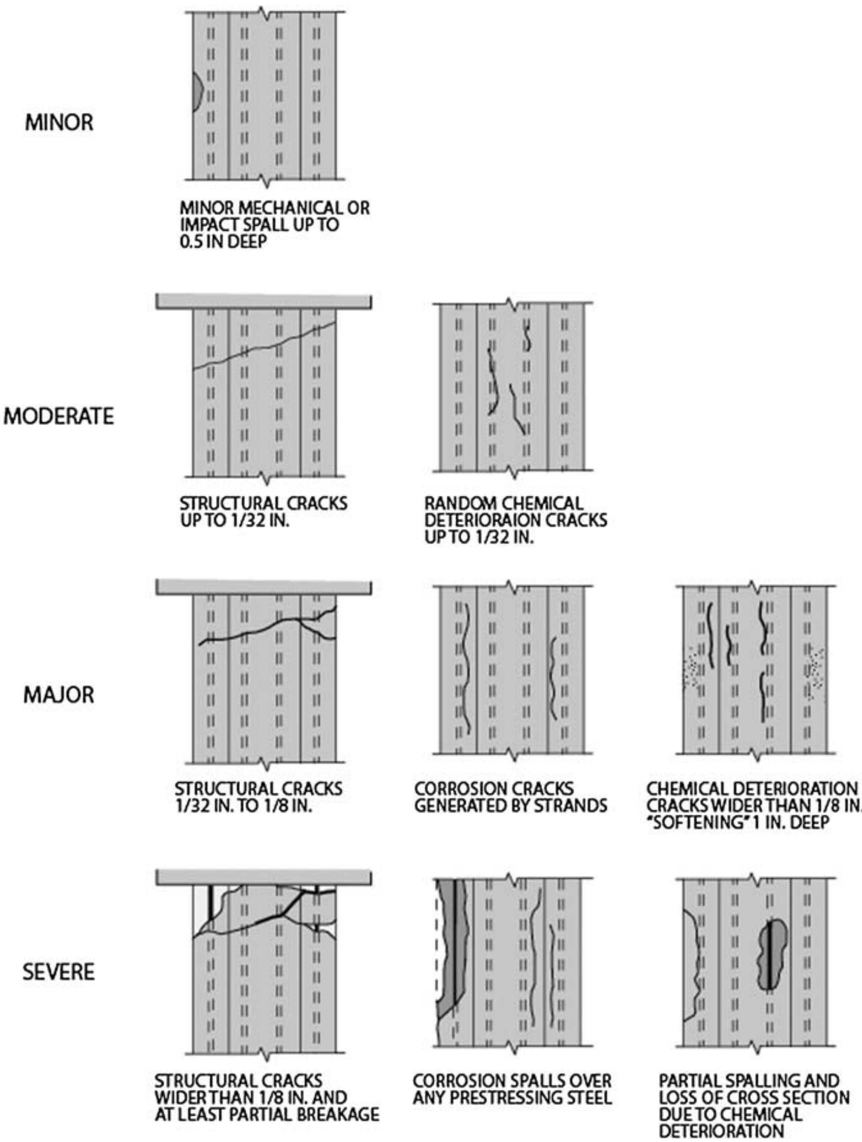

Fig. 2-5. Damage ratings for prestressed concrete elements
Source: Courtesy of CH2M HILL, Inc. and COWI, Inc., reproduced with permission.

Table 2-8. Damage Ratings for Mooring Hardware

Damage Rating		Existing Damage[a]	Exclusions [Defects Requiring Elevation to the Next Higher Damage Rating(s)]
NI	Not Inspected	• Not inspected, inaccessible, or passed by[b]	
ND	No Defects	• Material sound, surfaces smooth without indications of corrosion, surface coating in good condition, connections sound • Bolt countersinks grouted or sealed.	No Defects Rating not appropriate if • Surface coatings worn or damaged • Visible corrosion on fasteners
MN	Minor	• Fitting has surface corrosion over 10 to 25% of its area. • Minor wear marks or pitting on surface of fitting are less than 1/8-in. deep • Fasteners have minor corrosion with no significant loss of section	Minor Rating not appropriate if • Deep pits, gouges, or wear on fitting surfaces • Any noticeable loss of section on fastener threads, if visible
MD	Moderate	• Fitting has moderate surface corrosion with loose scale over less than 50% of its area • Significant surface wear marks or pitting on fitting are up to 1/4-in. deep • Fasteners have corrosion with less than 25% loss of section	Moderate Rating not appropriate if • Loose scale on fasteners • Inability to remove fasteners due to heavy corrosion, if accessible

MJ	Major	• Fitting has surface corrosion with loose scale over 50% or more of its surface area and/or less than 25% section loss • Significant surface wear marks or pitting on fitting are 1/4-in. deep or greater • Fasteners have corrosion with loose scale or loss of section greater than 25%	Major Rating not appropriate if • Displaced, damaged, or broken fitting components • Loose or missing fasteners
SV	Severe	• Fitting has heavy surface corrosion and loose scale with greater than 25% loss of section at critical areas of the fitting • Structural displacement, deformation, or rotation of the fitting are present; fitting components are broken, cracked, or delaminated • Loose, broken, or missing fasteners	

[a] Any defect listed is sufficient to identify relevant damage grade.
[b] If not inspected due to inaccessibility or passed by, note as such.

Table 2-9. Damage Ratings for Mooring Foundations

Damage Rating		Existing Damage[a]	Exclusions [Defects Requiring Elevation to the Next Higher Damage Rating(s)]
NI	Not Inspected	• Not inspected, inaccessible, or passed by[b]	
ND	No Defects	• Good original hard surface, hard material, sound	No Defects not appropriate if • Weathering on timber, steel, or composite elements • Hairline cracks in concrete elements
MN	Minor	• Timber Foundations: Weathered timber; evidence of fungal decay; minor checks, splits, and gouges up to 1/4-in. wide • Steel Foundations: Weathering of steel coating, light surface corrosion • Concrete Foundations: No significant section loss to load-bearing areas, hairline cracking of the concrete due to corrosion of the mooring hardware • Composites: Weathered surfaces	Minor Rating not appropriate if • Load-bearing areas around mooring hardware not sound • Displacements, loss of bearing, or connections • Fungal decay, insect infestation within or adjacent to the bearing area on timber elements • Corrosion loss exceeding fabrication tolerances (at any location) • Structural damage or corrosion cracking of concrete elements

MD	Moderate	• Timber cracked and checked up to 1/2-in. wide; weathered surfaces; fungal decay under or adjacent to the mooring hardware, with loss of section (max 1 in.) • Corrosion of steel with less than 10 to 25% section loss at any location • Noticeable cracking of concrete, larger than hairline but with no loss of interlock	Moderate Rating not appropriate if • Displacements, loss of bearing, or connections • Changes in straight-line configuration or local buckling • Loss of thickness exceeding 30% of nominal at any location for steel elements • Structural breakage, spalls, or corrosion cracks in concrete elements • Chemical deterioration[c] or "softening" of concrete elements
MJ	Major	• Timber cracked and checked greater than 1/2-in. wide; weathered; fungal decay present (max 3 in. depth); up to 25% loss of bearing • Steel corrosion with 25 to 50% section loss at any location • Noticeable cracking of concrete, resulting in loss of interlock • Composite elements cracked or split	Major Rating not appropriate if • Breakage or displacement of any element • Exposed steel strands in prestressed concrete elements • Perforations or loss of section exceeding 50% on steel elements

(Continued)

Table 2-9. Damage Ratings for Mooring Foundations *(Continued)*

Damage Rating		Existing Damage[a]	Exclusions [Defects Requiring Elevation to the Next Higher Damage Rating(s)]
SV	Severe	• Displacement/yielding of any support members • Loss of full bearing of fitting under hardware • Fungal decay of timber members (greater than 3 in. depth) • Significant corrosion of steel members with greater than 50% section loss at any location • Cracking or spalling of concrete base under hardware • Composite broken or damaged	

[a] Any defect listed is sufficient to identify relevant damage grade.
[b] If not inspected due to inaccessibility or passed by, note as such.
[c] Chemical deterioration: Sulfate attack, alkali-silica reaction, alkali-aggregate reaction, alkali-carbonate reaction ettringite distress, or other chemical/concrete deterioration.

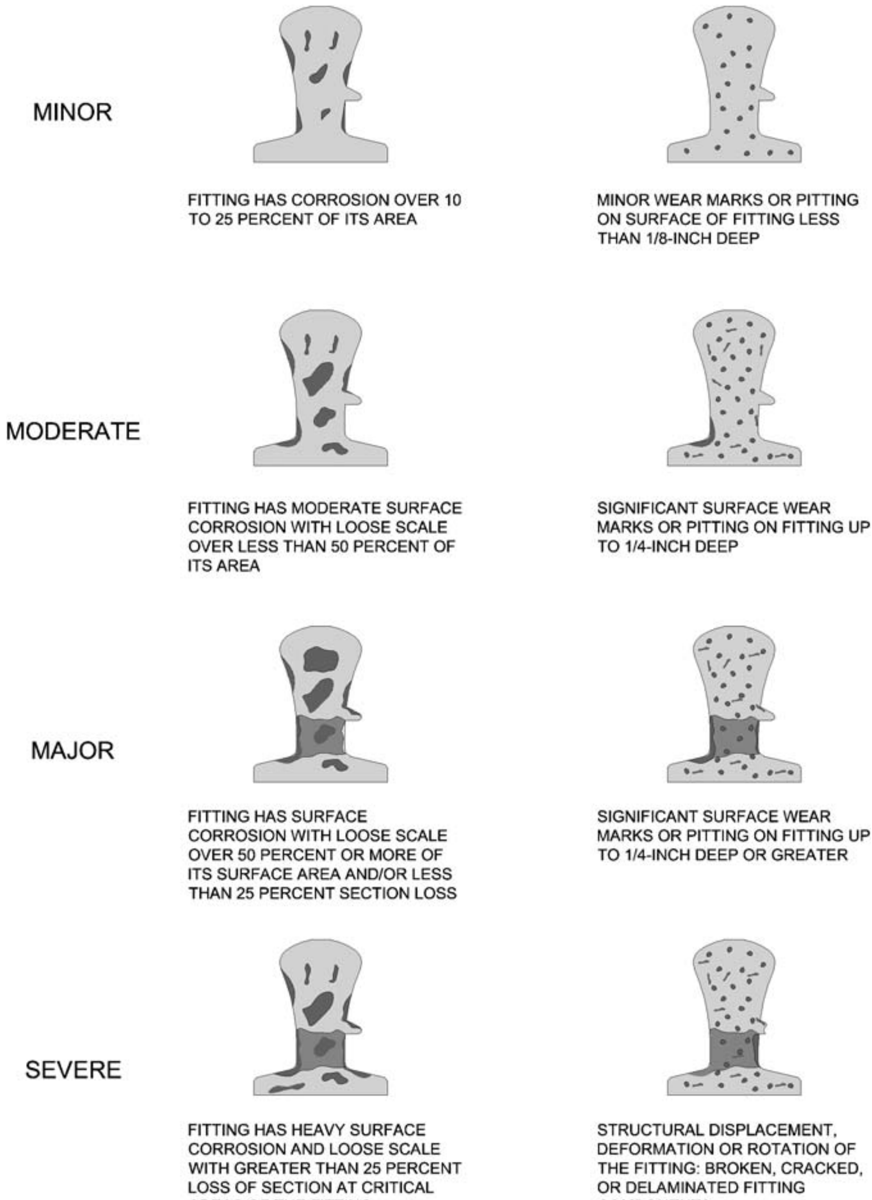

Fig. 2-6. Damage ratings for mooring hardware elements
Source: Courtesy of Moffatt & Nichol, Inc., reproduced with permission.

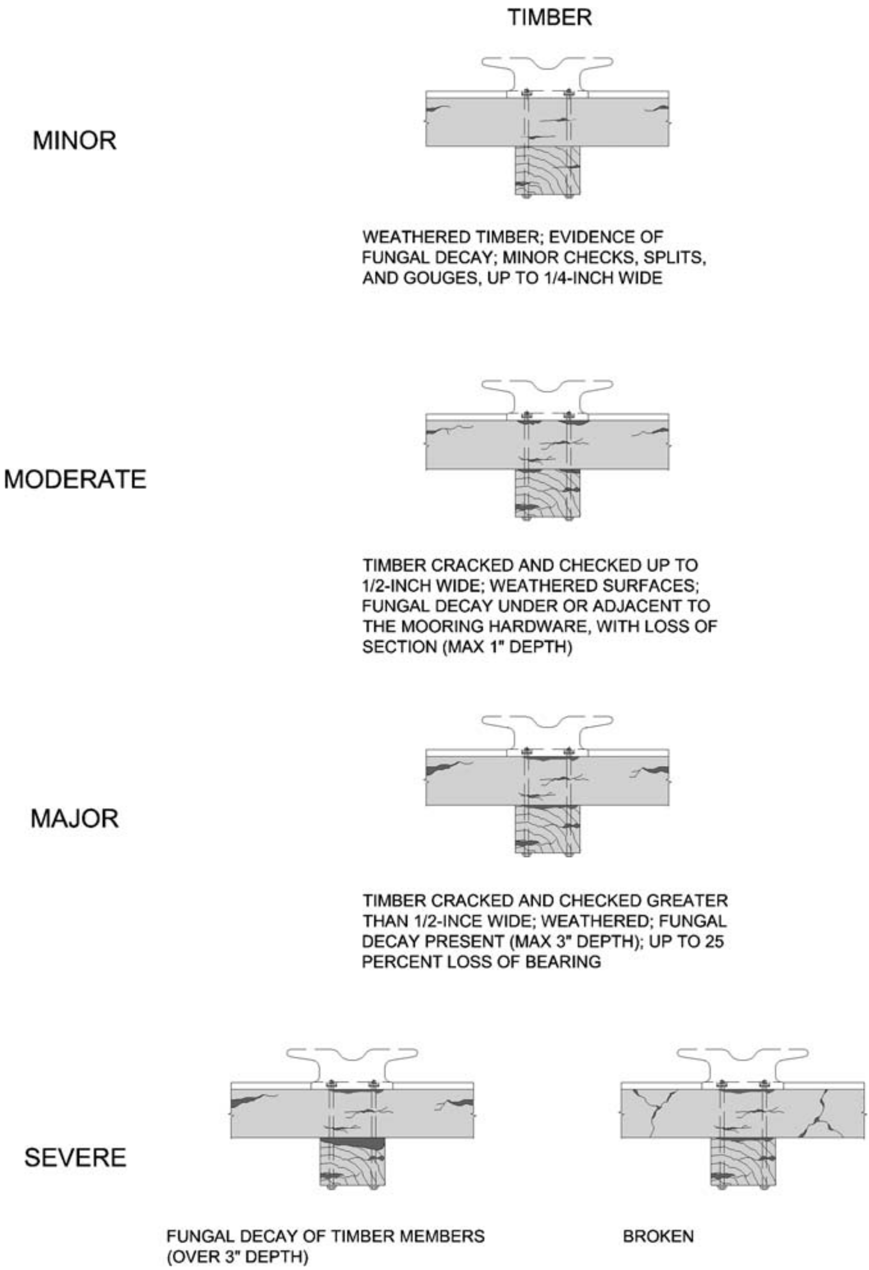

Fig. 2-7. Damage ratings for timber mooring foundation elements
Source: Courtesy of Moffatt & Nichol, Inc., reproduced with permission.

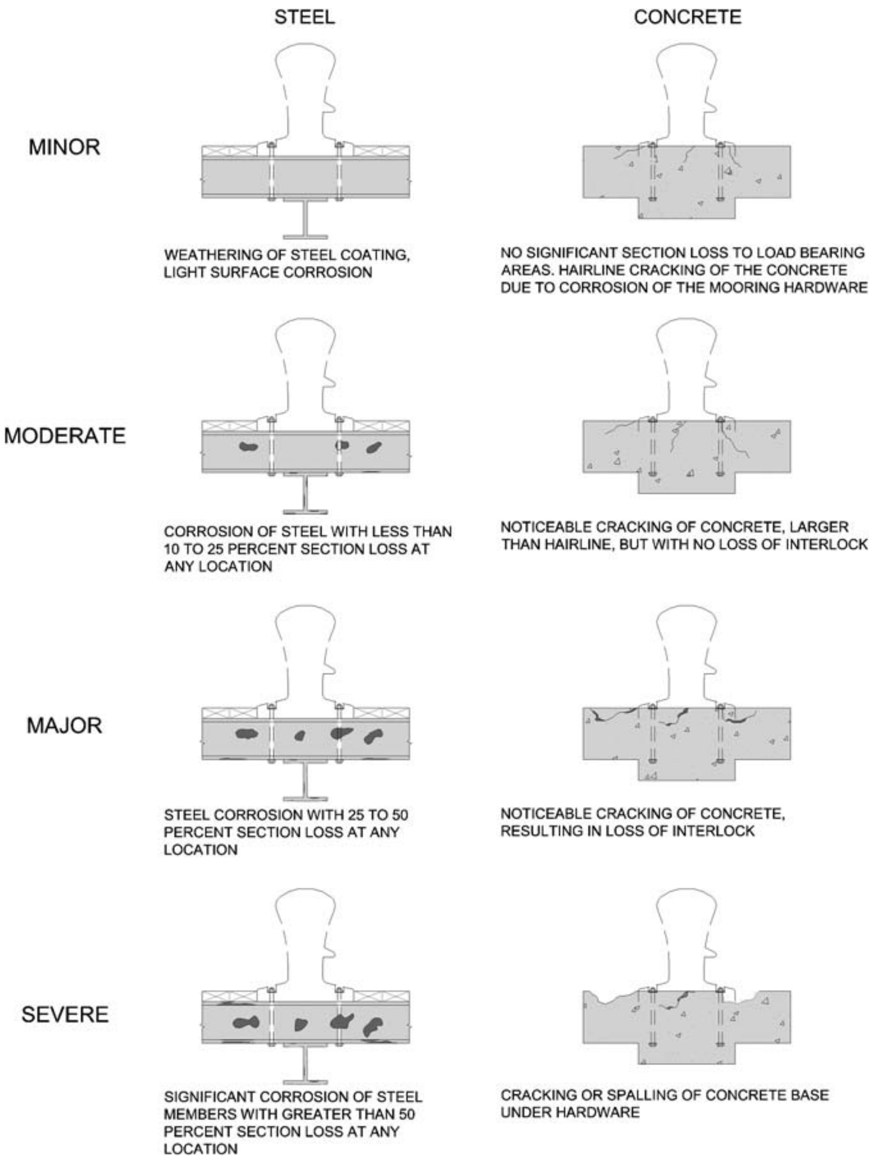

Fig. 2-8. Damage ratings for mooring hardware elements
Source: Courtesy of Moffatt & Nichol, Inc., reproduced with permission.

Table 2-10. Damage Ratings for Fender Piles

Damage Rating		Existing Damage[a]	Exclusions [Defects Requiring Elevation to the Next Higher Damage Rating(s)]
NI	Not Inspected	• Not inspected, inaccessible, or passed by[b]	
ND	No Defects	• Good original surface, sound, no defects observed	No Defects Rating not appropriate if • Surface coatings worn or damaged
MN	Minor	• Light abrasion less than 1/2-in. deep, light (surface) fungal decay, minimal marine borer activity observed (less than 5% section loss) • Weathering of steel coating, surface corrosion with no significant pitting • Hairline cracking of concrete • Weathered composite elements	Minor Rating not appropriate if • “Softening” of concrete
MD	Moderate	• Timber cracked and checked up to 1/2-in. wide, fungal decay (max 1 in. depth), abrasion up to 2-in. deep, loss of section due to marine borers less than 10% • Corrosion of steel with up to 25% localized section loss • Noticeable cracking of concrete but with no loss of interlock	Moderate Rating not appropriate if • “Softening” of the concrete (up to 1 in.) • Prestressed concrete fender piles (with a low effective prestress) are expected to crack under load; therefore, should be rated minor if no corrosion and the cracks are closed

MJ	Major	• Timber cracked and checked greater than 1/2-in. wide, fungal decay (max 3 in. depth), abrasion damage greater than 2-in. deep, loss of section due to marine borers between 10 and 25% • Corrosion of steel elements with 25 to 50% localized section loss, localized buckling of a flange • Noticeable cracking of concrete with loss of interlock, softening of the concrete greater than 1-in. deep • Composite elements cracked or split
SV	Severe	• Fungal decay on timber members (greater than 3 in. depth), loss of section due to marine borers (more than 25% of the section), broken • Significant corrosion of steel members with more than 50% localized section loss, broken, or yielded • Broken, exposed reinforcing steel or prestressing steel strands, spalling of the concrete, softening of the concrete greater than 3-in. deep • Composite elements broken

[a] Any defect listed is sufficient to identify relevant damage grade.
[b] If not inspected due to inaccessibility or passed by, note as such.

Table 2-11. Damage Ratings for Pneumatic, Foam-Filled, and Hydropneumatic Fenders

Damage Rating		Existing Damage[a]	Exclusions [Defects Requiring Elevation to the Next Higher Damage Rating(s)]
NI	Not Inspected	• Not inspected, inaccessible, or passed by[b]	
ND	No Defects	• Good original surfaces • Components sound • All hardware intact and operable	No Defects Rating not appropriate if • Components are weathered, worn, or torn
MN	Minor	• Wear on the fender unit with no visible belting • Hardware intact with visible surface corrosion, but less than 10% section loss • Swivel operable but binding	
MD	Moderate	• Wear on the fender, belting visible to a maximum depth of 1-in. • Hardware intact with 10 to 25% section loss • Swivel heavily corroded and or bound.	Moderate Rating not appropriate if • Fender unit permanently set or deformed
MJ	Major	• Wear on the fender, belting visible to a maximum depth of 2 in. • Permanent deformation of unit • Hardware loose or heavily corroded with between 25 and 50% loss of section • Swivel heavily corroded and or bound, or with 25 to 50% loss of section • Air pressure inflation and valves do not appear operable[3].	Major Rating not appropriate if • Components missing or broken

SV	Severe	• Considerable wear on the fender, belting visible to a depth greater than 2 in. • Punctures, tears, or holes in fender; foam exposed • Hardware heavily corroded with greater than 50% loss of section or missing or broken • Swivel heavily corroded and or bound, or with greater than 50% loss of section or broken • Air pressure inflation and valves are broken or damaged[c]

[a] Any defect listed is sufficient to identify relevant damage grade.
[b] If not inspected due to inaccessibility or passed by, note as such.
[c] For pneumatic and hydropneumatic fenders, an assessment of the air pressure and inflation/pressurization system should be confirmed.

Table 2-12. Damage Ratings for Rubber Fender Elements

Damage Rating		Existing Damage[a]	Exclusions [Defects Requiring Elevation to the Next Higher Damage Rating(s)]
NI	Not Inspected	• Not inspected, inaccessible, or passed by[b]	
ND	No Defects	• Good original surface, sound • Connections intact and tight	No Defects Rating not appropriate if: • Noticeable abrasion or wear of rubber surfaces
MN	Minor	• Small gouges or surface defects present less than 10% of nominal depth • Connection intact, tight with light corrosion (less than 10% section loss at any location)	Minor Rating not appropriate if: • Surface cracking or degradation of rubber components
MD	Moderate	• Gouges, wear, or tears less than 25% of nominal depth • Rubber damaged at the connectors or connection plates • Connections loose, a bolt missing, or corrosion with 10 to 25% section loss at any location	Moderate Rating not appropriate if: • Permanent deformation or misalignment of rubber elements

MJ	Major	• Cracks, gouges, or tears between 25 and 50% of nominal depth • Rubber torn at the connectors or connection plates • Connections loose, two bolts missing, or corrosion with 25 to 50% section loss at any location	Major Rating not appropriate if: • Rubber element is split or torn through
SV	Severe	• Cracks, gouges, or tears greater than 50% of nominal depth • Rubber torn through at the connectors or connection plates • Connections with loose or missing bolts, or corrosion with greater than 50% section loss at any location	

[a] Any defect listed is sufficient to identify relevant damage grade.
[b] If not inspected due to inaccessibility or passed by, note as such.

Table 2-13. Damage Ratings for Fender Panels

Damage Rating		Existing Damage[a]	Exclusions [Defects Requiring Elevation to the Next Higher Damage Rating(s)]
NI	Not Inspected	• Not inspected, inaccessible, or passed by[b]	
ND	No Defects	• Good original surfaces • All connections intact • Backing panel sound • Support chains intact and in good condition	No Defects Rating not appropriate if • Coatings damaged • Visible surface corrosion
MN	Minor	• Small cracks or gouges (less than 10% of nominal) • 90% of panel connections intact • Backing frame with surface corrosion with no significant loss of section • Support chains intact with light surface corrosion	Minor Rating not appropriate if • Panels worn or damaged
MD	Moderate	• Cracks or gouges (less than 25% of nominal) • 75% of panel connections intact • Panels displaced from the backing panel • Backing frame corroded • Support chains intact, with less than 25% section loss	Moderate Rating not appropriate if • Panels displaced or misaligned • Any loose or missing hardware

MJ	Major	• Cracks or gouges (less than 50% of nominal) • 50% of the panel connections intact or multiple panels displaced from the backing panel • Backing frame corroded with loose scale, but panel substantially in place • Support chains heavily corroded with more than 25% section loss	Major Rating not appropriate if • Panel/frame system sagging, misaligned, or with limited bearing
SV	Severe	• Cracks or gouges (greater than 50% of nominal) • Less than 50% of the panel connections intact or multiple panels displaced from the backing panel • Backing frame heavily corroded with loose scale • Sagging/displacement of panel/frame system • Support chains heavily corroded with loose scale and/or missing or broken	

[a] Any defect listed is sufficient to identify relevant damage grade.
[b] If not inspected due to inaccessibility or passed by, note as such.

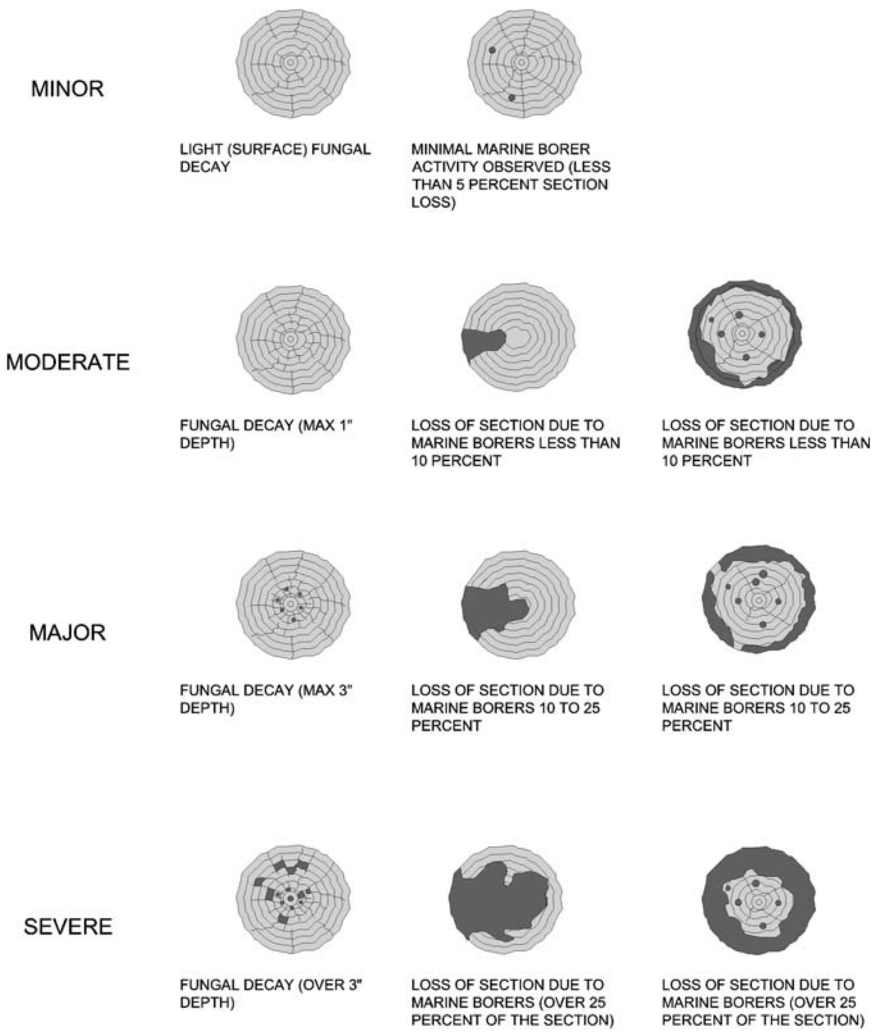

Fig. 2-9. Damage ratings for timber fender pile elements
Source: Courtesy of Moffatt & Nichol, Inc., reproduced with permission.

repair. For below-deck utilities, a reflected soffit plan is useful with the utilities depicted as solid lines. For utilities located in a utility trench, an above-deck plan with utility lines shown as dashed lines is useful to indicate that the lines are enclosed in a trench. The utility plans should also indicate the location and damage rating of valves, risers, clean outs, utility support brackets, pipe reducers, and expansion joints.

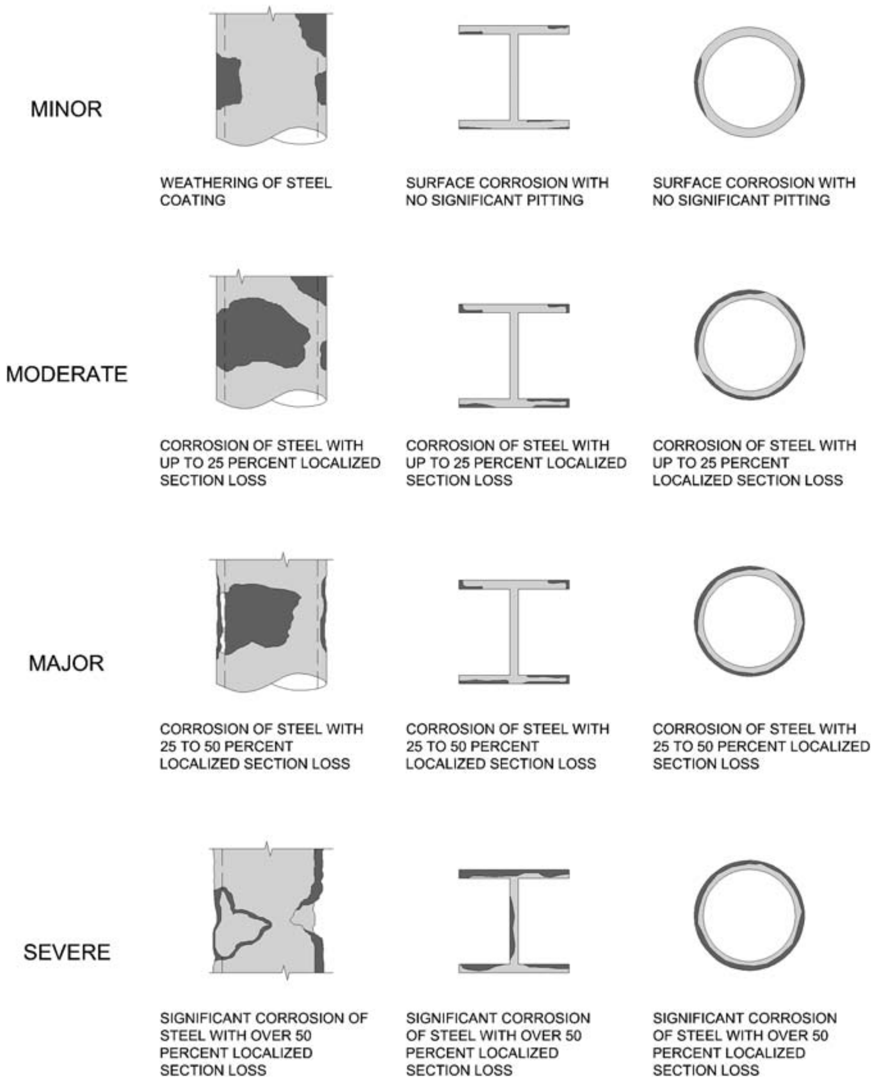

Fig. 2-10. Damage ratings for steel fender pile elements
Source: Courtesy of Moffatt & Nichol, Inc., reproduced with permission.

2.6 OVERALL SYSTEM RATINGS

2.6.1 General

Ratings are assigned to the inspected portions of each structure upon completion of Routine Inspections and Post-Event Inspections, as shown in

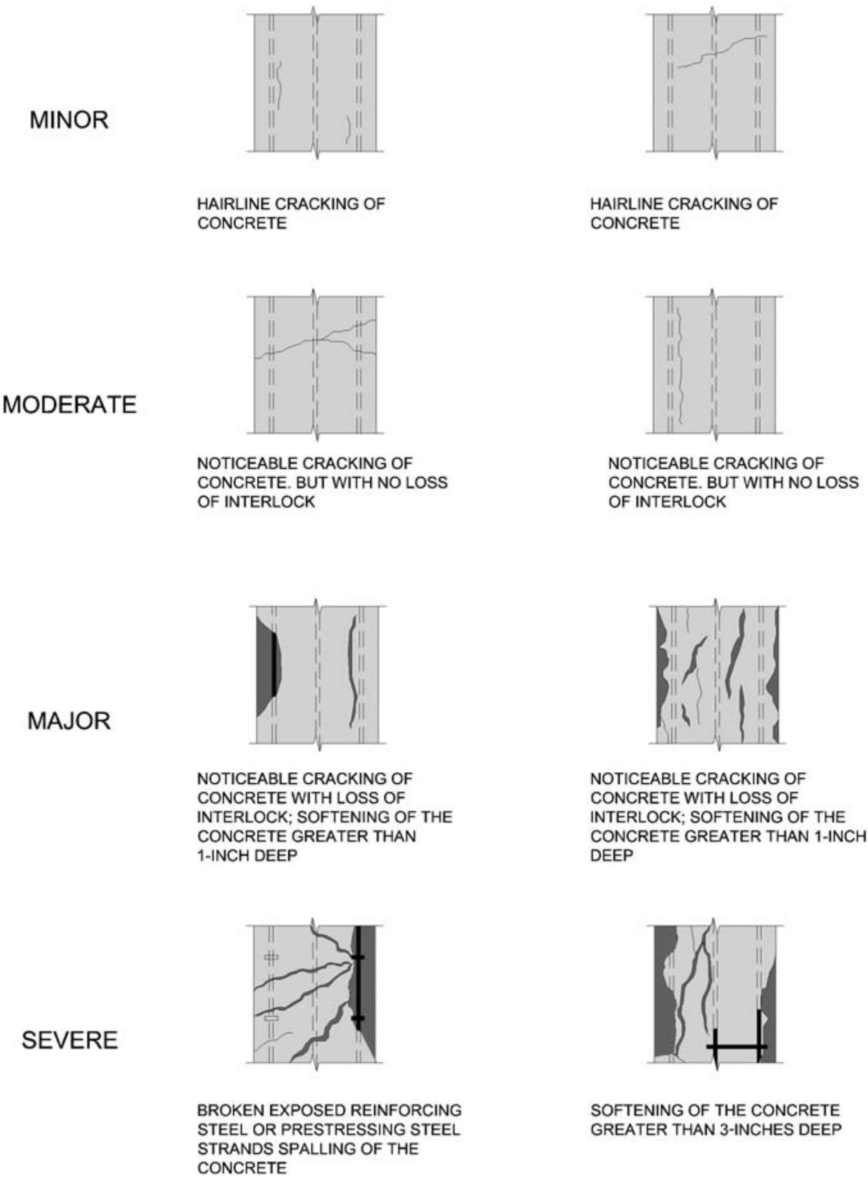

Fig. 2-11. Damage ratings for concrete fender pile elements
Source: Courtesy of Moffatt & Nichol, Inc., reproduced with permission.

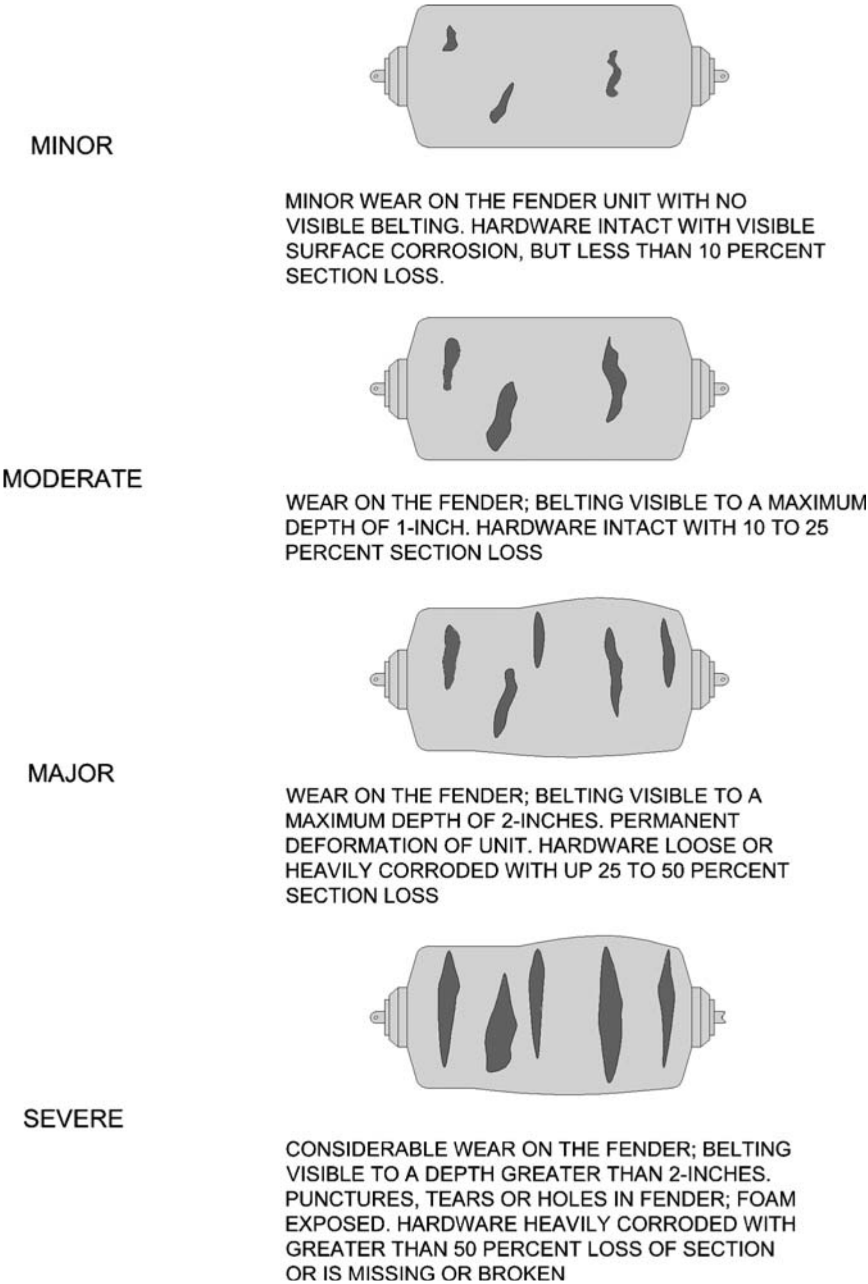

Fig. 2-12. Damage ratings for pneumatic, foam-filled, and hydropneumatic fender elements
Source: Courtesy of Moffatt & Nichol, Inc., reproduced with permission.

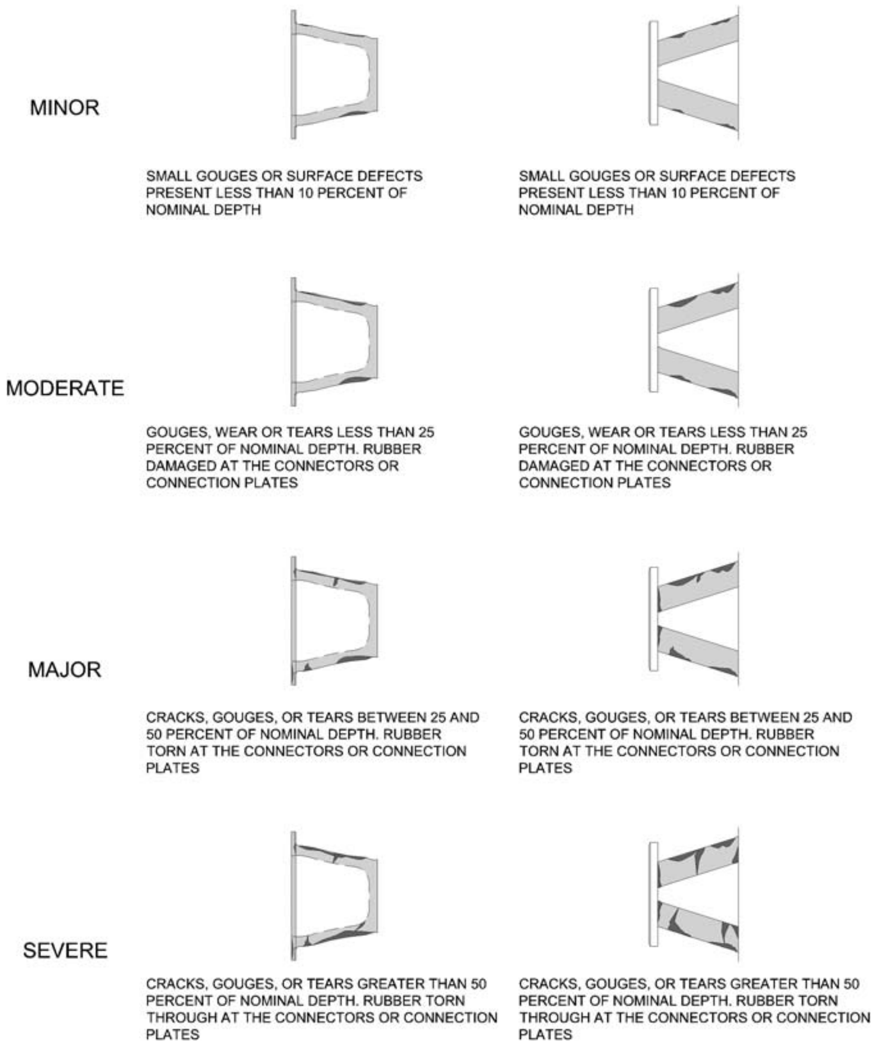

Fig. 2-13. Damage ratings for rubber fender elements
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Table 2-14. The ratings are important in establishing the priority of follow-up actions to be taken. This is particularly true when many structures are included in an inspection program, and follow-up activities must be ranked or prioritized due to limited resources.

The rating system used for Post-Event Inspections differs from that used for Routine Inspections because Post-Event Inspection ratings must focus on

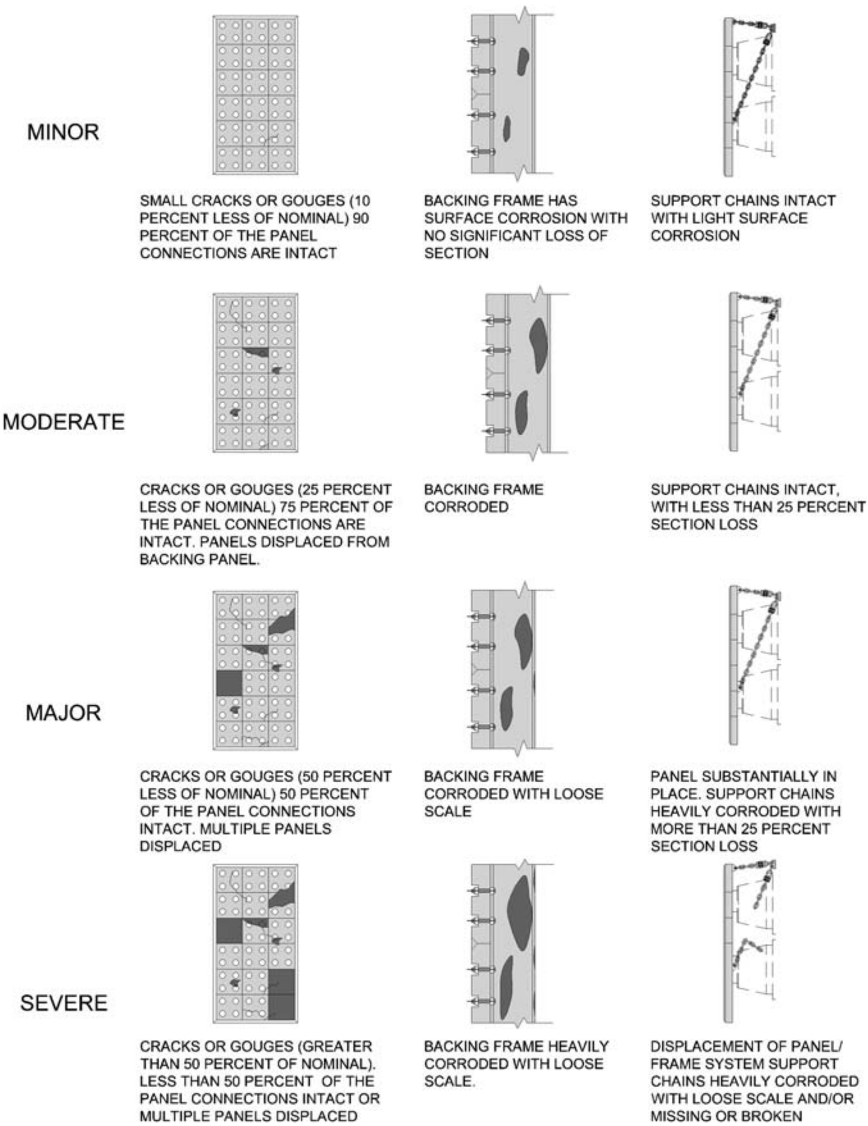

Fig. 2-14. Damage ratings for fender panel elements
Source: Courtesy of Moffatt & Nichol, Inc., reproduced with permission.

event-induced damage only, excluding long-term defects such as corrosion deterioration. An alphabetical scale is used for Post-Event Inspections to distinguish from the numerical condition assessment scale used for Routine Inspections, as shown in Table 2-15.

Table 2-14. Condition Assessment Ratings

Rating		Description
6	Good	No visible damage or only minor damage noted. Structural elements may show very minor deterioration, but no overstressing observed. No repairs are required.
5	Satisfactory	Limited minor to moderate defects or deterioration observed but no overstressing observed. No repairs are required.
4	Fair	All primary structural elements are sound but minor to moderate defects or deterioration observed. Localized areas of moderate to advanced deterioration may be present but do not significantly reduce the load-bearing capacity of the structure. Repairs are recommended, but the priority of the recommended repairs is low.
3	Poor	Advanced deterioration or overstressing observed on widespread portions of the structure but does not significantly reduce the load-bearing capacity of the structure. Repairs may need to be carried out with moderate urgency.
2	Serious	Advanced deterioration, overstressing, or breakage may have significantly affected the load-bearing capacity of primary structural components. Local failures are possible, and loading restrictions may be necessary. Repairs may need to be carried out on a high-priority basis with urgency.
1	Critical	Very advanced deterioration, overstressing, or breakage has resulted in localized failure(s) of primary structural components. More widespread failures are possible or likely to occur, and load restrictions should be implemented as necessary. Repairs may need to be carried out on a very high-priority basis with strong urgency.

2.6.2 Condition Assessment Ratings

The Condition Assessment Rating should be assigned upon completion of the Routine Inspection and remain associated with the structural unit (as defined in Section 3.1.1) until the structure is rerated following a quantitative engineering evaluation and repairs, or upon completion of the next

Table 2-15. Post-event Damage Ratings

Rating	Description
A	No significant event-induced damage observed; no further action is required
B	Minor to moderate event-induced damage observed, but all primary structural elements are sound. Repairs may be required, but the priority of repairs is low
C	Moderate to major event-induced damage observed that may have significantly affected the load-bearing capacity of primary structural elements. Repairs are necessary on a priority basis
D	Major event-induced damage has resulted in localized or widespread failure of primary structural components. Additional failures are possible or likely to occur. Urgent remedial attention is necessary

scheduled Routine Inspection. The ratings should be assigned against distinct structural units, groups of units, and the overall facility.

A scale of 1 to 6 is used for the rating system, as shown in Table 2-14. A rating of 6 represents a structure in good condition, whereas a rating of 1 represents a structure in critical condition. Other suitable rating systems may be substituted for a particular owner's purpose as appropriate.

Understanding that ratings are used to describe the existing in-place structure relative to its condition when newly built is important. The fact that the structure was designed for loads that are lower than the current standards for design shall have no influence on the ratings.

Equally important is understanding that the correct assignment of ratings requires both experience and an understanding of the structural system. Judgment must be applied in considering

- Scope of damage (total number of defects),
- Severity of damage (type and size of defects),
- Distribution of damage (local vs. general),
- Types of components affected (their structural "sensitivity"),
- Location of defect on component (relative to point of maximum moment/shear), and
- Serviceability.

The qualifications of individuals assigning ratings are important in ensuring that the ratings are assigned consistently and uniformly in accordance with sound engineering principles and the guidelines provided herein. The team leader, with oversight from the project manager, should verify that the assigned ratings are appropriate.

2.6.3 Post-Event Damage Ratings

The post-event damage rating should be assigned upon completion of the Post-Event Inspection, preferably prior to leaving the site. The rating should be used to reflect whether additional attention is necessary and, if so, at what priority level. Table 2-15 shows the four post-event damage ratings. A rating of "A" indicates no further action is required, whereas a rating of "D" indicates major structural damage requiring urgent attention.

The following guiding principles should be followed when assigning post-event damage ratings:

- Ratings should reflect only damage that was likely caused by the event. Long-term or preexisting deterioration such as corrosion damage should be ignored unless the structural integrity of the structure is immediately threatened.
- Ratings are used to describe the existing in-place structure as compared with the structure when new. The fact that the structure was designed for loads that are lower than the current standards for design should have no influence on the ratings.
- Assignment of ratings should reflect an overall characterization of the entire structure being rated. Correct assignment of a rating should consider both the severity of the deterioration and the extent to which it is widespread throughout the structure.
- The assignment of rating codes will require judgment. Use of standard rating guidelines is intended to make assignment of these ratings uniform among inspection personnel.

2.7 RECOMMENDED ACTION GUIDELINES

Whereas condition assessment and post-event damage ratings describe the urgency with which or *when* follow-up action should be taken, the recommended actions describe *what* specific actions should be taken. Recommended actions are assigned upon completion of each inspection type described in Section 2.1, with the exception that new construction inspections and repair construction inspections are in-process activities that typically require immediate follow-up action in the event of nonconformance.

A description of each recommended action choice is provided in Table 2-16. Typical recommended action options for each inspection type are depicted in Fig. 2-15. Multiple recommended actions may be assigned upon completion of each inspection; however, guidance should be provided to indicate the order in which the recommended actions should be carried out. For example, a structure that has received a Routine Inspection may be assigned recommended actions of an Emergency Inspection (due to broken piles), Repair or Upgrade Design Inspection (due to deteriorated and broken

Table 2-16. Description of Recommended Action Options

Recommended Action	Description
Emergency Action	Recommended whenever an unsafe condition is observed. If the situation is life threatening, significant property damage may occur, or significant environmental damage may occur, and appropriate owner representatives should be contacted immediately. Emergency actions may consist of barricading or closing all or portions of the structure, placing load restrictions, or unloading portions of the structure
Engineering Evaluation	Recommended whenever significant damage or defects are encountered that require a structural investigation or evaluation to quantify the structural capacity, determine if repairs are required, or determine what method of repair is appropriate. Although the scope of the routine inspections should include the structural assessment of the damage or defects on the capacity of typical structural components relative to their new condition, the engineering evaluation should consider the actual/anticipated loads that are or will be imposed on the structure
Structural Repair or Upgrade Design Inspection	Recommended whenever repairs are required, typically as a result of a routine inspection, but may also result from a special purpose inspection or post-event inspection
Special Purpose Inspection	Typically recommended to determine the cause or significance of nontypical deterioration, usually prior to designing repairs. Special testing, analysis, monitoring, or investigation using nonstandard equipment/techniques is typically required
Repair Plans Development	Recommended when the structural repair or upgrade design inspection has been completed and any special purpose inspections recommended have been completed. Indicates that the field data has been collected, and the structure is ready to have repair documents prepared
No Action	Recommended when no further action is necessary on the structure until the next scheduled routine inspection

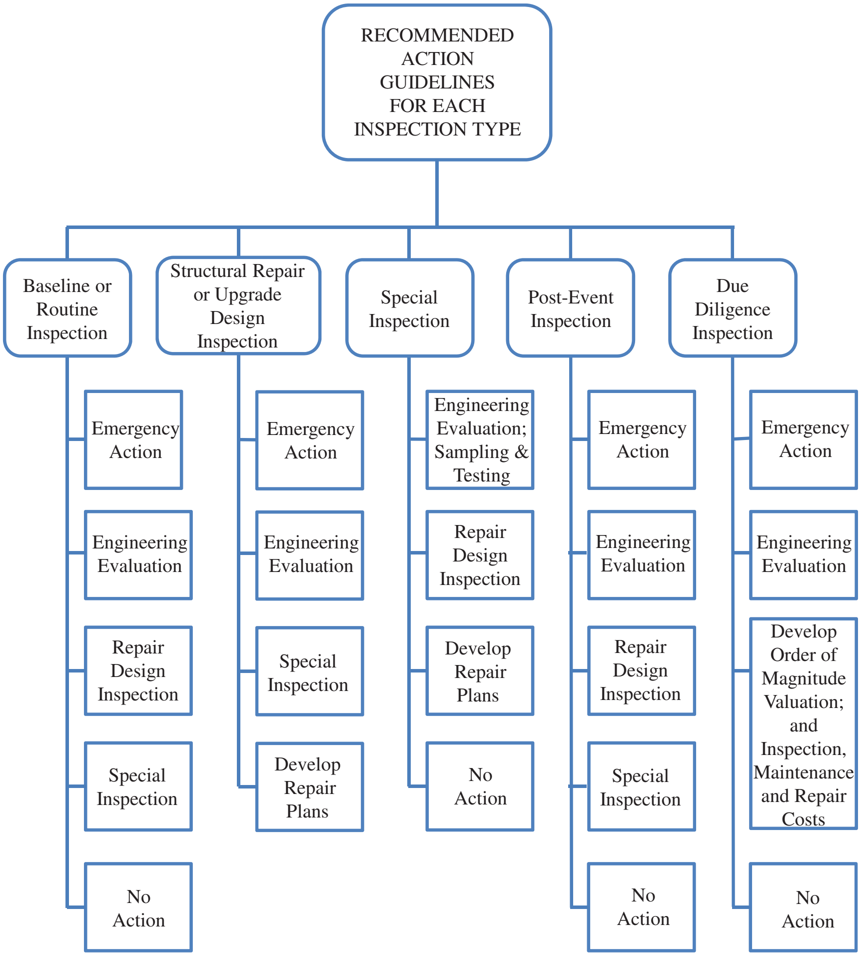

Fig. 2-15. Recommended action guidelines
Source: Courtesy of Moffatt & Nichol, Inc., reproduced with permission.

piles), and Special Purpose Inspection (because the cause of deteriorated piles is not known, and coring, testing, and analysis are required). In this example, guidance in the report should state that the emergency action should be taken first (erect barricades/close portion of the structure), then the Special Purpose Inspection should be executed to determine the cause of the deterioration, and then the Repair or Upgrade Design Inspection should follow.

CHAPTER 3
SCOPE OF INSPECTION WORK

3.1 GENERAL

The scope and methods for conducting the eight inspection types are presented in this section. These methods are general in nature and apply to all structure types and construction materials. This manual does not present detailed "how to" techniques but rather provides guidance as to methodology. The provider of inspection services is assumed to possess the required expertise to competently and professionally implement the methodologies described herein.

Appendix A addresses unique aspects of inspection scopes of work applicable to specific structure types and systems, and Appendix B presents definitions of defect types and deterioration mechanisms for each material and component type.

Confirming and documenting with the owner the specific scope and limits of the work at the outset of the work are imperative.

3.1.1 Structural Boundaries

Inspections should be conducted and ratings should be assigned against distinct structural units. For example, a timber pier projecting from a steel sheet pile bulkhead should be divided into at least two distinct structures for purposes of inspecting and assigning condition ratings. Structural units should typically be of uniform construction type and material and, in the case of pile-supported structures, should be in a continuous bent numbering sequence.

The boundaries of structures must be clearly defined at the outset of the work. Breaking other structures, such as large piers or wharves, into separate sections may be advantageous. Common boundaries include property lines, expansion joints, configuration changes, changes in age of construction, changes in direction, or changes in bent numbering sequence.

3.1.2 Limits of Inspection

Inspections should be conducted on all accessible components as agreed on with the client in the scope of work for the specific project. The upper limit may be defined as the elevation of the highest element to be inspected. The lower limit is typically defined as the channel bottom, mudline, or sea floor. Inspections may be conducted on some inaccessible components as agreed on with the client provided that a mean of access (e.g., excavation) to those components is provided. Typically, the owner will arrange for the inaccessible items to be uncovered. An example of such is the excavation and exposure of sheet pile wall tie-rods in the backlands behind the wall.

Accessible components are defined as those components that are readily accessible without the need for excavation or extensive removal of materials that may impair visual inspection. Inaccessible components that are not included in the scope of the inspection should be identified in the inspection report.

3.1.3 Definition of Inspection Levels of Effort

Given the relative cost of performing the underwater portion of the inspection as compared with the above water inspection, defining the level of underwater inspection effort in the scope of work, as defined following, is important. Due to limited visibility, the inherent access restrictions of the underwater environment, and the presence of marine growth, certain inspection types, such as routine and baseline inspections, focus on the investigation of a statistically representative sample of underwater components. As indicated in Chapter 2, three levels of underwater inspection effort are defined, with the underwater inspection requirements defined as a percentage of these three levels of effort. The levels of effort are as follows:

Level I effort: Includes a close visual examination above and underwater or a tactile examination using large sweeping motions of the hands where visibility is limited underwater. Although the Level I effort is often referred to as a "swim by" inspection, it must be detailed enough to detect obvious major damage or deterioration due to overstress or other severe deterioration. It should confirm the continuity of the full length of all members and system components and detect undermining or exposure of normally buried elements. A Level I effort may also include limited probing of the substructure and adjacent channel bottom.

Level II effort: A detailed inspection above and underwater that requires wrappings, coatings, corrosion, and/or marine growth to be removed from portions of the structure. Underwater marine growth removal is costly, hence, the need to base the inspection on a representative sampling of components. For piles, a 12-in. high band should be cleaned at designated locations, generally near the low waterline, at the mudline, and midway between the low waterline and the mudline. On a rectangular pile, the marine growth removal should include at least three sides; on an octagonal pile, at least six sides; and on a round pile, at least three-fourths of the perimeter. On large-diameter piles, 3 ft or greater, 1 ft × 1 ft areas should be cleaned at four locations approximately equally spaced around the perimeter, at each elevation. On large solid faced elements, such as retaining structures, 1 ft × 1 ft areas should be cleaned at these three elevations. The Level II effort should also focus on typical areas of weakness such as connections, attachment points, and welds. The Level II effort is intended to detect and identify damaged and deteriorated areas that may be hidden by surface bio-fouling, coating, or corrosion, or that which may not be readily accessible for a Level I inspection effort. The thoroughness of marine growth removal should be governed by what is necessary to discern the condition of the underlying material. Removal of all bio-fouling staining is generally not required. Means and methods for the removal of bio-fouling growth are not typically defined in a scope of work. However, it may be appropriate for owners to specify particular methods based on environmental and site conditions or on concern for maintaining the integrity of coating materials. Methods may include hand scrapers or mechanical systems ranging from high-pressure water blasters to barnacle busters and pressurized air bubble devices based on the principles of cavitation.

Level III effort: A detailed inspection above and underwater typically involving nondestructive or partially destructive testing conducted to detect hidden or interior damage, or to evaluate material homogeneity. Typical inspection and testing techniques include the use of ultrasonic, coring or boring, physical material sampling, and in situ hardness testing. Level III testing is generally limited to key structural areas, areas that are suspect or areas that may be representative of the structure or system.

Table 3-1 presents a summary of the information typically collected for these levels of effort.

3.2 ROUTINE INSPECTIONS

3.2.1 Objectives

The Routine Inspection is a basic function performed in support of normal maintenance of waterfront facilities. Decisions made as a result of the

Table 3-1. Summary of Inspection Levels

		Detectable Defects			
Level	Purpose	Steel	Concrete	Timber	Composite
I	General visual/tactile inspection to confirm as-built condition and detect severe damage	• Extensive corrosion, holes • Severe mechanical damage	• Major spalling and cracking • Severe reinforcement corrosion • Broken piles	• Major loss of section • Broken decking, caps, stringers, piles, and bracings • Severe abrasion or marine borer attack	• Permanent deformation • Broken piles • Major cracking or mechanical damage
II	Visual/tactile inspection to detect surface defects normally obscured by marine growth, coating, corrosion, etc.	• Moderate mechanical damage • Corrosion pitting and loss of section	• Surface cracking, spalling, and erosion • Rust staining • Exposed reinforcing steel and/or prestressing strands	• External pile damage due to marine borers • Splintered piles • Loss of bolts and fasteners • Rot or insect infestation	• Cracking • Delamination • Material degradation

III	Visual/tactile inspection to detect hidden or interior damage, evaluate loss of cross-sectional area, or evaluate material homogeneity	• Thickness of material • Electrical potentials for cathodic protection • Thickness of coatings	• N/A	• Internal damage, voids, marine borer activity • Decrease in material strength	• N/A

information gathered during routine inspections dictate the course and priority of future maintenance activities for a structure. Objectives of the Routine Inspection include

- Assessment of the overall condition of underwater and intertidal portions of the structure,
- Assessment of the overall condition of the above water portions of the structure,
- Determination of Condition Assessment Ratings for all elements of the structure,
- Development of recommendation(s) for follow-up action, and
- Determination of the recommended interval for subsequent inspection.

3.2.2 Methods of Inspection and Documentation

3.2.2.1 General Considerations A Routine Inspection should be limited to the collection of sufficient information to address each key objective. In most cases, documenting the exact location and size of each observed defect is not necessary. Rather, rating components on a relative scale of no damage, minor damage, moderate damage, advanced damage, or severe damage is standard practice. These damage grades must be specifically defined, wherever they are used, in terms of cross-sectional loss, crack widths, causation, location of damage, etc.

When observed damage could have a significant effect on the load-bearing capacity of a structural component, sufficient data should be collected in the field to allow the damage to be quantified by structural analysis.

In some cases, the objectives of the Routine Inspection may be expanded to include such issues as estimating the remaining useful life of the structure or developing order-of-magnitude estimates of probable costs for rehabilitation work. In such cases, expanding the scope of the inspection and documentation to include sufficient information to address these issues may be necessary. Conducting a Special Inspection along with the Routine Inspection may also be necessary to address such issues. The scope of work described in the remainder of this section does not include these additional issues.

3.2.2.2 Routine Above Water Inspections Routine inspection of above water structural elements should include a general overview inspection of all exposed portions of the structure, plus sufficient close-up scrutiny of specific structural elements so as to establish a condition rating of individual structural component types to assemble a rating for the structure as a whole.

Above water inspections may involve considerations related to issues of access and safety. Below-deck (above water) access for piers may be limited such that scaffolding, use of an inspection device ("bridge snooper" or man lift), or other similar means may be necessary. When using apparatus that results in significant loading, the load-carrying capacity of the supporting structure should be evaluated. Appropriate measures should be taken to ensure that applicable safety regulations are followed regarding use of such equipment.

The use of destructive testing (DT) or nondestructive testing (NDT) techniques may be appropriate, depending on the structural material. For instance, ultrasonic thickness measurements of a certain percentage of steel structural members, or material sampling and testing of various aspects of concrete or timber structures, can yield valuable information. When such testing techniques require the removal of surficial material or protective covering, then an appropriate repair material should be applied to maintain protection. Specific recommendations for DT/NDT related to above water inspections are provided in subsequent sections of this manual.

3.2.2.3 Routine Underwater Inspections A Routine Inspection of underwater elements should include the sampling and methods of inspection summarized in Table 3-2. At a minimum, routine underwater inspections should include a Level I inspection effort for all components within the defined scope. In addition, a Level II inspection effort should be conducted on at least 10% of the submerged structural components. A Level III inspection effort should also be conducted, depending on the material being inspected. The Level III effort typically involves either partially destructive or nondestructive investigation of approximately 5% of the underwater components. The type of testing will depend on the material and the specific damage or deterioration mechanism to be quantified.

Descriptions should include information on bio-fouling (marine growth) and the approximate zone or elevation where the damage is present, such that the significance of the deterioration may be evaluated.

3.2.3 Methods of Inspection for Steel Components

3.2.3.1 Routine Above Water Inspection Topside inspection efforts of steel structures should be conducted using visual/tactile means. Additional testing techniques, such as thickness and profile measurements, should be employed to supplement the visual findings.

Above water/below-deck inspection efforts of steel structures should also be conducted using visual means. Additional testing techniques, such as thickness and profile measurements, should be employed to supplement the visual findings. The above water inspection is typically done from a boat, snooper, man lift, ladder, or accessway.

Table 3-2. Levels of Inspection Effort

	Level I		Level II		Level III	
	Sample Size[a]	Method	Sample Size[a]	Method	Sample Size[a]	Method
Topside and Above Water Steel[b,c]						
Piles (≤24 in. dia.)	100%	Visual/ Tactile	As necessary	Visual: Removal of corrosion to observe parent metal and pitting size	As necessary	Remaining thickness measurement
Large or Solid-Faced Elements/Piles (>24 in. dia.)[d]	100%	Visual/ Tactile	As necessary	Visual: Removal of corrosion to observe parent metal and pitting size	As necessary	Remaining thickness measurement
Concrete[3]						
Piles (≤24 in. dia.)	100%	Visual/ Tactile	As necessary	Visual/Auditory: Sounding	As necessary	Electrical potential measurements, corrosion mapping, coring
Large or Solid-faced Elements/ Piles (>24 in. dia.)[d]	100%	Visual/ Tactile	As necessary	Visual/Auditory: Sounding	As necessary	Electrical potential measurements, corrosion mapping, coring

Timber[c]						
Piles	100%	Visual/ Tactile	As necessary	Visual/Auditory: Sounding and Probing	As necessary	Drilling, coring
Large or Solid-faced Elements[d]	100%	Visual/ Tactile	As necessary	Visual/Auditory: Sounding and Probing	As necessary	Drilling, coring
Masonry						
Pilasters (≤24 in. per side)	100%	Visual/ Tactile	As necessary	Visual/ Probing: Sampling of joint material	As necessary	Coring
Large or Solid-faced Elements (>24 in. per side)[d]	100%	Visual/ Tactile	As necessary	Visual/ Probing: Sampling of joint material	As necessary	Coring
Underwater Steel[b,c]						
Piles (≤24 in. dia.)	100%	Visual/ Tactile	10%	Visual: Removal of marine growth in three elevation bands	5%	Remaining thickness measurement, electrical potential measurements, corrosion profiling as necessary

(Continued)

Table 3-2. Levels of Inspection Effort *(Continued)*

	Level I		Level II		Level III	
	Sample Size[a]	Method	Sample Size[a]	Method	Sample Size[a]	Method
Large or Solid-faced Elements/Piles (>24 in. dia.)[d]	100%	Visual/ Tactile	Every 100 lin ft (LF)/ Quarter Points	Visual: Removal of marine growth in 1 sq ft area at three elevations	Every 200 LF/5%	Remaining thickness measurement, electrical potential measurements, corrosion profiling as necessary
Concrete[c]						
Piles (≤24 in. dia.)	100%	Visual/ Tactile	10%	Visual: Removal of marine growth in three elevation bands	0%	N/A
Large or Solid-faced Elements/Piles (>24 in. dia.)[d]	100%	Visual/ Tactile	Every 100 lin ft/ Quarter Points	Visual: Removal of marine growth in 1 sq ft areas at three elevations	0%	N/A

Timber[b]						
Piles	100%	Visual/ Tactile	10%	Visual: Removal of marine growth on three bands Measurement: Remaining diameter	5%	Internal marine borer infestation evaluation
Large or Solid-faced Elements[d]	100%	Visual/ Tactile	Every 50 lin ft	Visual: Removal of marine growth in 1 sq ft area at three elevations	Every 100 LF	Internal marine borer infestation evaluation
Masonry						
Pilasters (≤24 in. per side)	100%	Visual/ Tactile	10%	Visual: Removal of marine growth in three elevation bands	0%	N/A
Large or Solid-faced Elements (>24 in. per side)[d]	100%	Visual/ Tactile	Every 100 lin ft/ Quarter Points	Visual: Removal of marine growth in 1 sq ft area at three elevations	0%	N/A

[a]The minimum inspection sample size for small structures shall include at least two components of each underwater component type.
[b]Coated elements: Inspect the element with the coating intact.
[c]Jacketed or encased elements: Visually inspect the jackets and encasements for deterioration. Inspect the base element to the extent possible.
[d]Large, solid-faced elements may include bulkheads, retaining walls, dam fascia, tunnel/pipeline walls, piers, gates, tank walls, caissons, piles greater than 24 in. in diameter, etc.

3.2.3.2 Routine Underwater Inspection Level I inspection efforts for steel structures are conducted using visual/tactile means. It is recommended that the Level I inspection include 100% of the structure, and particular attention should be applied to areas of known elevated deterioration. This is particularly true on steel structures in the splash zone and slightly below low water, as these zones are fairly prominent on all marine structures. Corrosion rates vary significantly based on environmental factors and site-specific characteristics, and, therefore, local knowledge should be applied.

Level II efforts are also visual upon removal of corrosion, coatings, marine growth, or other materials that prevent Level I inspection effort in areas to be inspected. Level II efforts are generally performed on 10% of the structure or system. The splash zone should be closely evaluated to identify magnitude and extent of corrosion losses.

Level III efforts for steel structures require that the remaining thickness of the element be measured in locations that are representative of the structure. Such measurements may be taken by micrometer or pipe pit gauge, where feasible, or by ultrasonic thickness measuring device. At a minimum Level III inspections should be conducted on 5% of the elements. Specific structures may warrant additional Level III efforts such as inspecting welds using magnetic particle testing, coupon samples, and voltage potential measurements.

If the inspected components exhibit significant corrosion that could affect the load-carrying capacity of the structure, then corrosion profiling should be performed to establish the extent of corrosion as it varies along the height of the structure. Multiple profiles may be necessary to establish the uniformity or variability of the damage throughout the structure. The results of the corrosion profiling should be used to evaluate the structural significance of the corrosion. It is particularly important while inspecting fill-containing structures, such as sheet pile cells or bulkheads, to inspect closely for corrosion holes, as small holes may result in large voids behind the structure, potentially resulting in sinkholes and failures.

For steel members that are cathodically protected, an electrical potential survey should be conducted. Potential measurements should be taken at points throughout the structure to determine the effectiveness of the cathodic protection system. Generally, an Ag-AgCl half-cell is used in the marine environment and readings between −0.733 and −1.200 mV indicate adequate protection.

For coated steel members, the Level I and II efforts should focus on the evaluation of the integrity and effectiveness of the coating. For submerged elements, care should be taken to avoid damage to the coating during removal of marine growth for the Level II effort. Level III efforts for coated steel members should include ultrasonic thickness measurements without removal of the coating, where feasible. Collecting coating samples for evaluation of hazardous materials, such as lead, may be prudent if a repair may entail removal of the coating system.

For steel members that have been wrapped, the Level I and II efforts should focus on the evaluation of the integrity of the wrap. For submerged elements, care should be taken to avoid damage to the wrap during the removal of marine growth for the Level II effort. Because the effectiveness of a wrap may be compromised by removal and because the removal and reinstallation of wraps is time consuming, such removals should not be done routinely. However, if evidence of significant corrosion exists, or if the effectiveness of the wrap may be in question, then a sample of the wraps should be removed to facilitate inspection and evaluation. The sample may be limited to particular zones or portions of the member if damage is suspected, for example, at the waterline. The sample size should be determined based on the physical evidence of potential problems and the aggressiveness of the service environment. A minimum sample size of three members should be used. A 5% sample size, up to 30 total members, may be adequate as an upper limit on large structures.

For steel members that have been encased, the Level I and II efforts should focus on the evaluation of the integrity of the encasement. Encasements should not typically be removed for a Routine Inspection. However, if evidence of significant deterioration of the encasement is present, or if evidence of significant deterioration is present on the underlying member despite the encasement, then the damage evaluation should consider whether the encasement was provided for protection, structural capacity, or both. For encasements where the formwork has been left in place, the inspection should focus on the integrity of the encasement, not the formwork. Level I and II efforts in such cases should concentrate on the top and bottom of the encasement.

Encasements only installed to low water can elevate the rate of corrosion below the encasement, especially if a cathodic protection system is not active. Therefore, this should be an area of particular focus.

3.2.4 Methods of Inspection for Concrete Components

3.2.4.1 Routine Above Water Inspection Topside inspection efforts of concrete structures should be conducted using visual means, supplemented by audio methods, such as dragging a chain over the deck to find hollow-sounding areas, which indicate delamination and potential spalls. Additional testing techniques, such as corrosion mapping, chloride profiling, etc., may be necessary to supplement the visual findings; however, this type of testing is not typically included in a Routine Inspection.

Above water/below-deck inspection efforts of concrete structures should also be conducted using visual means, supplemented by audio methods. Here, a hammer or other metal probe is used to find loose concrete.

Additional testing techniques, such as corrosion mapping, chloride profiling, etc., may be necessary to supplement the visual findings. The above water/below-deck inspection is typically done from a boat, snooper, man lift, ladder, or accessway.

3.2.4.2 Routine Underwater Inspection For underwater inspections, the effort typically comprises Level I and Level II inspections. Level I inspections for concrete structures are conducted using visual/tactile means. Level II efforts are also visual, upon removal of marine growth in areas to be inspected. Level III efforts are not typically required on concrete elements.

For encased concrete members, the topside inspection, above water inspection, and Level I and Level II efforts should focus on evaluating the integrity of the encasement. Encasements should not typically be removed for a Routine Inspection. If evidence of significant deterioration of the encasement is present, or if evidence of significant deterioration is present on the underlying member despite the encasement, then the evaluation of damage should consider whether the encasement was provided for protection, structural capacity, or both. For encasements where the formwork has been left in place, the inspection should focus on the integrity of the encasement, not the formwork. In such cases, Level I and II efforts should concentrate on the top and bottom of the encasement. If deterioration, debondment, or other significant problems with the encasement are suspected, conducting a Special Inspection may be necessary. The Special Inspection in such circumstances may include coring of the encasement and laboratory evaluation of the materials.

For wrapped concrete members, the topside inspection, above water inspection, and Level I and II efforts should focus on evaluating the integrity of the wrap. Care should be taken to avoid damage to the wrap during the removal of marine growth for the Level II effort. Because the effectiveness of a wrap may be compromised by removal and because the removal and reinstallation of wraps is time consuming, such removals should not be done routinely. However, if evidence of significant damage exists, or if the effectiveness of the wrap may be in question, then a sample of the wrap should be removed to facilitate the inspection and evaluation. The sample may be limited to particular zones or portions of the member if damage is suspected, for example, at the waterline. The sample size should be determined based on the physical evidence of potential problems. A minimum sample size of three members should be used. A 5% sample size is typically adequate.

3.2.5 Methods of Inspection for Timber Components

3.2.5.1 Routine Above Water Inspection Routine inspection of above water timber components primarily consists of visual assessment to verify that the elements are intact and functioning as intended. Specific focus should include noting evidence of section loss, rot, preservative treatment retention, insect damage, abrasion, wear, or overstressing. Visual assessments should be supplemented with ice pick or awl penetration examination to check softness. Inspection efforts conducted on timber elements to detect internal deterioration should be implemented if timber elements have suspected deficiencies not apparent during visual inspections. Boring or coring to quantify internal deterioration is typical. Laboratory analyses of core samples are often conducted to determine the presence of marine borers and the density, specific gravity, and moisture content of the wood. Core samples extracted from creosote pressure-treated timber elements can be subject to composite creosote penetration and retention analysis. Bore holes and core holes should be filled with oversize treated hardwood dowels, epoxy, or nonshrink grout. The above water/under-deck inspection is typically done from a boat, snooper, man lift, ladder, or accessway.

3.2.5.2 Routine Underwater Inspection Level I inspection efforts for timber structures are conducted using visual/tactile means. An ice pick or awl should be used to probe for softness, except for wrapped members. Level II efforts are also visual, upon removal of marine growth or other materials that would preclude visual inspection in areas to be inspected. Level III efforts conducted on timber elements have historically been conducted using several different methods. The intrinsic nature of the material causes the rate of deterioration after initiation to progress rapidly compared with other materials utilized in marine construction. Therefore, employing boring or coring is typical to quantify internal deterioration. Bore holes and core holes should be filled with oversize treated hardwood dowels, epoxy, or nonshrink grout.

For timber members that have been repaired by encasement, the Level I and II efforts should focus on evaluating the integrity of the encasement. Such encasements should not be removed for a Routine Inspection. However, if evidence of significant deterioration of the encasement is present, or if evidence of significant deterioration is present on the underlying member despite the encasement, then the evaluation of damage should consider whether the encasement was provided for protection, structural capacity, or both. For encasements on which the formwork has been left in place, the inspection should focus on the integrity of the encasement, not the formwork. Level I and II efforts in such cases should concentrate on the top and bottom of the encasement.

For wrapped timber members, the Level I and II efforts should focus on evaluating the integrity of the wrap. Care should be taken to avoid damage to the wrap during the removal of marine growth for the Level II effort. Level III efforts should consist of removal of the wraps from a representative sample of components to evaluate the condition of the wood beneath the wrap. The sample may be limited to particular zones or portions of the member if damage is suspected, for example, at the mudline/bottom of the wrap or in the tidal zone. The sample size should be determined based on the physical evidence of potential problems and the aggressiveness of the service environment. A minimum sample size of three members should be used. A 5% sample size, up to 30 total members, may be adequate as an upper limit. Upon removal of the wrap, the wood should be evaluated using visual/tactile means and boring or coring as described for nonwrapped timber elements. Wraps that are removed to facilitate such inspections should be restored or replaced in accordance with the wrap manufacturer's installation requirements. Cutting the wrap over half the perimeter of the member and then repairing it upon completion of the inspection may be advantageous.

3.2.6 Methods of Inspection for Masonry Components

3.2.6.1 Routine Above Water Inspection Masonry structures, including grouted cyclopean walls, typically used for quay walls or abutments, rely on their overall geometry and gravity for stability and resistance to environmental and operational loads. Therefore, it is important while conducting the inspection to lay out a baseline to evaluate such factors as location of sinkholes or depressions, alignment and batter changes, or displacement of discrete sections of the wall. Void networks located within/behind the masonry retaining structure may be evidence of sinkholes below paved surfaces and may warrant more detailed inspections, such as ground-penetrating radar or excavation of test pits.

While conducting inspections, the following characteristics of the masonry structure should be noted:

- Type of stone and joint construction;
- Size and orientation of stones;
- Condition of stones and joint material;
- Size of voids, noting large voids by hand probing;
- Scour or erosion of the toe;
- Alignment and batter;
- Surface drainage or tidal water flow through the wall; and
- Attachments and embedded items.

The primary modes of deterioration of masonry structures are loss of joint material, settlement of the toe, and sinkholes behind the structure. Sinkholes may not be outwardly apparent; therefore, collecting overall observations and probing for void networks to develop conclusions are important.

3.2.6.2 Routine Underwater Inspection Level I inspection efforts for masonry components are conducted using visual/tactile techniques with particular focus on overall alignment and attitude and position of individual blocks. Any missing masonry should be noted.

Level II efforts are also visual, after removal of marine growth or other material that would prevent visual inspection in areas to be inspected. Generally, marine growth removal underwater is based on the size of the structure, but, at a minimum, marine growth should be removed at three elevations: mudline, mid water, and low water every 100 linear ft. This level of inspection should be more detailed and include inspection of the joints and void networks that may be present.

Level III efforts are not typically required on masonry elements.

3.2.7 Methods of Inspection for Composite Components

3.2.7.1 Routine Above Water Inspection A Routine Inspection of above water composite components primarily consists of visual assessment to verify that the elements are intact and functioning as intended. Specific focus should include noting evidence of ultraviolet (UV) degradation (often characterized by discoloration), creep, or excessive deflection or overstressing, particularly at hardware connections.

3.2.7.2 Routine Underwater Inspection Level I inspection efforts for composite components are conducted using visual/tactile means. Level II efforts are also visual, upon removal of marine growth in areas to be inspected. Level III efforts are not typically required on composite elements.

3.2.8 Methods of Inspection for Slope Protection

3.2.8.1 Routine Above Water Inspections A Routine Inspection of exposed above water portions of slope protection, revetments, and other similar structures primarily consists of rapid visual assessment to verify that the components are stable and remain somewhat unchanged when compared with the original cross section. This is best accomplished at low tide to take advantage of the ability to see as much exposed surface as possible.

Structures consisting primarily of various sizes of rock, such as graded revetments or rubble mound structures, are typically designed to tolerate a certain amount of in-place settlement and may have shifted accordingly. Weather-related phenomenon, such as waves, ice, river runoff, and earthquakes, also may have resulted in significant deformation of these structures.

These structures may also have hardened areas at or near the top of the structure, often as a means of retaining stone, or for use as “rat guard” (concrete used to solidify the section to prevent the migration of rodents though the rock). If the overall slope of the section has undergone settlement, then a significant distortion of the cross section may have occurred at the intersection between hardened and unhardened areas.

As with underwater inspections (see next section), remote sensing techniques can also be used in above water inspections. Using static laser scanning, or the more recently developed mobile laser scanning, very detailed survey data of the features in question can be attained. Supplementing laser scanning with coincident photography for data interpretation is very useful. Multibeam and side scan sonar techniques provide a parallel for below-water inspections. Harmonizing captured data on both sides of the waterline can be highly valuable for assessing structures spanning the waterline. Remote sensing techniques such as these are only as accurate as their horizontal and vertical controls, thus a detailed and accurate baseline survey is needed with tie-ins to known benchmarks.

Besides visual means, an inclinometer (a device that is used to measure slope), if installed, may be used to verify the stability of the slope relative to original placement. Traditional survey methodology can also be implemented to verify profiles.

An above water Routine Inspection should note overall stability and performance of the structure and any significant defects or discontinuities found as a result of exposure to weather-related phenomena or settlement.

3.2.8.2 Routine Underwater Inspection Level I inspection efforts on slope protection, such as armor stone, riprap, gabions, concrete liners, scour protection mattresses, etc., are conducted using visual/tactile means. Level II efforts are not typically required unless removal of marine growth from representative areas is necessary to judge the condition of the slope protection, as may be the case for concrete liners or unless removal of silt is necessary to expose the structure.

For slope protection under pile-supported structures, such as wharves, the Level I and Level III inspection can be completed in conjunction with the pile inspection. In this case, the elevation to top of rock or soil can be measured directly at each pile to give transections at each bent.

In some cases, performing Level I efforts may not be feasible or practical due to waves, currents, or restricted visibility. This is particularly true for the offshore face of breakwaters, which can pose higher risk. In such cases, performing the inspection using Level III remote-sensing techniques may be more cost effective or technically advantageous. Common remote-sensing techniques for features below the water line are typically acoustic (sonar) and generally include side-scan sonar and multibeam sonar systems. Laser scanning and photogrammetry provide a parallel for above water inspections. Harmonizing captured data on both sides of the waterline can be highly valuable for assessing structures spanning the waterline.

Recent developments in these technologies have dramatically increased accuracy and resolution (detail) and allowed integration of these sensors to provide more comprehensive information. The results of such surveys may indicate areas of potential problems such as discontinuities, protrusions, or other inconsistencies. These issues may be further investigated using engineer-divers. Remote-sensing techniques such as these are only as accurate as their horizontal and vertical control; therefore, proper control is vital. Differential global navigation satellite system (DGNSS), differential global positioning systems (DGPS), inertial measuring units (IMU), and/or digital compasses are frequently used to interface with these sonar systems. In locations where obstructions prevent acquiring sufficient satellite signals, range-azimuth systems may be employed also. Differentially referencing to the appropriate geodetic or local coordinate control and reference to the correct datum is critical (e.g., North American Datum of 1983 [NAD83], North American Vertical Datum of 1988 [NAVD88], tide gauges, Mean Lower Low Water [MLLW], etc.).

3.2.9 Methods of Inspection for Channel Bottom or Mudline

Level I inspection efforts on the channel bottom or mudline around structural elements are conducted using visual/tactile means to evaluate scour or changes in the bottom conditions. Level II efforts are not typically required.

In some cases, performing Level I efforts may not be feasible or practical due to waves, currents, or restricted visibility. This is particularly true for the offshore face of breakwaters, which can pose high risk. In such cases, performing the inspection using Level III remote-sensing techniques may be more cost effective or technically advantageous. Common remote-sensing techniques for features below the waterline are typically acoustic (sonar) and generally include side-scan sonar and multibeam sonar systems. Laser scanning and photogrammetry provide a parallel for above water inspections. Harmonizing captured data on both sides of the waterline can be highly valuable for assessing structures spanning the waterline.

Recent developments in these technologies have dramatically increased accuracy and resolution (detail) and allowed integration of these sensors to provide more comprehensive information. The results of such surveys may indicate areas of potential problems such as discontinuities, protrusions, or other inconsistencies. These issues may be further investigated using engineer-divers. Remote-sensing techniques such as these are only as accurate as their horizontal and vertical control; therefore, proper control is vital. DGPS or range-azimuth systems may be used to interface with the sonar system, tidal depth gauge, etc., to locate the anomaly for investigation.

3.2.10 Methods of Inspection for Mooring Hardware and Fender Systems

3.2.10.1 Mooring Hardware Level I inspections involve a walk-through inspection of the mooring hardware. Major defects and obvious damage should be noted. Level I inspections are typically done annually, after major storm events, or after a mooring incident such as hardware breakage or lines parting.

Level II inspections involve a visual inspection of the mooring hardware components. The mooring hardware should be assessed for significant signs of wear or stress from the mooring lines. Exposed fasteners should be observed for signs of corrosion or if displacement has occurred. The mooring fitting base should also be inspected for signs of cracking or other stress-related defects. In addition, the plumb and level of the mooring hardware should be measured to determine if any movement has taken place. Level II inspections are typically done every 3 to 5 years or if results from a Level I inspection warrant.

Level III inspections involve a detailed inspection of the mooring hardware. For mooring hardware that is secured through the deck, the underside of the deck and any visible fasteners should also be inspected. In addition, load testing may also be conducted by qualified personnel using specialty equipment. Load testing can be broken into three levels and is typically done when significant defects are found in a Level II inspection or if a suspicion exists that the mooring hardware has been overloaded during an extreme event. The following tests can be completed depending on the requirements and available equipment and expertise of the testing personnel:

- Bolt pull test: The bolt pull test involves the removal of the grout and nuts. A test rig is screwed onto the mooring hardware bolt and pulled to 110% of its working load. If any bolt becomes displaced during this process, it must be replaced before being put back into service.
- Indirect line load: The indirect line load test involves pulling the mooring fitting to the actual line forces, but not in the direction that it would normally be pulled in. This allows for mooring hardware along the face of a pier to be tested by a device behind it on the pier or by pulling from one bollard to another.
- Direct line load: The direct line load involves pulling the mooring fitting to the actual line force and in the actual direction the force would be applied to monitor the reaction of the mooring hardware in common conditions.

3.2.10.2 Fender Systems Fender systems are made out of many different material types, and, depending on the type of material, the relevant subsection appears elsewhere in this section.

3.2.11 Methods of Inspection for Anchors and Chains

3.2.11.1 Routine Above Water Inspections Routine inspection of the exposed portions of the anchor and chain system primarily consists of assessing the chain and hardware connection that is connected to a structure.

The chain should be inspected for wear, distortion, corrosion, and alignment with the attachment point. This is best accomplished at a low water elevation to take advantage of the ability to see as much of the chain as possible. The connection hardware should be inspected for wear, distortion, corrosion, and a secure connection to the structure.

Some anchor system designs may involve dissimilar material types connected to each other, such as a galvanized anchor chain and connection hardware attached to an epoxy-coated, "black steel" mooring buoy. In this example, if the epoxy coating has deteriorated such that the two dissimilar metals are in contact, increased corrosion rates could occur at the intersection. Another similar scenario involves using nongalvanized (or nonstainless) anchor bolts to secure a galvanized pad-eye to a concrete surface; in this case increased corrosion will occur on the anchor bolt. The remaining material thicknesses should be measured using calipers to determine the remaining capacity.

3.2.11.2 Routine Underwater Inspection Level I inspections for anchor and chain leg assemblies are conducted using visual/tactile means and consist of examining the overall alignment of the anchor and chain leg, the anchor connection components, the anchor position on the ground and surrounding ground material type, orientation of the stabilizers and flukes, and any evidence of drag movement in the surrounding area. The anchor chain inspection should focus on the riser section, catenary section, dip section, and ground section. Level II efforts are also visual upon removal of marine growth in areas to be inspected.

Level III inspection of an anchor consists of measuring the remaining thickness of the connection components and measuring the offset angle of the chain to the shank end.

Level III inspection of the anchor chain legs consists of measuring the single-link diameter to determine the amount of remaining steel. A double-link measurement is used to determine the amount of wear at the adjoining two-link connection. A five-link measurement is used to check for chain stretch. A single-link measurement is used to check the individual chain link for stretch and to determine that it falls within the manufacturer's tolerance. In special mooring configurations, measuring the angle of the chain at the catenary and dip sections using an inclinometer device may be necessary. The connecting Kenter link should be inspected for the connection stud, keeper pins, and lead pellets (plugs).

See Appendix A.11 Mooring Buoy Systems for additional information.

3.2.12 Methods of Inspection for Buoys

3.2.12.1 Routine Above Water Inspection A Routine Inspection of the exposed portions of buoys primarily consists of visually assessing the buoy and its topside hardware, fenders, and chafing strips. Also, the buoy should be assessed to verify that it hasn't been dragged from its intended location.

The buoy should be examined to detect physical damage such as holes, dents, distortion, or listing. For fiberglass or fiberglass-coated buoys, assess the exterior noting cracks, wear, peeling, or rust staining. For painted buoys, assess the coating system for cracking, chipping, peeling, or debondment. For all buoys, measure the freeboard and assess any penetrations and/or drains. Fenders and chafing strips should be assessed for remaining section, cracks, attachment, and fastener corrosion.

Mooring components such as chains, linkages, and jewelry should be assessed as indicated in Section 3.2.11.

3.2.12.2 Routine Underwater Inspection Level I inspection efforts for submerged buoy hulls are conducted using visual/tactile means and consist of examining the overall exposed surface, identifying damage and/or deterioration as previously mentioned; the mooring leg connection components; and the integrity of the coating system. Level II efforts are also visual, upon removal of marine growth in areas to be inspected. Level III inspection of a buoy consists of measuring the remaining thickness of the buoy hull.

3.2.13 Methods of Inspections for Utility Systems

Utility systems on marine structures can include steam, potable water, fire water, seawater, sanitary sewer, oily waste disposal, fuel, compressed air, electrical, data and communication services, and fire alarm systems. This section does not include specialty systems such as marine-handling systems. For utilities, the inspections envisioned herein are surficial in nature, where readily visible. Evaluating the utility's ability to perform its function as designed is beyond the scope of this manual. In such cases, inspections require the inclusion of experienced engineers in the evaluation of the utility systems in question on the inspection team.

The scope of inspections shall be performed in accordance with Table 3-2. Level I inspections for utilities are conducted using visual/tactile means. Level II and III inspections are not normally conducted unless the utility extends underwater and marine growth removal is needed to observe the condition of the utility. Caution must be used when removing marine growth or corrosion from deteriorated exposed utilities because this may result in rupture of the line, causing leakage (for wet utilities) and possibly environmental contamination. If the line is color coded, ensure it conforms with the American Public Works Association's (APWA) Uniform Color Code, is labeled, and matches the material in the line.

Where utility systems run within sleeves, encasements, utility vaults, or underground, methods to determine the line condition are limited. Sleeves and encasements provided with drain holes should be checked for signs of leakage. Uncovering buried utility systems is not usually performed. Equipment and valves should not be operated. Typically, having the owner operate the valves is advantageous. Any inability or reluctance to do so should be noted.

The surfaces of the utility lines, including coatings, should be inspected for condition. Other common components requiring inspection include appurtenances such as hangars, mounts, and cradles.

3.2.14 Evaluation and Rating

A Condition Assessment Rating should be assigned to each inspected element group and/or system in accordance with Section 2.5. Each structure should be assigned an overall rating in accordance with Section 2.6.

For structural elements, if significant damage or deterioration is observed that could affect the load-carrying capacity of the structure, then a quantitative engineering evaluation of the effect of the damage on the structural capacity should be conducted prior to assigning a Condition Assessment Rating. Such a quantitative evaluation should typically be limited to the assessment of individual or typical components and should also be limited to an evaluation of the effect of the damage on the individual component capacity, without considering the actual or anticipated loading (structural demand). A Routine Inspection's purpose does not include conducting a detailed structural analysis of the structure. Should the need for a more rigorous structural analysis become apparent as a result of a Routine Inspection, then an engineering evaluation should be recommended as a follow-up action.

Utility systems should be assigned a Condition Assessment Rating. A Routine Inspection's purpose is not to provide comprehensive functional testing. Should the need for a more thorough inspection or function testing become apparent as a result of the Routine Inspection, then further investigation should be recommended as a follow-up action.

3.2.15 Recommendations

Upon completion of the Routine Inspection, recommended actions should be assigned to the structure in accordance with Section 2.7. In addition, the recommended interval to the next regularly scheduled Routine Inspection should be assigned using the guidelines of Section 2.1.1.

3.3 REPAIR OR UPGRADE DESIGN INSPECTIONS

3.3.1 Objectives

A Repair or Upgrade Design Inspection should be conducted once the decision to proceed with repairs has been made or if better repair cost data are desired. Structural upgrades to the facility that result in an improvement in operations or load-carrying capacity also require a Detailed Inspection. Theoretically, the upgrade work could be accomplished in combination with or independent of repairs. However, by including the two together, upgrade work that involves the removal and reconstruction of deteriorated elements will eliminate the need to repair these items and thus reduce costs. The types of repairs or upgrades to be implemented should be made after determination of the expected remaining service life of the facility. Examples of facility upgrades include improvement of deck structure capacity to resist concentrated loads from mobile truck cranes or other equipment; operational improvements such as additional space, new utility trenches, or larger gantry cranes; or improvement in the structural performance under seismic loading. Ideally, the decision to upgrade a structural component should be made prior to commencement of the Repair or Upgrade Design Inspection. However, preliminary results from the inspection may modify the extent of the initial upgrade plan to be more cost effective. An example of this might be the extension of a deck reconstruction into an adjacent area that is highly deteriorated in lieu of repairs.

Data collected during a Repair or Upgrade Design Inspection will be used to prepare contract bid documents to address specific defects and/or upgrade of components. Information gained from previous inspections should be used as appropriate to supplement the Repair or Upgrade Design Inspection. Specific objectives of a Repair or Upgrade Design Inspection include

- Documentation of the location and size and selection of the proposed method of repair for each defect or component to be repaired;
- Thorough investigation of the areas of the upgrade reconstruction work where such upgrades tie back into or re-use existing structure;
- Information leading to preparation of quantity estimates for the project; and
- Thorough documentation of all site-related conditions that could affect or impede straightforward execution of the work.

Upon completion of the Repair or Upgrade Design Inspection, bid documents can be prepared for the work. Bid documents typically include drawings and specifications covering each aspect of the work, along with bid forms, quantity estimates, and estimates of probable cost. Discussion of the preparation of bid documents is beyond the scope of this manual. However, the owner should be made aware of the differences in contract pricing methods for repair work, i.e., extensive use of unit-priced bid items with estimate quantities at bid time and final quantities determined in the field.

3.3.2 Methods of Inspection and Documentation

The Repair or Upgrade Design Inspection should focus primarily on documentation of only those elements that are intended to be repaired or upgraded. For this reason, defining specific repair criteria prior to executing the inspection is important. Defects that do not meet these predefined criteria need not be recorded, thereby improving the efficiency of the field inspection work. However, also important are understanding the client's funding requirements and recognizing that future repair money may not be available and that repairing more than minimally necessary may be in the owner's best interest. Closely aligned with this concept are the need to understand the owner's expectations for future repairs and the possible need to increase the expected life of the repairs being made to postpone future repairs.

The information required to prepare contract bid documents from the Repair or Upgrade Design Inspection results typically includes the following:

- Types of defects;
- Locations and extent of demolition and removal (when required);
- Location of the defects on the structure (component ID);
- Position of the defect on each component;
- Size of the defects;
- Method of repair for the defects;
- Location of items to be upgraded; and
- Method of upgrade (supplement, strengthen, or replace).

Documentation of repair size should always consider the increase in, or "growth" of, the defect size as a result of repair preparation, as in the case of preparation for repair of concrete spalls. In many cases, this can be a significant increase in the size of the visible or apparent repair area. It may also be advantageous to prioritize the elements of work, because some defects will require repairs more urgently than others and upgrade work may take precedence over repair work, or vice versa. Use of unit-price costing, bid alternatives, or bid options can be implemented to accomplish these goals. Such prioritization will allow the repair project to be readily altered to focus on the most important elements of the work if funding is restricted. The bid documents and pay clauses in the technical specifications should reflect these arrangements, if used.

Ideally, the Repair or Upgrade Design Inspection is conducted shortly after the decision to repair and/or upgrade the structure has been made and also with minimal delay before soliciting bids for repair work. The Repair or Upgrade Design Inspection should focus only on those portions of the structure identified in previous inspections to be in need of repair, or to be upgraded. Should a lengthy time elapse between the original inspection and the implementation of the contract, additional investigation and effort may be required to inspect and document components that have sustained additional deterioration. Also, the contractor, having significantly longer and closer contact with the structure than the inspectors, may uncover additional needs for repairs, especially those that were hidden from view.

The methods used for repair or upgrade may significantly affect the amount of time necessary to conduct a Repair or Upgrade Design Inspection. If concrete piles supporting a wharf exhibit extensive defects such as cracks (above or below water), knowing at the outset of the Repair or Upgrade Design Inspection the cause of the cracking and whether the piles will be repaired by jacketing, epoxy injection, sealing, or even replacement is critical. If the cracks are to be repaired by epoxy injection or sealing, recording the location and size of each crack will be necessary to produce repair plans and properly estimate repair quantities. However, if the cracks are to be repaired by jacketing, knowing only that cracks meeting the predefined repair criteria exist on the pile and that it should, therefore, be jacketed may be sufficient. The specific attributes of each crack become irrelevant in this case.

The difference in inspection time required to support these two scenarios may be significant. The documentation of every defect could require the removal of all marine growth from each pile. By contrast, to establish only the presence of cracking, only minimal removal of marine growth may be required. It is important to tailor the methodology used for conducting the Repair or Upgrade Design Inspection to the repair method employed.

3.3.3 Inspection of Buried Elements

Prior to implementation of repairs or upgrades to a structure, verifying the condition of buried elements that contribute to structural capacity is prudent. Such elements may include tiebacks, wales, dead men, soldier piles, cofferdams, relieving platforms, or similar items. Implementation of repair or upgrade projects without confirmation of the condition of buried structural members is not recommended because the integrity of the full structural load path has not been confirmed. Inspection of these elements requires consideration of the following issues:

- Excavation pit size and methodology, i.e., laid-back soil or use of shoring;
- Identification of potential obstructions (buried or surficial);
- Verification of safety requirements; and
- Investigation of dewatering requirements (if any) and appropriate disposal of dewatering effluent.

3.3.4 Recommendations

Upon completion of the Repair or Upgrade Design Inspection, recommended actions should be assigned to the structure in accordance with Section 2.7.

3.4 NEW CONSTRUCTION INSPECTIONS

3.4.1 Objectives

A New Construction Inspection should be performed on a new structure concurrent with the construction. The inspection should address the following objectives:

- Control quality to verify compliance with design documents,
- Verify quantities installed for contractor payment,
- Respond to field questions and resolve field problems, and
- Develop a list of deficiencies for contractor to correct.

3.4.2 Method of Inspection and Documentation

New Construction Inspection is conducted during construction to ensure quality control for the waterfront project. In addition, resolution of field questions and problems is provided to ensure that design intent and construction documents are properly interpreted and implemented and to contribute to keeping the project within the established budget and schedule.

Documentation obtained during a New Construction Inspection should provide details about any modifications to the design documents and the quantity of installed materials. Specific information should include confirmation of dimensions, verification of installed members (e.g., cotter pins and plates for anchor systems), locations, and other physical features. Additionally, all field problems and associated resolutions should be documented for future reference, including deviations from the design plans documented in the record drawings.

The scope and level of inspection required may vary significantly depending on the type of structure and methods of construction being used. At a minimum, a visual inspection of the underwater components should be conducted to ensure compliance with the contract documents and to make any corrections to the record drawings for future reference and inspections. In addition, a visual inspection may be performed at critical stages during the construction sequence to ensure that components and/or systems are being installed correctly.

Issues may arise during construction that warrant more detailed inspection or testing to verify installed components and conditions. As an example, placement of a concrete caisson may require two phases of inspection: (1) to ensure proper preparation and leveling of the site prior to the installation of the structure and (2) to inspect the caisson after placement to ensure that no damage has occurred during placement. Alternatively, a New Construction Inspection of a timber pile-supported structure may only require one phase of inspection to confirm that no damage has occurred to the members, such as breaching of the protective treatment, allowing for possible accelerated deterioration due to marine borer infestation. Conducting an inspection of piles in a pile-supported structure is generally advantageous to make sure no broken or severely damaged piles are present prior to construction of the deck.

3.4.3 Methods of Inspection for Steel Components

Inspection of the above water elements should include visual inspection, observation, and material testing on a daily basis to ensure the construction is being performed in accordance with the contract plans and specifications.

Because this is a New Construction Inspection, a Level I underwater effort is all that should be required. A Level I inspection effort is conducted using visual/tactile means. Marine growth should be nonexistent to minimal for a New Construction Inspection, so a Level II effort should not be required; likewise Level III efforts are not typically required.

If steel thicknesses must be verified after placement, measurements may be taken by micrometer where feasible, or by an ultrasonic thickness measuring device. This can be accomplished on above water elements and underwater.

All material submittals should be reviewed to ensure they comply with the contract documents. Field materials should be verified that they are what were proposed in the submittals.

Additional inspection, such as inspecting welds using magnetic particle testing, coupon samples, and voltage potential measurements may be warranted for specific structures.

An electrical potential survey should be conducted for steel members with cathodic protection. Potential measurements should be taken at points throughout the structure to determine the effectiveness of the cathodic protection system. Generally, an Ag-AgCl half-cell, dry electrode immersed in seawater is used in the marine environment, and readings between −0.800 mV and −1.100 mV Ag-AgCl indicates adequate protection. Readings less negative than −0.800 mV Ag-AgCl may indicate inadequate protection, and readings more negative than −1.100 mV Ag-AgCl may indicate overprotection, which could lead to accelerated anode depletion, coating disbondment, and possible accelerated corrosion for amphoteric metals such as aluminum.

For coated steel members, the Level I effort should focus on the evaluation of the integrity and effectiveness of the coating.

3.4.4 Methods of Inspection for Concrete, Timber, Masonry, and Composite Components

Inspection of the above water elements should include visual inspection, observation, and material testing on a daily basis to ensure the construction is being performed in accordance with the contract plans and specifications.

Because this is a New Construction Inspection, a Level I underwater effort is all that should be required. A Level I inspection effort is conducted using visual/tactile means. Marine growth should be nonexistent to minimal for a New Construction Inspection, so a Level II effort should not be required; likewise Level III efforts are not typically required.

All material submittals should be reviewed to ensure they comply with the contract documents. Field materials should be verified that they are what were proposed in the submittals.

3.4.5 Methods of Inspection for Slope Protection

Because this is a New Construction Inspection, a Level I underwater effort is all that should be required. Inspection efforts on slope protection, such as armor stone, riprap, gabions, concrete liners, scour protection mattresses, etc., are conducted using visual/tactile means.

In some cases, performing Level I efforts may not be feasible or practical due to waves, currents, or restricted visibility. This is particularly true for the offshore face of breakwaters. In such cases, performing the inspection using techniques, such as sonar, may be more cost effective or technically advantageous. Common sonar techniques include side-scan sonar and multibeam sonar systems. The results of such surveys may indicate areas of potential problems that may be further investigated by diving. Techniques, such as side-scan sonar, precision bathymetry, or multibeam sonar, are only as accurate as their horizontal control. DGPS or range-azimuth systems may be used to interface with the sonar system, tidal depth gauge, etc., to locate the anomaly for investigation.

3.4.6 Methods of Inspections for Channel Bottom or Mudline

An inspection of the channel bottom or mudline around structural elements is conducted using visual/tactile means to evaluate scour or changes in the bottom conditions.

In some cases, performing a hands-on underwater inspection may not be feasible or practical due to currents, restricted visibility, or the scale of the task. In such cases, performing or supplementing the inspection using techniques, such as multibeam or side-scan sonar, fathometers, lead lines, or similar depth measurement equipment, may be more cost effective or technically advantageous. However, the method(s) of inspection used must be able to detect undermining if it is identified as a potential concern. The results of the survey may indicate areas of potential problems that may be further investigated by an underwater inspection.

3.4.7 Evaluation and Rating

A Condition Assessment Rating should be assigned to each inspected facility in accordance with Section 2.6. Significant damage or improper installation that is observed should be included in a list of deficiencies provided to the owner's representative. These deficiencies could affect the capacity of the element, whether it is a utility, load-bearing structure, mooring, etc. A New Construction Inspection's purpose is not to conduct a detailed analysis of the facility; however, if the deficiency is not corrected, a quantitative engineering evaluation of the effect of the deficiency on the capacity should be conducted prior to assigning a Condition Assessment Rating. Such a quantitative evaluation should typically be limited to the assessment of individual or typical components and should also be limited to an evaluation of the effect of the damage on the individual component capacity, without considering the actual or anticipated loading (demand). Should the need for a more rigorous analysis be apparent as a result of a New Construction Inspection, an engineering evaluation should be recommended as a follow-up action.

3.4.8 Recommendations

Upon completion of the New Construction Inspection, a list of deficiencies should be prepared and presented to the owner's representative for contractor resolution. This should ideally be done on a continuous or periodic basis throughout the construction project. In addition, a Baseline Inspection, if not already scheduled, should be recommended prior to acceptance of the structure by the Owner. If a Baseline Inspection is not warranted, the recommended interval to the next regularly scheduled routine inspection should be assigned using the guidelines of Chapter 2.

3.5 BASELINE INSPECTIONS

3.5.1 Objectives

A Baseline Inspection should be conducted on a newly constructed structure prior to acceptance by the owner, or it may be conducted on an existing structure that has not been previously inspected. The objectives of a Baseline Inspection include

- Verifying general compliance with design drawings, if available;
- Ensuring no significant defects prior to owner acceptance;
- Establishing a structure/component datum for future reference and comparison;
- Developing recommendation(s) for follow-up action; and
- Determining the recommended interval to the first Routine Inspection.

In addition, for existing structures without available drawings or design details, the Baseline Inspection may be used to gather information sufficient to support a structural evaluation. Alternatively, the Baseline Inspection may be used to develop record drawings or "as-builts" of the facility.

3.5.2 Method of Inspection and Documentation

3.5.2.1 General Considerations Baseline Inspection is conducted to confirm dimensions, component locations, existing conditions, and other physical features. For new construction, the scope and level of effort expended depends on the specific type of construction and material type and whether the facility has undergone a New Construction Inspection. Information documented during the New Construction Inspection can be utilized as a basis for the Baseline Inspection, thus reducing field time requirements. Sufficient information should be collected during the Baseline Inspection to allow future comparisons to be made.

When conducting a Baseline Inspection of an existing facility for which no previous inspection information is available, the scope of the inspection will depend on the availability of design drawings.

For new construction and existing construction where design drawings are available, the Baseline Inspection should be conducted to verify the general accuracy of the drawings. However, for existing structures where design drawings are not available, the Baseline Inspection should be conducted to gather sufficient information to generate drawings or develop structural details of the facility. The level of detail required for this effort will depend on what the information will be used for. In some cases, documenting the dimensions of individual members and of the overall facility may be sufficient.

However, where a structural analysis must be performed using the results of the Baseline Inspection, the inspection must be much more detailed. Detailed measurements and testing should be used in such cases. For concrete structures, establishing the location, size, and cover of reinforcing steel may be necessary. In addition, establishing the compressive strength of the concrete by testing of core samples by NDT, such as Schmidt Hammer or Windsor Probe testing or by a combination of core sample testing and NDT, may be necessary. For structural steel or reinforcing steel, collecting coupon samples to determine tensile strength and other properties relevant to the structural analysis may be required. Similarly, it may be necessary to collect and test timber samples to establish strength and ductility characteristics of timber portions of the structure. Finally, where connection details are unknown or are not readily apparent, dissecting typical connections to document details may be needed.

At a minimum, a visual inspection of all underwater elements in the scope should be performed verifying size, location, and material. In addition, the inspection should also include water depths at defined locations to aid in determining scour and/or sediment deposition rates and possibly debris surveys.

Similar to the underwater inspection, the above water inspection for a Baseline Inspection should include a visual inspection of all elements, verifying size, location, and material.

3.5.3 Recommendations

Upon completion of the Baseline Inspection, recommended actions should be assigned to the structure in accordance with Section 2.7. In addition, the recommended interval to the first regularly scheduled Routine Inspection should be assigned using the guidelines of Section 2.1.1.

3.6 DUE DILIGENCE INSPECTIONS

3.6.1 Objectives

A Due Diligence Inspection is an assessment of a facility for the purposes of generally determining its value and fitness for purpose and confirming the status of its assets and liabilities. A Due Diligence Inspection is performed when a transfer of ownership or other financial transaction related to the facility is being considered. Due Diligence Inspections are typically requested by the principals in a transaction but can also be requested by third parties, such as investment banks, pension funds, private equity firms, and others, that may have a stake in the transaction. The objectives of a Due Diligence Inspection include

- Forming an engineering opinion of the general condition of a structure;
- Estimating order-of-magnitude replacement costs and/or repair costs;
- Supporting the performance of a financial, investment, or insurance valuation process; and
- Developing recommendations for follow-up actions.

A Due Diligence Inspection can include a significant degree of engineering effort beyond just the inspection, such as the review of past records, analysis of known or discovered deficiencies, and consideration of future life-cycle costs of the facility that includes the calculation of present value. The Due Diligence Inspection is only one piece of a broader due diligence exercise, the result of which is ultimately reduced to a financial determination as to whether or not the investment or transaction should proceed and, if so, whether the cost is reasonable. For the purposes of this section, only the engineering inspection element of a Due Diligence Inspection will be discussed.

3.6.2 Methods of Inspection and Documentation

A Due Diligence Inspection can be performed at various levels of detail, depending on the type of facility being evaluated, the needs of the requester, and schedule. For instance, the needs of a major terminal investor/operator will be different from a financial investor looking to acquire a stake in an asset. However, each needs to determine the value of the facility and what liabilities are associated with it.

The Due Diligence Inspection includes a condition assessment that results in the documentation and assessment of the physical condition of each facility being inspected. The condition assessment should be performed as described in this manual, with the scope defined by discussions with the requester. Because these types of inspections are requested late in the negotiation process after many other agreements have been hammered out, and usually with the expectation that the facility is "as advertised," schedule (i.e., available time to complete the inspection) may become the driving factor in developing the scope and completing the inspection. This may require multiple teams working on short notice and over weekends and holidays, including more senior staff, or just a reduced level of inspection detail. Because of this, the report may need to be heavily qualified.

3.6.3 Recommendations

Upon completion of the Due Diligence Inspection, condition ratings should be assigned to the structures in accordance with Section 2.5 and overall ratings should be assigned as per Section 2.6. Service life modeling may be developed in accordance with Section 2.3. In addition, if follow-up repair design is required at a future date, recommendations of specific repair methods based on the results of the inspection should be provided to establish future costs. If repair design is not warranted, the recommended interval to the next regularly scheduled Routine Inspection should be assigned using the guidelines of Section 2.1.1.

3.7 SPECIAL INSPECTIONS

3.7.1 Objectives

Special Inspections are conducted with a specific purpose in mind. Such purposes may include

- Further quantification of the extent of observed deterioration, where not readily apparent;
- Determination of the cause of observed deterioration to develop the appropriate repair method, or to prevent future deterioration;
- Determination of structural significance that has resulted or will result from observed deterioration;
- Determination of the significance of observed deterioration on future durability and maintenance requirements; and
- Development of recommendation(s) for follow-up action.

3.7.2 Methods of Inspection and Documentation

Special Inspections typically include field sampling and testing, laboratory testing and analysis, or a combination thereof. The scope of Special Inspections should be dictated by the type of testing or analysis to be performed. The scope may need to be expanded depending on initial results. Standard test methods exist for many Special Inspection types. Such methods are typically defined by organizations such as ASTM or AASHTO.

Documentation obtained during the Special Inspection will also vary greatly depending on the specific investigation technique and objective. Recorded information may include field-testing results, laboratory-testing results, or materials analysis results.

3.7.3 Recommendations

Upon completion of the Special Inspection, recommended actions should be assigned to the structure in accordance with Section 2.7. In addition, if follow-up repair design is required, recommendations of specific repair methods, based on the results of the Special Inspection, should be provided. If repair design is not warranted, the recommended interval to the next regularly scheduled Routine Inspection should be assigned using the guidelines of Section 2.1.1.

3.8 REPAIR CONSTRUCTION INSPECTIONS

3.8.1 Objectives

A Repair Construction Inspection should be conducted during the construction of repairs and should be ongoing with the construction, providing inspection at strategic points during the work. Generally, these inspections are conducted by the owner's construction management (CM) team that manages the repair construction contract on a day-to-day basis, with or without the assistance of a professional CM firm and/or consulting engineering firms with specialized marine inspection and repair experience. In some cases, the design engineer of record, or a specially contracted firm, conducts the inspections. Timely execution of Repair Construction Inspection can often prevent costly remobilization costs, back charges, unintentional acceptance of nonconforming work, etc. The primary objectives of the Repair Construction Inspection are as follows:

- Evaluating quality to verify contractor compliance with repair design documents,
- Verifying repair quantities for contractor payment,
- Responding to field questions and resolving field problems, and
- Developing a list of deficiencies for contractor to correct.

3.8.2 Methods of Inspection and Documentation

Repair Construction Inspections are conducted during construction to control quality of the repairs. In addition, resolution of field questions and problems can be provided to ensure that design intent and repair construction documents are properly interpreted and implemented and contribute to keep the project within the established budget and schedule.

The scope of Repair Construction Inspection will be dictated by the repair methods employed for specific projects. Repair Construction Inspection should typically be conducted throughout the repair process rather than waiting until the end of the project to perform an acceptance inspection. This is because the success and longevity of repairs often depend on proper surface preparation, and such preparation is typically only visible in-process.

As an example, placement of a timber pile post with a concrete collar around the mudline connection may require three phases of inspection: (1) to ensure the soundness and elevation of the existing cut-off pile stub; (2) to inspect the placement of formwork, internal reinforcing, and attachment of the timber sections; and (3) to inspect the final concrete placement and condition. Alternatively, a Repair Construction Inspection for patching a steel sheet pile wall may only require two phases of inspection: the first to confirm the proper surface preparation and the second to visually confirm the quality of the weld.

Documentation obtained during a Repair Construction Inspection should provide details on the activities of the contractor, any modifications to the design documents, and the quantity of repairs completed. In addition, all field problems and associated resolutions should be documented for future reference.

3.8.3 Recommendations

Upon completion of the Repair Construction Inspection, a punchlist of deficiencies should be prepared and presented to the contractor for resolution. This should ideally be done on a continuous or periodic basis throughout the repair project.

3.9 POST-EVENT INSPECTIONS

3.9.1 Objectives

Post-Event Inspections should be conducted following significant, potentially damage-causing events such as a major storm, earthquake, flood, vessel impact, fire, observation of a significant structure change, or other similar incident. The objectives are as follows:

- Conduct a rapid investigation to determine if any damage resulting from the event may have significantly affected the integrity of the structure either locally or globally,
- Assign a post-event condition rating to the structure, and
- Develop recommendation(s) for follow-up action.

3.9.2 Methods of Inspection and Documentation

Post-Event Inspections should be somewhat rapid visual/tactile inspections. The focus of the Post-Event Inspection should be damage that was likely to have been caused by the event. Such damage may include breakage, overstressing cracks, buckling, settlement, slope failure, etc. General observations of long-term or preexisting deterioration, such as significant corrosion-related damage or other deterioration, should be made as appropriate but should not be the focus of the inspection. Post-event damage can often be observed and differentiated by noting fresh breaks or changes in the material.

The decision to execute a Post-Event Inspection should depend on the type and severity of the event and the structure type and its vulnerability to damage. Above water observations often provide the best clues as to whether an underwater inspection is prudent. Such observations may include shifting or differential settlement, misalignments, significant cracking, bulging, breakage, etc.

Major storms or tsunamis may trigger an underwater Post-Event Inspection of breakwaters or other structures in the path of the event. Many U.S. waterways have USGS web sites with real time and historical flow data. Similarly, USGS marine buoys record historical wave height, wave period, wind speed, and direction.

Damage caused by earthquakes or vessel impact on structures such as pile-supported waterfront facilities often occurs both above and below water. The underwater Post-Event Inspection may, therefore, be reserved only for structures that exhibit above water damage.

Ultimately, the decision to execute an underwater Post-Event Inspection is a matter of judgment and should be weighed against the importance of the structure in terms of public safety and/or economic impact.

The methodology of conducting a Post-Event Inspection should depend upon the structure type and the type of damage anticipated. Whereas slope failures or scour may be readily apparent in waters of adequate visibility, overstressing cracks on piles covered with marine growth will not be readily apparent. Where such hidden damage is suspected, marine growth removal should typically be performed on a representative sampling of components in accordance with the Level II inspection requirements described in Section 3.1.3.

Due to the rapid nature of the inspection, documentation should be minimal, consisting primarily of brief notes describing observed conditions and summarized into a post-event condition rating.

3.9.3 Ratings and Recommendations

A post-event condition rating should be assigned to each inspected structure in accordance with Section 2.6.3. This rating system is different from that used for other inspections because the focus of the Post-Event Inspection is to identify significant damage that has resulted from the event. However, if significant damage or deterioration is observed that does not appear to have resulted from the event, this information should be documented. A Post-Event Inspection's purpose is not to conduct a detailed structural analysis of the structure. Should the need for additional inspection or for a more rigorous structural analysis be apparent as a result of a Post-Event Inspection, recommendations for follow-up action such as Special Inspection, Structural Repair or Upgrade Design Inspection, or engineering evaluation should be assigned as appropriate in accordance with Section 2.7.

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CHAPTER 4
SERVICE LIFE ESTIMATION

4.1 GENERAL

This section provides guidance on estimating the remaining service life of a marine facility. Service life is the length of time a structure or facility may be used economically before emergent damage or deterioration causes increasing interruptions in facility operations or a threat to public safety.

This section covers the three basic construction materials most commonly used for waterfront facilities: concrete, steel, and timber. Although composite materials are becoming more common in the construction of waterfront facilities, they are typically limited to discrete areas of the facility with minor impact on overall service life and are not addressed in this section. It is important to understand that predicting the remaining service life is not an exact science but rather a tool to aid the owner in facility planning. Once the service life is estimated, the remaining service life may be extended through maintenance and repairs focused on the controlling members. Coatings used to provide a barrier to the environment or cathodic protection that arrests the corrosion process through an electrochemical process (Fig. 4-1) are examples of service life extension.

4.2 IMPORTANCE OF ACCURATE ESTIMATIONS

Waterfront facility planners must be able to determine and understand the remaining service life of a facility with and without repairs. To estimate a structure's remaining service life, obtaining information on the original design, any previous maintenance, the current and anticipated loads on the structure, and, most importantly, the existing condition of the structure is

Fig. 4-1. Concrete pier with pile jackets incorporating cathodic protection to increase service life
Source: Courtesy of Appledore Marine Engineering, Inc., reproduced with permission.

important. As with any assessment, the better the information gathered, the closer the estimated service life will be to that actually obtained. The better the estimate of the remaining service life, the more feasible the decisions made concerning short- and long-term planning, maintenance, repair, and possible replacement of the facility. However, predicting the remaining service life can be challenging, as many factors affect the service life of a waterfront structure, including climate, water properties, zone in relation to the tide, exposure, and original material treatments and/or composition.

4.3 STATE OF THE ART

In the last decade, the science of predicting the remaining service life of marine structures has advanced, due to technology changes and a better understanding of deterioration mechanisms. Of particular note are the advances made in assessing concrete structures. These advances have been made through better understanding and tracking of deterioration species and the development of analytical models to more accurately establish the remaining service life.

The service life estimation approach to steel and timber structures is more elemental; basic principles are important in making defensible predictions.

For steel structures, the estimated rate of corrosion is typically the key metric for steel deterioration. For timber structures, the key metrics are related to fungi, insects, bacteria, and marine borers, and the locations and environments in which they thrive. For example, a timber pile may be susceptible to marine borers and bacteria in the submerged and tidal zones and also susceptible to fungi, insects, and bacteria in the splash and atmospheric zones. Timber structures often deteriorate from the inside making it difficult to assess the quantity and extent of deterioration. Experience with similar structures is important, and simple tools, such as cores, can aid in assessing the level of deterioration.

Although the technology of service life prediction is advancing, experience and knowledge of similar structures are an important foundation in making accurate predictions. Also important is understanding the variety of factors that affect the service life; therefore, developing an inspection history of a structure provides firsthand knowledge of deterioration rates.

4.4 CORROSION ZONES

For concrete and steel, and to some degree timber, deterioration rates are, in part, related to where they exist vertically in the water column. The definitions of these corrosion zones are provided in Table 4-1, from highest to lowest.

The accelerated rates of corrosion of steel structures in the splash and low water zones highlight the importance of zones. The splash zone is one of the more severe zones, where chloride, moisture, and oxygen combine in greatest quantity. Chloride availability is greatest in the splash zone, where salt accumulates and crystallizes just above the tidal zone and is not dispersed by tides. Timber structures are typically affected the greatest by fungal decay and marine borer deterioration. Fungal species are only active above the reach of salt spray, and marine borers can be active below low water to the mudline. The primary mode of deterioration for concrete structures is corrosion of the embedded reinforcing steel. This type of deterioration is most prominent in the splash zone and is generally minimal below low water due to the reduced oxygen levels.

4.5 CONCRETE FACILITIES

The service life of concrete structures is a function of various exposure variables and deterioration modes. One of the more common modes affecting remaining service life is the ingress of chlorides, leading to corrosion of the reinforcing steel. Other modes of deterioration include delayed ettringite formation, sulfate attack, or reactive aggregate. To better

Table 4-1. Corrosion Zone Definitions

Zone	Definition
Atmospheric Zone	The area above the upper limits of the splash zone, which remains consistently dry. However, the area may be subject to salt-laden air.
Splash Zone	The area above the high water mark (MHHW MHW, MHWS, etc.) that is subject to constant wetting and drying due to splashing of water; except for rare extreme events, the area is never continually immersed for any period of time. The area is characterized by the abundance of oxygen and the buildup of chlorides in high concentrations. The upper limit is defined by local conditions of splashing by wake, wave, and chop.
Tidal Zone (intertidal)	The area between the low water mark (MLW, MLLW, MLWS, etc.) and the lower limit of the splash zone. The zone is subject to daily tidal wetting and drying, but chloride buildup is not as severe as in the splash zone, and average oxygen availability is lower. A subzone of the tidal zone, known as the low water zone, is defined as the area between the 0.5 m below MLWS and the lower astronomical tide (LAT). Certain very aggressive steel corrosion activities are known to occur in this zone.
Low Water Zone	The area approximately between 0.5 m below the lower limit of the tidal zone and MLW where certain very aggressive steel corrosion activities are known to occur in some locations. Does not occur in all areas.
Submerged Zone (immersed)	The area between the mudline and the lower limit of the tidal zone. Except for rare extreme events, the area is never exposed to the atmosphere and is constantly wet. The average oxygen availability is lower than in the tidal zone.
Disturbed Soil Zone	Defined as those first few feet of loose soil or soilslurry that are disturbed or put in motion by waves, currents, propeller/thruster wash, etc. The zone is characterized by soil densities far less than the firmer soils below. The upper limit is usually referred to as the mudline.
Undisturbed Soil Zone	The zone underlying the disturbed soil zone and extending to the lowest elevation of the structure (tip elevation). Characterized by low oxygen availability.

understand and predict the deterioration process of concrete, representative samples need to be collected and analyzed to identify the inherent material properties of the concrete matrix. This is important, as two concrete mixes made around the same time may be visually similar but could have significantly different properties. Once the properties are known, the specific concrete elements may be modeled with software such as STADIUM, Life-365 or COMSOL.

A primary mode of deterioration in the marine environment is corrosion of the embedded reinforcing steel caused by chloride exposure. The exposure and transport properties of the concrete greatly affect this process. For instance, concrete generally deteriorates more rapidly in tropical environments where the concentration of chlorides in the seawater is higher. The transport properties of concrete are a measure of how quickly deterioration mechanisms, such as chlorides, are transported from the surface of the concrete to the reinforcing steel. A concrete structure goes through several stages, including full chloride penetration, time to initiation of corrosion, and the critical corrosion threshold that results in damage to the structure. Some agreement exists in the industry that the time from corrosion initiation to the point where damage is seen, such as spalling, is about 10 years. Given that the matrix of the concrete, location, and exposure zone may significantly affect the time of each phase, modeling is the best tool to determine time from corrosion to visible damage.

4.5.1 Sampling

Once it has been determined that an estimation of service life is desired, sampling, testing, and service life modeling of a structure should be performed. One of the first steps is to collect representative samples from the structure to define the material properties. Once collected, the samples are used for material testing to define the parameters for modeling.

The samples should be extracted from areas within the structure that best represent its structural load-carrying capabilities and integrity and its relevant modes of deterioration. Obtaining concrete core samples that are statistically representative is important. A small number of cores may be designated to evaluate specific areas of more advanced deterioration that may not be representative of the entire structure. The testing laboratory should be involved in determining the diameter and number of cores required to complete the testing program, as some tests require a specific volume or size of material. Careful thought should go into the development of a coring plan due to the difficulty and expense of extracting cores in the marine environment. For instance, coring of piles often requires a larger and more specialized crew and a vessel or other similar type of floating working platform (see Fig. 4-2).

Fig. 4-2. Coring operations over water to extract samples from prestressed piles Source: Courtesy of Appledore Marine Engineering, Inc., reproduced with permission.

The coring plan should include the following specific characteristics:

- Plan depicting overall locations; the selection of sampling locations should account for the various concrete types and exposure conditions;
- Core diameter (typically 2 to 4 in., depending on the element, testing protocol, and reinforcing location and spacing);
- Depth of core;
- Element to be cored, i.e., deck, pile, pile cap, etc.;
- Boundary conditions, i.e., submerged, tidal, splash, or atmospheric;
- Handling of core after extraction; and
- Core labeling.

Checking local environmental regulations is an important part of the planning process to assess any requirements for containment and collection of coring wastewater (see Fig. 4-3). Record documents (plans and specifications) should be reviewed prior to developing the coring plan for a basic understanding of reinforcing steel density; the final field core layout should be completed with the assistance of a reinforcing steel locating instrument.

Once extracted, the cores should be assembled as extracted and labeled for identification by the laboratory (see Fig. 4-4). The cores should also be packaged or wrapped per the laboratory's requirements.

Fig. 4-3. Coring operation of dry dock wall; note wastewater containment Source: Courtesy of Appledore Marine Engineering, Inc., reproduced with permission.

4.5.2 Laboratory Testing and Analysis

Laboratory analysis is required to ascertain the specific characteristics of the concrete, chemistry profiles (typically chlorides), and the boundary conditions.

The transport properties of the concrete identify the pathways and rate of migration for deterioration species. This testing allows the engineer to better understand deterioration mechanisms of the concrete and the migration of contamination. The testing regime provides the necessary input constituents to complete modeling and service life prediction of the concrete.

To characterize the concrete, the following tests are generally completed; however, coordinating with the developers of the modeling software is important, as many of these tests have been modified to more accurately reflect actual conditions.

Fig. 4-4. Extracted core sample
Source: Courtesy of Appledore Marine Engineering, Inc., reproduced with permission.

1. Compressive strength in accordance with *ASTM C39*, "Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens" (2014). The preferred length/diameter ratio for cores is two; however, the test can be completed down to a ratio of one. This may be required for slender elements such as prestressed piles.
2. Air void network determination in accordance with *ASTM C457*, "Standard Test Method for Microscopical Determination of Parameters of the Air-Void System in Hardened Concrete" (2012). This test is used to aid in modeling the rate of migration of deterioration species.
3. Petrographic examination in accordance with *ASTM C856*, "Standard Practice for Petrographic Examination of Hardened Concrete" (2014). This test identifies the water-cement ratio and possible degradation mechanisms.
4. Chloride profiling. Chloride ion profiling determines the extent and limit of chloride contamination. Chloride determinations are made in accordance with *ASTM C1152*, "Standard Test Method for Acid-Soluble Chloride in Mortar and Concrete" (2012).

The latest version in modeling software defines the migration of contaminants on the ionic level. To describe the migration, specific testing of these parameters is completed. The following tests are required:

1. Porosity in accordance with *ASTM C642*, "Standard Test Method for Density, Absorption, and Voids in Hardened Concrete" (2013).
2. Rapid chloride penetration test in accordance with *ASTM C1202*, "Standard Test Method for Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration" (modified, 2012).
3. Drying laboratory test in accordance with *ASTM C1585*, "Standard Test Method for Measurement of Rate of Absorption of Water by Hydraulic-Cement Concretes" (modified, 2013).

4.5.3 Service Life Modeling

One of the primary modes of concrete structure deterioration in the waterfront environment is corrosion of the internal reinforcing steel. Corroding reinforcing steel may expand in volume up to seven times its original volume, exerting significant pressure that may result in mechanical damage, typically exhibited as cracks or spalls. This mechanical damage results in an acceleration of the deterioration due to exposure of fresh substrate and additional avenues of ingress for the deleterious chemicals. This is one example of a deterioration mode, and, due to the heterogeneous nature of concrete, many modes need to be modeled.

Many technological advances have occurred in concrete modeling software to determine the remaining service life of a structure, with one of the latest evolutions being the development of the software STADIUM. This software is a finite element model that accounts for the composition of the concrete, the transport properties of the concrete, the exposure of the site, and the structure's dimensions to estimate the remaining service life. For instance, the software models the exposure conditions in the tidal zone differently than below low water due to the difference in available chlorides and oxygen. The software also accounts for elements that may have different environments on each side, such as a deck element. STADIUM is an example of commonly used modeling software; others are used in the industry including Life 365 and COMSOL.

The key output parameter is expressed in duration to corrosion initiation (see Fig. 4-5). Whereas some debate is ongoing, 500 ppm of chlorides is generally accepted to represent a reasonable value for the critical corrosion initiation threshold value for black steel with some incremental increases in threshold value for treatments such as epoxy or galvanizing. Once chlorides reach the level for corrosion initiation, corrosion propagates over time. The generally accepted propagation period is 10 years for black steel to cause significant cracking, eventually resulting in deterioration and ultimately component failure.

Although engineering judgment and experience continue to be important factors in evaluating the remaining service life of concrete structures, the

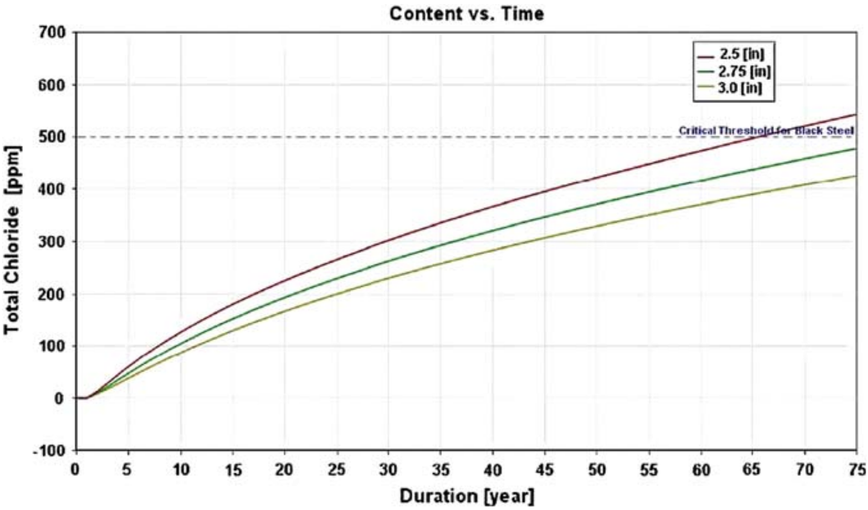

Fig. 4-5. STADIUM output data depicting time to corrosion initiation as a result of chloride contamination
Source: Courtesy of Appledore Marine Engineering, Inc., reproduced with permission.

development of modeling software is a valuable tool in the decision-making process.

4.6 STEEL FACILITIES

4.6.1 Background

Understanding that no single accepted value exists for the corrosion rate of uncoated steel in seawater is important. The rate of corrosion depends on site-specific environmental factors that can vary greatly. These factors include

- Chloride content,
- Dissolved oxygen,
- Moisture content,
- Chemical or pollution content,
- Oxygen,
- Nutrient and bacteria content,
- Hardness,
- pH,
- Soil resistivity,
- Sulfate content,
- Range of tide,

- Temperature,
- Current velocity,
- Wave action, and
- Cathodic protection.

The rate of corrosion also varies along the vertical length of the element and where it lies within the corrosion zones, defined in Table 4-1. The International Navigation Association's 2005 publication "Accelerated Low Water Corrosion" (ALWC), also defines a special zone, the low water zone (0.5 m below MLWS to LAT), where microbe-related ALWC is prone to occur. ALWC is a localized but aggressive form of corrosion that occurs worldwide and is becoming more frequent. The exact reasons for its occurrence are not well understood.

4.6.2 Variation in Published Unprotected Steel Corrosion Rates

To determine an economic service life and design-appropriate measures to extend that life, the rate of corrosion of steel must be estimated. As previously mentioned, many factors affect the rate of steel corrosion in a waterfront environment. Many studies have been undertaken to empirically document rates in different locales. A compilation of reference documents, studies, and consultations addressing steel corrosion in the seawater splash zone were examined and are presented in Table 4-2. Rates were expressed in various units, and the three most common units—mil per year (mpy), mm per year (mm/y), and in. per year (ipy)—are used along with the conversions. The table is included to illustrate the variability in the corrosion values reported.

The California Department of Transportation (California Department of Transportation, 2014) uses the following corrosion rates for steel piling exposed to corrosive soil and/or water:

- Soil embedded zone: 0.001 in./year,
- Immersed zone: 0.004 in./year, and
- Splash zone: 0.005 in./year.

These corrosion rates only apply to the exterior surface of the steel pipe pile. Typically, the interior surface of the pile (soil plug side) will not be exposed to sufficient oxygen to support significant corrosion. This may also be the case in instances where oxygen is depleted, such as behind bulkheads. However, depending on the nature of the backfill, corrosion may still progress although at some diminished rate.

Eurocode 3 (BS 2007) provides corrosion rates for structures in temperate waters as shown in Table 4-3.

Table 4-4 provides the recommended value for the loss of thickness due to corrosion for piles and sheet piles in soil, and Table 4-5 provides the

Table 4-2. Summary of Estimated Corrosion Rates for Unprotected Steel in the Seawater Splash Zone

#	Source	Rate (mpy)	Rate (mm/y)	Rate (ipy)
1	FHWA Driven Pile Manual (Hannigan, et al. 1998)	7	0.18	0.007
2	Peruvian Port (Farro, Veleva and Aguilar 2009)	21.86	0.56	0.022
3	Swedish Commission Report (Camitz 1998)	11.8	0.3	0.012
4	U.S. Environmental Protection Agency Report (CH2M HILL 2004)	12–20	0.30–0.51	0.012–0.020
5	Fontana (Fontana 1986)	10–16	0.25–0.40	0.010–0.016
6	Port Engineering textbook references (Bruun 1989):			
	Chellis (1961)	25–40	0.64–1.02	0.025–0.040
	Edwards (1963)	4–14	0.10–0.36	0.004–0.014
	Creamer (1970)	55	1.4	0.055
7	FDOT Seawall Study (Florida Department of Transportation 2014)[a]	16	0.41	0.016
8	Tomlinson (Tomlinson 1987)	3.54	0.09	0.004
9	Campeche, Mexico (Balasubramanian 1999)	3.07	0.078	0.003
10	Eurocode (BS 2007)	3	0.075	0.003
11	Chef Menteur Pass (Romanoff 1962)[b]	5	0.127	0.005
12	Seymour Coburn (Coburn 1988)	27.9	0.709	0.028
13	British Standard 6349 (British Standard 6349-1 2000)	6.69	0.17	0.007
14	U.S. Navy Study, Key West (Brouillette and Hanna 1960, p. 17)	10	0.254	0.01
15	Cook Inlet, AK (Daley, J.C. and D. Ingraham 1996)[c]	30–60	0.76–1.50	0.03–0.06

[a]Uncoated steel sheet piling on Florida Atlantic Ocean beach exposed directly to seawater at high tides only.
[b]1961 observations of four lengths of coated sheet-pilings pulled after 32 years in service at site nearby IHNC, Chef Menteur Pass.
[c]Cathodic Protection in Cook Inlet Waters, Materials Performance, February 1991.

Table 4-3. Corrosion Rates from the European Building Code

Location	Total Loss in 25 Years	Equivalent Annual Loss
Splash zone	1.9 mm (0.075 in.)	0.076 mm/year (0.003 ipy)
Immersed zone	0.90 mm (0.035 in.)	0.036 mm/year (0.0014 ipy)
Atmospheric zones	0.25 mm (0.010 in.)	0.010 mm/year (0.0004 ipy)

Source: BSI (2007), reproduced with permission.

Table 4-4. Recommended Value for the Loss of Thickness (mm) due to Corrosion for Piles and Sheet Piles in Soils, with or without Groundwater

Required working life	5 years	25 years	50 years	75 years	100 years
Undisturbed natural soils (sand, silt, clay, schist, etc.)	0.00	0.30	0.60	0.90	1.20
Polluted natural soils and industrial sites	0.15	0.75	1.5	2.25	3.00
Aggressive natural soils (swamp, marsh, peat, etc.)	0.20	1.00	1.75	2.50	3.25
Noncompacted and nonaggressive fills (clay, schist, sand, silt, etc.)	0.18	0.70	1.20	1.70	2.20
Noncompacted and aggressive fills (ash, slag, etc.)	0.50	2.00	3.25	4.50	5.75

Notes: Corrosion rates in compacted fills are lower than in noncompacted ones. In compacted fills, the figures in the table should be divided by two.
The values given for 5 and 25 years are based on measurements, whereas the other values are extrapolated.
Source: BSI (2007), Table 4-1, reproduced with permission from British Standards Institution.

Table 4-5. Recommended Value for the Loss of Thickness (mm) due to Corrosion for Piles and Sheet Piles in Freshwater or in Seawater

Required working life	5 years	25 years	50 years	75 years	100 years
Common fresh water (river, ship canal, etc.)	0.15	0.55	0.90	1.15	1.40
Very polluted freshwater (sewage, industrial effluent, etc.) in the zone of high attack (water line)	0.30	1.30	2.30	3.30	4.30
Seawater in temperate climate in the zone of high attack (low water and splash zones)	0.55	1.90	3.75	5.60	7.50
Seawater in temperate climate in the zone of permanent immersion or in the intertidal zone	0.25	0.90	1.75	2.60	3.50

Source: BSI (2007), Table 4-2, reproduced with permission from British Standards Institution.

recommended value for the loss of thickness due to corrosion for piles and sheet piles in water per Eurocode 3.

4.6.3 Data Summary

A summary of the various recommendations for corrosion rates in the splash zone from the sources noted previously is provided in Table 4-6:

Table 4-6. Summary of Corrosion Rates in the Splash Zone

Zone	in./year (ipy)	mils/year (mpy)	mm/year (mm/y)
High	0.06	60	1.50
Low	0.003	3	0.08
Average	0.016	16	0.41

Several of the references clearly indicate that steel intended for service in seawater tidal or splash zone locations should be coated. These include FDOT and CALTRANS. The FDOT Structures Design Guidelines state "Do Not Use" in its "Table of Additional Sacrificial Steel Thickness Required for Pipe and H-piles in Water (>2 ppt)" (Florida Department of Transportation 2011). The CALTRANS Memorandum to Designers states, "Steel piles should not be used in the splash zone unless alternative mitigation measures such as protective barrier coatings and/or cathodic protections are considered" (California Department of Transportation 2014).

Chemical, pollution, and high nutrient content have also been shown to increase the corrosion rate by "an order of magnitude," as quoted in a University of South Florida study for FDOT (Sagues, et al. 2009). For example, Beech and Campbell (Beech and Campbell 2008) found that the corrosion rates were 10 times higher in a particular part of a southern England harbor where sulfate-reducing and sulfate-oxidizing bacteria and higher concentrations of organic carbon were found. As noted previously, International Navigation Association (2005) addresses microbial-related corrosion. Although widespread, ALWC is not present in every location and must be investigated locally at the site.

It can be concluded that without site-specific studies focused on measuring the corrosion rate in the splash and tidal zones, data from other observations and research must be used cautiously and conservatively.

4.6.4 Corrosion Protection Systems

Corrosion protection is typically used for steel marine structures. This method of protection is effective and economical in particular zones. The various approaches often used include

- Cathodic protection,
- Jacketing or encasements,
- Coatings and wrappings, and
- Combinations of the aforementioned.

Cathodic protection (active or passive) can be used in the soil and submerged zones, but it is only partially effective in the tidal zone and not applicable in the splash or atmospheric zones. The design of a cathodic protection system is complicated and can have unwanted and unintended negative consequences. Cathodic protection systems (CPS) require periodic measurement, adjustment, and maintenance. (Note: annual maintenance and/or inspection after significant events are typically required for effectiveness.)

A passive CPS consists of bulk zinc or aluminum alloy blocks electrically connected to the structure typically by welding of a steel core. An active CPS uses a rectifier to convert the power source from alternating current to direct current that powers an underwater anode sled or deep well anodes or both. In this scenario the negative side of the cathodic protection battery is the steel structure, and the positive side is the impressed current through the anode. It is difficult to predict how effective the system has been over the years (especially true with active impressed current systems versus passive systems) without actual remaining steel thickness measurements, due to the absence of any visual changes to the anodes. Likewise for passive systems, it may be impossible to tell how long the system was ill maintained even if its anodes currently appear adequate.

Plastic coating is limited to use on pipe piles and H-piles. Concrete encasement is an effective but expensive means of providing protection.

Protective coatings offer a means of providing additional life to piles in marine environments at moderate additional first cost and can be reapplied as needed to those portions of the piles exposed to severe corrosion. Coatings generally have a service life of 20 years or less in the marine environment.

Table 4-7 provides *Unified Facilities Criteria (UFC) 4-151-10* approximate expected periods of protection (negligible loss of metal) afforded by various coating systems for marine exposure assuming the coatings are applied properly (DoD 2001).

Table 4-7. Period of Protection for Steel to Expect from Various Common Coating Systems

Coat Description	Period of Protection
Coal tar epoxy (15 to 20 mils thickness)	10–20 years
Galvanizing (7 to 9 mils thickness)	10–15 years
Metalized aluminum	15–20 years
Concrete encasement	25 years

Source: DoD (2001).

4.6.5 Original Service Life Calculation

The first step in calculating remaining service life is to calculate the expected life at the time of original construction using the data and recommendations provided in the aforementioned sections. Consider the following three possibilities for a steel pipe pile that was designed for service in the seawater splash zone where the bare steel corrosion rate is 5 mpy:

- Bare steel,
- Coal tar epoxy coating and sacrificial steel, and
- Concrete encasement and sacrificial steel.

4.6.5.1 Bare Steel Only In this case, corrosion of sacrificial steel is assumed to be average, at 5 mpy (0.005 ipy, 0.127 mm/y). If the record documents indicate how much steel was added for sacrificial purposes, the calculation is complete (sacrificial steel thickness/5 mpy = design service life). If the sacrificial steel thickness isn't provided or known, a structural analysis would need to be performed to determine the required thickness to support the various imposed loads. In either case, if the use of the structure has changed (e.g., the live load has increased or decreased), more or less sacrificial thickness may be currently available, which should be calculated. For this example, assume 1/8 in. (3 mm) of sacrificial steel thickness was provided in the original steel pipe pile design; a 5 mpy corrosion rate would yield a design service life of 25 years.

4.6.5.2 Coal Tar Epoxy Coating and Sacrificial Steel A review of the record documents may indicate the original coating thickness. (Note: The original coating may have been augmented over the years). However, if this information is not available, a coating thickness must be assumed. From Table 4-7, for this example, a coating thickness of 20 mils of coal tar epoxy will be assumed, which has a 15-year period of protection. The expected design service life would be the period of protection provided by the sacrificial steel plus the period of protection provided by the coating, or 25+15 = 40 years.

4.6.5.3 Concrete Encasement and Sacrificial Steel Similar to the previous coating example, a concrete encasement offers 25 years of service life. The encasement has to extend far enough below the intertidal zone to ensure that the expected life of the bare steel at the termination of the encasement is greater than the encasement in the splash zone. If this is not the case, then the corrosion rate of the steel for the zone in which the encasement ends is the lone factor in determining the service life. For the previous example, the expected service life is just 25 years, because the sacrificial steel within the encasement is never utilized. The reinforcement of the encasement itself is the governing factor. Caution should be taken as in some instances a partial jacket without an accompanying cathodic protection system may significantly accelerate corrosion due to the potential corrosion cell from the change in environment just below the jacket.

4.6.6 Remaining Service Life Calculation

Roughly speaking, the remaining service life is the expected service life at design less the current age. However, many assumptions are made in the calculation of the original service life. For a more accurate estimate of life expectancy, the simple model presented herein can be calibrated and modified with field measurements and results of site-specific studies. Additional data that could be collected and used include

- Measurements of actual site-specific bare steel corrosion rates;
- Measurements of remaining steel thicknesses in the splash zone, above and below;
- Measurements of remaining coating thicknesses; and
- The following data to a lesser degree as the effects of these are not well understood:
  - Currents, waves, and prop wash;
  - Measurements of salinity, water temperature, pollution, and other environmental data (including any changes over the time period in question); and
  - Stray current measurements.

If the data collected are representative of what was expected given the age, then the service life model can be expected to be fairly accurate. If the data collected differ from expectations, two possibilities exist: (1) the assumptions were not correct and should be adjusted or (2) something else is contributing to the anomalous data that must be reconciled before accepting.

4.7 TIMBER FACILITIES

4.7.1 Background

Research and development of methods and modeling to predict the service life of timber have not received the level of attention concrete and steel have received. Specific methods and criteria for determining the estimated or remaining service life of timber is highly dependent on engineering judgment, coupled with known environmental parameters and historical data for the specific structure and location being evaluated.

As with structures constructed of concrete and steel, several items affect the service life of timber structures, including design details, exposure variables, and modes of deterioration. Timber can be affected by one or more of the following modes of deterioration: mechanical, physical, chemical, or biological. Mechanical and biological degradation are the most common forms of timber deterioration and often work in concert with one another resulting in significant damage.

Mechanical degradation results from induced stresses caused by loading, which can be instantaneous, short-term, medium-term, long-term, or permanent. Typically, damage is caused only by the instantaneous and short-term loads such as berthing or impact forces. Biological degradation of timber results from attack by various destructive agents, including fungi, insects, bacteria, and marine borers. These agents attack timber, resulting in changes to the member cross section and/or material strength.

4.7.2 Service Life Estimation

As stated in the previous section, determining the service life of timber structures depends on several factors—especially past history, coupled with engineering judgment.

When investigating the existing condition of a timber structure, it is important to remember that, unlike concrete and steel, timber is a nonhomogeneous material, and timber degradation is typically random. Although patterns of deterioration are sometimes present (i.e., extensive damage of the lower connections on timber bracing in the intertidal zone but no comparable damage to the timber piling at this elevation), the location of the damage may be concentrated in a specific localized area of the structure (i.e., several adjacent, heavily damaged piles). This may be due to minute differences in environmental factors such as areas of hard driving due to rocky subsurface conditions that can damage the outer portions of piling, allowing breaches in the protective treatment and possible accelerated attack by marine borers. In addition, a portion of a structure may be constructed with timbers from a different treatment plant or from a different treatment batch, resulting in slightly different levels of protection. As a result, the use of sampling to determine the existing condition of a timber structure must be used with care, and obtaining any design information, historical information on construction of the structure, and data from any inspections that may have been conducted, is critical to providing additional information for assessing and determining the estimated service life of an existing structure.

Once information about a structure has been obtained, it can be used to estimate a rate of deterioration. Because timber is susceptible to several deteriorative processes, this estimate should account for all the deteriorative processes identified. In some instances, the remaining service life may be based on more than one rate of deterioration. As an example, structures in a marine environment often have a much different rate of deterioration affecting the substructure piles than that affecting the superstructure members (i.e., pile caps, stringers, and decking). Often the expected life of these two structural components is significantly different. However, once determined, these rates of deterioration can be used, along with engineering judgment and experience, to obtain an estimated remaining service life for the structure.

When determining the remaining service life of a timber structure, consideration should be given to the amount and type of anticipated maintenance repair work that will be conducted. The remaining service life of a structure that will not be maintained will obviously be less and, in many cases, much less than that of a structure that is routinely inspected and repaired (i.e., ongoing maintenance repair will reduce the effective rate of deterioration, thus extending the service life). Therefore, three types of analysis might be considered: (1) the current state of the structure, including damage and deterioration both above and below water, is assessed using an average rate of decay to date; (2) the structure can be evaluated assuming maintenance of only the worst case, critical damage; and (3) the structure can be evaluated based on the current conditions and assuming regular maintenance is conducted.

Several models exist to address and estimate the strength of timber under load. Because these models deal only with the strength of the timber over time, modifications must be made to incorporate the influence of deterioration and maintenance. Some success has been made by combining durability models with strength models to develop estimates of the remaining service life; research has been conducted in Canada and in Australia. The Forestry and Wood Products Research and Development Corporation (FWPRDC) conducted work in Australia that addresses fungal decay, termites, corrosion of fasteners, and marine borers. This work was developed utilizing various hardwood species and pine treated with chromated copper arsenate (CCA) that were subjected to coastal waters in Australia. The results were then compared with data on in-service marine pilings that, in a marine environment, are frequently the members that limit the service life of the structure. The studies indicate that even though several inherent uncertainties exist in determining the service life of timber structures, the findings generated by the study model provided good agreement with field data. This line of research may hold promise for the future and other locations but will require significant effort to determine estimated service life data for specific areas, regions, and environmental conditions.

In summary, by understanding a timber structure's historical information, including design, exposure, usage and rehabilitation, current inspected condition, and anticipated future use of the structure, an estimate can be made of its residual service life with the assistance of engineering experience and judgment.

CHAPTER 5
DOCUMENTATION AND REPORTING

5.1 GENERAL

An engineering report, including documentation, generally provides a systematically organized record of the inspection; the conditions encountered; the analyses, assessments, and judgments made by the responsible engineer; and recommendations for future use and remedial measures. Depending on the needs of the client, the report may range from a simple summary letter to a highly detailed narrative supplemented by extensive documentation of existing conditions, testing, and analyses.

The extent of the report should be determined by the complexity of the structure, the type of inspection, and the needs of the owner. Factors that may influence the choice of report format and detail include the owner's standards; the size, complexity, and importance of the structure; the existing condition; the anticipated use and distribution of the final report; and the potential for public involvement or litigation related to the facility.

The type of report may influence the extent of data collection and documentation work necessary. Even simple letter reports, which summarize the results of inspection and analysis activities, may require broad inspection and analysis activities as a basis for the report. The documentation of these activities may not be included in the final report but should be available to support the contents.

In the case of a Structural Repair or Upgrade Design Inspection, a formal report may be unnecessary, because the data collected is typically used to prepare a set of plans and specifications for construction.

5.2 ROUTINE INSPECTION REPORT

This section describes the contents of a comprehensive report for a Routine Inspection. It is beyond the scope of this manual to provide narrative for reports that discuss the findings of other types of inspections (Design/Upgrade, Construction, etc.). Reports for these inspections may contain many of the same items discussed herein. Some items may not apply to all reports, and additional items may be essential to certain reports. Though the length, detail, organization, and arrangement of specific items within a report may vary, reports should include the following sections:

- Executive summary,
- Introduction,
- Existing conditions,
- Evaluation and assessment,
- Recommendations, and
- Appendices.

5.2.1 Executive Summary

If the report is a comprehensive document, then an executive summary is commonly provided. This summary provides an up-front "snapshot" of the contents and findings of the report. By definition, the executive summary is brief, stating only the most basic information about the inspection, findings, and recommendations.

5.2.2 Introduction

The following items are typically provided in the introductory section of a Routine Inspection Report:

- Scope of work with enumeration of any items specifically excluded, limitations on inspection, or analysis dictated by the owner or site conditions.
- Description of the facility generally including drawings depicting the structural configuration of the structure. These drawings typically consist of a location plan, general plan(s), and cross sections through the overall structure sufficient to describe the basic features of the facility. A description of the functions and uses of the facility and design loads should also be provided.
- Listing of pertinent documents that includes original drawings, drawings of subsequent repairs or alterations, and previous reports pertaining to the facility.
- Description of inspection, testing, and analysis methods may be included in one or more appendices if lengthy.

- Administrative details including coordination and point-of-contact information (this information is sometimes provided in an appendix).

5.2.3 Existing Conditions

This section should include the results of the inspection, special testing accomplished in the field, and results of any laboratory testing. The inspection information should be reported in a factual manner without comment or analysis. This section serves as the basis for further assessment and evaluation and contains only data that are repeatable and would be accepted by another competent engineer conducting a similar inspection. These results should be documented with notes, sketches, photographs, and video as appropriate.

5.2.4 Evaluation and Assessment

This section should include an evaluation of the structure, based on the information described and gathered in the introduction and existing conditions sections. Each condition described in the earlier section should be evaluated and a statement made as to the effect of the condition on the capacity and serviceability of the structure. If the results of prior inspections are available, comments on changes since the previous inspections and estimates of the rate of deterioration should be included. If a reported condition does not have an adverse effect on the load capacity of the structure, this fact should also be stated.

This section may also contain narrative describing causes contributing to the observed conditions. The engineer's assessment of the structure and the rationale for that assessment should also be included. If a numerical Condition Assessment Rating system is used, similar to that described in Chapter 2, the rating should be assigned. The assessment should be based on engineering judgment and accepted standards of engineering practice.

5.2.5 Recommendations

This section should contain recommendations for future use (or restrictions on the use) of the structure; recommendations for repairs or replacement, including estimates of costs; recommendations for structural upgrades (when appropriate); and recommendations for the type of inspection and timing thereof.

5.2.6 Appendices

One or more appendices may be included containing data, analyses, and supporting information. They may include items such as environmental data, record drawings, detailed inspection procedures, a description of the rating system utilized, lists of defects, field and laboratory testing results and procedures, calculations, life-cycle cost analyses, detailed cost estimates, subconsultant reports, and references.

5.3 DOCUMENTATION

The type of report and extent of documentation should be defined in the scope of work. The type of documentation required can have a significant effect on the cost of conducting an inspection.

Detailed field notes and sketches should always be prepared and maintained as a record of the inspection. Written field notes should be prepared with the care that would be used for survey notes as they could become evidence in legal proceedings. The required level of detail will depend on the type of inspection being conducted. Notes prepared for an inspection made in anticipation of developing repair plans, specifications, and cost estimates (such as Structural Repair or Upgrade Design Inspection) would typically be prepared in greater detail than notes taken in support of a Routine Inspection.

Digital photography can be used to depict typical conditions and defects. Underwater photography in clear, calm water is simple when compared with taking photographs in turbid water—where special equipment such as a clear water box must be used. The importance of good-quality above- and below-water photographic documentation cannot be overstated. This is especially true when the description of findings will be digested by lay persons. Photographs are also extremely useful for illustration of existing conditions when developing repair documents.

Typical conditions should be photographed, but documenting every defect may not be necessary. A minimum number of photographs may be required at each structure, including general views of the facility. These are usually most effective when the photo is taken from a heightened perspective ("bird's eye view"). Photograph quality should be assessed prior to leaving the geographic area of the inspection.

Video recording may also be used for documentation, either alone or in combination with still photography. Additional time is required to view and edit the digital files. The video system should record both the inspector's comments and descriptions. Follow-on editing may be used to supplement the original comments. Scrutiny of video recordings should not be considered a substitute for "hands-on" inspection by qualified personnel, particularly for underwater inspections.

When using video recording, recorded footage not pertinent to the inspection report findings such as starting, stopping, moving, adjusting lighting, malfunctions, etc., should be deleted. An engineer or owner may quickly become disinterested in video recordings if they contain recorded material that is not pertinent. Originals of the video files should be maintained, but editing can be used to produce a video executive summary and to remove unessential footage. The use of an on-screen clock or counter is useful when reviewing the files and finding specific items.

5.3.1 Electronic Record Keeping

Hard copies of inspection records have been traditionally retained for the record. Although simple and to the point, the information is subject to loss, destruction, or misinterpretation due to the individuality of the inspector and the method of recording and maintaining the information. Inspection records are now often collected and maintained electronically. Furthermore, with various tools embedded in the software applications, the possibility of misinterpretation and data loss (or duplication) is greatly reduced if data is entered directly into the application in the field.

Spread Sheets. Spread sheets (such as Microsoft Excel) are the easiest way to set up and record information and are commonly used. Spread sheets can be rapidly configured to meet the requirements of the inspection project. Spread sheets have certain limitations: (1) the ease of setup and modification allows for potential corruption of the data; (2) they don't provide the capability to analyze the input information to ensure validity; (3) they have limited search capability; (4) they are considered "flat files" that have no relationship between various tables, meaning each record must contain all of the common information of the structure and offer no hierarchical presentation of data; and (5) they do not efficiently handle photos and other images.

Databases. Databases store and manage data according to the configurations of the particular application. The most prevalent small database application suitable for personal computer is Microsoft Access. Although the current version has many more features and operates with fewer problems than the original, it is still limited to a database of approximately 4 GB in size. When high-quality photos are stored, the storage capacity can be easily exceeded.

Other types of mainframe server implementations exist, such as SQL Server, that are virtually limitless in the number of records that can be handled. These databases are accessed from personal computers over a network or the Internet. They require IT expertise to set up and maintain. These servers easily store photos of any size, although transmission rates across the Internet may set a practical size limit.

Basic Architecture of the Inspection Database. The fundamental building block of the inspection database is the table. Like a spread sheet, it is simply an aggregate of columns and rows, typically referred to as fields and records. Unlike the spread sheet, the fields (columns) are uniquely defined and categorized as to the type of data. An inspection database would most probably include multiple tables. By relating the tables to one another, powerful search and sorting functions can be utilized to select specific data from the mass of information. Inspection data ranging from a simple structure to the entire inventory of a port can be stored and intelligently retrieved.

Reporting Data. Spread sheets have the simplest setup for printing, what you see is essentially what you get. However, multiple presentation formats of the same data are limited. Most database client applications also provide the capability to produce reports suitable for immediate printing. The report differs from the forms used for inputting data in that the report is read-only, formatted and optimized for printing, and typically provides various sorting and grouping of data capabilities that are not available in the forms. Reports can display most of the types of data that can be stored in the database, including photos.

Trends. With the increased use of in-the-cloud data storage and unlimited secure access over the Internet, the opportunities for setting up remote databases to warehouse an owner's inspection data is nearly limitless. Standardization of inspection protocols, such as provided by this manual, allows for rapid development of standard architectures, routines, and applications to be used in the database systems. Having a central server allows instant updates of the forms the user sees and the reports that can be generated. Multiple users can be easily accommodated at one time.

Although most applications present data in two dimensions using currently available technology, there is no reason why data cannot be presented in three dimensions, with fly-through or time stepping through the data showing changes between various inspections. The development of inexpensive tablet computers with very good embedded cameras, Internet access via WIFI or cell, and inexpensive custom applications, will allow inspectors to upload field data directly to the database. This approach will also allow the owner's maintenance or repair staff to access the information while on site.

5.3.2 Data Comparison over Time

Various inspections may have taken place for a specific facility over the course of years or decades. This creates an opportunity to "track the damage" and develop information that can be helpful in forming opinions as to future degradation and recommendations for repairs. If data is compiled in such a manner that allows for modification during future inspections, the information can be configured to provide "snapshots" of information at any particular time while allowing for subsequent alteration of the records to incorporate future degradation. Data that are developed to support this type of analysis must be prepared in a well thought-out and organized manner using software designed for this purpose.

CHAPTER 6
ADMINISTRATIVE CONSIDERATIONS

6.1 AGREEMENTS

The facility owner's employees or independent engineering consultants may conduct inspections. When consultants perform the inspection, a well-defined agreement is essential to a successful project.

A well-defined scope of work is also essential to a successful project. The contractual agreement based on the scope of work will specify certain tasks to be performed but should contain some provision for adjustment to scope and fee as the work progresses. Such an arrangement allows for additional testing and/or inspection should the need arise. An "additional services" provision in the contract is commonly used to address this potential need.

A scope of work generally contains the following items:

- **Description of facility.** A description of the facilities to be inspected, including extents and an estimate of the number and type of structural components (piles, fenders, etc.). Basic plans and photographs are of great value during the proposal process. When possible, this description should include basic information regarding marine environmental conditions (current, water visibility, etc.), access restrictions, and any other information relevant to execution of the work.
- **Pertinent documents.** A description of the content of previous inspection reports, if appropriate, for example, existing conditions, engineering assessment, recommendations, estimates of probable cost, and detailed lists of defects.
- **Engineer of Record.** A statement that all work shall be conducted under the direction and direct control of a civil/structural engineer licensed or registered in the jurisdiction of the facility.

- **Intent.** A statement of the purpose and type(s) of inspection(s), i.e., Routine, Construction, etc.
- **Meetings.** Number and types of meetings that will be required during the course of the project.
- **Limitations.** Acknowledgment that good engineering practice may, in some situations, not require inspection of all elements.
- **Deliverables.** A list of deliverables, for example, engineering report, repair drawings, and cost estimates.
- **Schedule.** Timeline for intermediate submissions and completion of the work, including a stipulation regarding the potential variability of weather conditions and the effects of same on the ability to execute the work.
- **Security requirements.** A description of any mandatory security clearance or specialized training required for personnel, vehicles, and/or boats to access the facility.
- **Safety requirements.** A description of any mandatory safety qualifications or on-site briefing required to work on site.
- **Additional services.** A clause stating that the extent of the inspections to be conducted may be revised, based on an initial field assessment. The work should be redirected to areas determined to have more significance on the condition of the structure.
- **Insurance requirements.** Statements listing the types and minimum limits of insurance required by the owner.

Above and below-water inspection of waterfront facilities is specialized work conducted in a challenging environment. The efficiency of the work can be impeded by weather-related conditions. This is particularly true for diving work, which can be greatly affected by cold water, currents, poor visibility, waves, and in-water boat traffic. Provisions should be included to compensate the consultant for variations in working conditions that are beyond control. The owner must provide timely access to the facility to be inspected, and the engineer should schedule the work to minimize disruption to other operations at the facility.

6.2 INSURANCE

The liability issues related to fieldwork typically involve the potential for accident and/or injury, whereas the liability associated with office-related work may involve issues concerning professional liability. Careful planning and conduct of the work can reduce liability, but insurance is highly recommended and often required by law. A thorough understanding of the appropriate insurance requirements is essential to protect employees, the general public, consultants, and owners/clients involved in the project.

The types of insurance coverage that will be required for a particular project vary but often include the following:

- Comprehensive general liability and property damage,
- Automobile liability and physical damage,
- Workers' compensation,
- Longshoremen and harbor workers' insurance,
- Jones Act maritime insurance (for vessels),
- Professional liability (errors and omissions),
- Contractor's pollution liability, and
- Railroad protective insurance (RRP).

Certain clients, including governmental agencies, may also require special types of insurance, such as railroad protective liability insurance or owner's and contractor's protective liability insurance. The insurance coverage, with appropriate monetary limits, is provided by individual policies for each of these categories or is sometimes provided by basic policies in conjunction with an umbrella policy to raise the limits of the underlying policies.

6.2.1 Comprehensive General Liability and Property Damage Insurance

Comprehensive general liability insurance can provide a wide range of coverage to protect consultants and owners from losses and claims alleging liability for bodily injury or damage to the property of others. This policy would normally cover damage caused by the consultant's operations, but special endorsements may be necessary to cover watercraft operations. Typical coverage limits range between $1 million to $5 million.

6.2.2 Automobile Liability and Physical Damage

Automobile liability insurance provides coverage to protect consultants and owners from losses and claims associated with vehicular accidents. This is important coverage, as divers and dive equipment are often transported to the project site by vehicle and, in many cases, dive equipment is directly operated out of a vehicle to support dive operations. Automobile liability insurance typically comes with two components to address bodily injury and property damage.

Bodily injury liability coverage addresses claims alleging liability for injuries and lost wages associated with a vehicular accident. This coverage is typically only for injuries to other people, as coverage does not apply to the consultant's own injuries.

Property damage coverage addresses claims alleging liability for property damage resulting from a vehicular accident but does not apply to the consultant's own property. Typical coverage minimums are $1 million for bodily injury and property damage liability.

6.2.3 Workers' Compensation Insurance

Workers' compensation insurance (WC) is a no-fault type of insurance that protects workers who suffer occupational injury, disability, or disease. If a worker is injured on the job, he or she does not have to prove the employer was negligent to be compensated for medical expenses and lost time, or for partial or complete disability. This is a state-mandated insurance requirement, and its benefits are administered by individual state boards. Workers' compensation provides coverage for work on land, and on, over, under, or adjacent to waters that are not considered to be navigable.

A waiver of subrogation endorsement, which prohibits the insurer from attempting to seek restitution from a third party that causes any kind of loss to the insured, may be required by the contract. The cost is typically 2% of the workers' compensation premium.

Workers' compensation rates for diving and vessel operations are typically expensive, on the order of 20 to 30% of direct labor costs. These rates apply even to somewhat low hazard types of underwater investigations, because engineers performing shallow underwater inspections are rated in the same classification as salvage divers dismantling a sunken ship under hazardous conditions.

6.2.4 Longshoremen and Harbor Workers' Insurance

Longshoremen and harbor workers' insurance (USL&H) is similar to workers' compensation insurance but provides coverage for employees working on, over, and adjacent to navigable waters of the United States. USL&H is federally mandated coverage and generally provides greater benefits to the employee than workers' compensation insurance. Its benefits are monitored by a federal board, but the coverage must be purchased from a private insurance company. Workers' compensation insurance coverage does not include USL&H coverage unless it is specifically added as an endorsement to the workers' compensation policy. The determination of applicability for state workers' compensation laws versus the USL&H Act is not clear-cut, especially in cases where the location of the injury or disability occurrence is not clear or where the limits of the navigable waterway are not well defined.

6.2.5 Jones Act Maritime Insurance

Jones Act maritime insurance is a no-fault coverage for employees, similar to WC and USL&H, except it covers employees who are members of vessel crews. Because divers and other inspection-related support personnel may work from a boat or a floating work platform, Jones Act maritime insurance may apply. Jones Act maritime insurance has generally not been considered applicable to inspection-related work unless the diver or inspector was regularly assigned to a vessel. Court decisions on this coverage have not been consistent, and prudence dictates that the coverage be provided for inspection work to prevent a possible gap in coverage.

6.2.6 Professional Liability Insurance (Errors and Omissions)

Professional liability insurance, sometimes called "errors and omissions insurance," provides owners with a means of protecting themselves from negligent or erroneous acts of engineering consultants on a project. It also serves to protect a consulting engineer from excessive losses resulting from claims by the owner or third parties. Professional liability insurance is not typically available to commercial divers or contractors attempting to provide engineering services.

If, for example, an engineer was negligent in the inspection and evaluation of a structure that was later associated with injuries, property damage, contractor's claims for extras, or owner's claims, the professional liability insurance, after satisfaction of a nominal deductible, would provide coverage against claims for the consultant and protection for the client or owner. Professional liability insurance limits of at least $1 million are typically considered to be the minimum coverage.

6.2.7 Contractor's Pollution Liability

Contractor's pollution liability insurance (PLI) covers events occurring in the field during inspection or similar work. This insurance covers pollution caused by the inspectors themselves or the equipment they are using. Examples include an oil discharge from the motor on the inspection boat, breakage of a hydraulic line from a hydraulic pack used for inspection equipment, or the accidental dislodging of contaminated materials into the water while cleaning or probing the structure. Pollution caused during or after construction because of a faulty design by the engineer would be covered under the professional liability insurance policy, providing pollution coverage has not been excluded. PLI does not cover pollution caused by the engineer while he or she is in the field.

6.2.8 Railroad Protective Insurance

When work takes place in close proximity to the right of way of a regulated railroad, railroad protective insurance (RRP) will most likely be required. The railroad will need to be listed as an "additional insured" under the policy. The insurance provides coverage for damage to the railroad's property and rolling stock and liability under the Federal Employer's Liability Act (should a railroad employee get injured). In some cases, a "hold harmless" agreement—indemnifying the railroad—may be used in lieu of RRP (at the discretion of the railroad).

6.3 CERTIFICATES OF INSURANCE

Certificates of insurance are issued by insurance companies or their authorized representatives, generally insurance brokers, as evidence of the insurance coverage provided by a company. The certificates show the types of insurance, the insurance company's name and policy number, the limits for each type of coverage, and the expiration date for each policy. The certificate should be issued in the client's name as the certificate holder and indicate the project for which it is issued. The certificate will also indicate the notification process that will be used to provide the certificate holder notice prior to cancellation of the insurance. Certificates may also indicate special endorsements such as the inclusion of other parties as "additional insureds."

Providing certificates of insurance is a routine procedure that is without cost to the insured. Facility owners should not accept certificates of insurance that are not addressed specifically to them; otherwise, the insurance could be canceled without their knowledge.

APPENDIX A

SPECIAL CONSIDERATIONS FOR SPECIFIC STRUCTURE TYPES AND SYSTEMS

A.1 INTRODUCTION

This appendix serves as a reference document for users and providers of waterfront facility inspection services. Its purpose is to provide a general description of the most common problem areas associated with structural components for specific structure types. Given the variety of structures in use and the multitude of conditions under which these structures are expected to perform, presenting an all-inclusive listing of what to look for during an inspection at a specific site is impractical. Instead, the information contained in this appendix could be used as a starting point for developing the scope and methodology of a particular investigation and location. In addition, the descriptions of common problems described herein refer primarily to considerations during a Routine Inspection and generally do not apply to other types of inspections, which may be focused in specific areas.

A.2 OPEN-PILED STRUCTURES

A.2.1 General

Open-piled structures generally consist of a solid deck supported on piles driven or drilled into the site soils. They are commonly used in various configurations such as piers, wharves, jetties, and dolphins (see Fig. A-1). Open-piled structures can be constructed of concrete, steel, timber, composites, or any combination of these materials. The superstructure (decking, beams, joists, etc.) and substructure (piles, bracing, pile caps, etc.) may be of different materials depending on design and use of the structure. To a large

Fig. A-1. Typical, open-piled concrete wharf with timber pile fender system Source: Courtesy of Simpson Gumpertz & Heger, Inc., reproduced with permission.

extent, deterioration patterns for the various structures are directly related to the materials used.

Horizontal loads may be distributed by either rigid or flexible deck diaphragms depending on construction type and configuration. These loads are resisted either by axial loading of batter (sloped or raked) piles or by a combination of bending and frame action of the plumb (vertical) piles. In some cases, bracing is provided to improve pile performance.

Typically, an underwater inspection team is responsible for inspecting the portions of the piles below the high water mark, although the exact demarcation can vary. An above water inspection team will usually perform the inspection of deck framing and decking of an open piled structure. For structures that do not extend far above the waterline, the underwater inspection team may inspect the entire pile. For tall ocean piers or similar structures with significant freeboard, inspection of the upper portions is not feasible from the water or by boat. In these cases, an above water team may employ special equipment to provide access from the deck above (see Fig. A-2).

A.2.2 Timber Structures

Timber structures are typically constructed with timber piles supporting pile caps, deck beams (stringers), and timber decking. On a typical timber dock, timber stringers are laid above and perpendicular to the pile caps and the decking is fastened directly to them. The structure is mostly held in place

Fig. A-2. Above water inspection team using a man lift to access the underside of a timber pier deck
Source: Courtesy of CH2M HILL, Inc., reproduced with permission.

by gravity, with lateral restraints between each member. Some steel connectors are provided to provide some load continuity, for example, drift pins and brackets between piles and pile caps, brackets between deck stringers and pile caps, and spikes between decking and stringers (see Figs. A-3 and A-4). Timber piles can be supported by bracing to reduce the effective length of the piles for vertical loads. Timber structures are subjected to rot, fungus, attack by marine borers, and other environmental factors. To provide a long service life, timber elements are typically treated with preservatives or wrapped. Table A-1 provides a summary of what to look for when inspecting the condition of timber open-piled structures.

A.2.2.1 Timber Piles and Bracing Timber piles are found on older structures or on lightly loaded modern docks. Timber piles are commonly used for breasting and fender systems as well. Timber piles are naturally limited in length and diameter by the available size of trees. Typical upper bound length is about 75 ft with nominal diameters ranging between 12 in. and 16 in. Timber piles naturally taper with length, with the smaller diameter being driven into the soil. Due to the limitation in element size, marine structures supported by timber piles often have a comparatively large number of closely spaced piles. This is often on the order of 10 ft on-center. Timber structures in deep waters are also typically braced.

To determine physical condition, inspect piles for rot; checking or splitting; abrasion; shell peeling; attack by marine borers; and vertical,

Fig. A-3. Typical connection detail of a timber wharf showing steel elements connecting a plumb fender and a battered pile to a pile cap (left); steel strapping securing a mooring cleat to the pile cap is also shown on the right
Source: Courtesy of Simpson Gumpertz & Heger, Inc., reproduced with permission.

Fig. A-4. A view of the underside of a typical timber wharf. Note the stringers spanning between pile bents. Bridging is provided at midspan of the stringers to stabilize the members during installation.
Source: Courtesy of Simpson Gumpertz & Heger, Inc., reproduced with permission.

Table A-1. Open-Piled Timber Structures: Checklist for Inspections

Section or Part	What to Look for	Comments
Piles	Damaged or missing piles, alignment (straightness) of piles from top to bottom, scour pits at mudline, pile-head bearing, fungal rot, and wrap conditions	Accelerated rates of deterioration in the splash zone and wet areas
Pile caps, stringers, and braces	Damaged, loose, or missing members; alignment of members along length (rotation); signs of distress at bearing areas; fungal rot on top surfaces or wet areas; deterioration at connections; condition of wrapping	Underside of low decks may need to be inspected by diver Undersides of high decks may need to be inspected by man lifts, snoopers, or other inspection access equipment
Deck	Damaged, loose, or missing members; alignment of members along length (rotation or sagging); rot; wear	Localized removal of deck coatings, surfaces or overlayments may be necessary to assess condition of supporting members Underside of low decks may need to be inspected by diver Undersides of high decks may need to be inspected by man lifts, snoopers, or other inspection access equipment
Over-dredging	Excessive dredging at the face of the structure	Measure mudline depths at the structure face and compare with design dredge depths for the structure

lateral, or rotational displacement. Also check for scour and undermining at the mudline, especially for piles along the berthing area subject to propeller wash and piles in strong currents. Check exterior and fender piles, particularly corner piles, for damage or abrasion from vessel contact, as they are especially vulnerable to this type of damage. Examine them closely for breaks or splintering associated with a hard impact. Examine fasteners to make sure they are not loose, damaged, or missing, or protrude at locations with the potential of damaging a berthing vessel. Also, check piles for bearing against the pile cap. Large gaps between the members might indicate damage to the pile below water or the loss of shims.

Inspection for rot and marine borer attack may require drilling into and/or sounding the pile as some damage is not evident from the exterior. For piles constructed of marine borer-resistant timber, or not exposed to borer attack, the key inspection areas are at the top of the piles and at connections to bracing members. For piles vulnerable to marine borer attack, the zone of highest deterioration is typically near the mudline and within the splash zone [generally, about 5 ft above and below mean low water (MLW)]. Pay close attention at locations where the piles are cut or altered for structural connections (e.g., holes for bolts, notches, tapers, etc.), as these locations provide direct exposure of the timber to the environment.

Inspect the overall condition of pile wraps, and assess their effectiveness at keeping marine borers away from the timber. Inspect the pile wrap for damage or deterioration, as these areas may allow marine borers to penetrate behind the wrap. Critical areas include the seams and lap splices of the wrap materials (see Fig. A-5). Also check steel bands or nails that are used to fasten the wrap for damage or deterioration. Loose or missing fasteners and bands may prevent a tight wrap. Depending on the thickness of the wrap material, assessing the condition of the pile can be difficult. In some cases, a sounding can give an indication of the condition of the pile immediately under the wrap. Thin wraps may also deteriorate from UV exposure; wrapped exterior piles with a southern exposure are especially vulnerable to this type of damage.

Inspect the bracing for severe damage or deterioration, misalignment or rotation, and evidence of overloading. Check connections between the bracing members and piles/pile caps for looseness or missing hardware. Braces are susceptible to damage at the location of the connection hardware and at the ends. Like piles, check the condition of wrapping for damage or deterioration.

A.2.2.2 Timber Pile Caps and Stringers Perform a general observation of the pile caps and stringers for severe damage or deterioration, misalignment or rotation, and evidence of overloading. Evidence of cap or stringer overloading may appear at points of maximum bending stress and maximum compression stress, appearing as cracking or sagging at mid span and buckling or crushing directly over supports. The upper surfaces of these members are also most susceptible to environmental deterioration. Timber pile caps and stringers are susceptible to rot at the bearing points, because water will dry slower at the contact surface between members. Also inspect

Fig. A-5. Typical timber pile with wrap damage; note wrap tear that originates from the nailed seam
Source: Courtesy of Simpson Gumpertz & Heger, Inc., reproduced with permission.

the connections, looking for loose, damaged, or missing hardware. Locations where these elements have been cut or altered for structural connections (e.g., holes for bolts, notches, tapers, etc.) are also vulnerable to damage, as these locations provide direct exposure of the timber to the environment.

A.2.2.3 Timber Decking Timber decking is typically fastened to timber stringers with spikes. Nominal sizes of 3 × 12 or 4 × 12 timbers are often used as decking on timber docks. Inspect the decking for damage, deterioration, misalignment or rotation, and evidence of overloading. Note loose planks; areas of rot; damage due to insect attack; and checking, splitting, and missing connection hardware. Decks supporting vehicles, especially forklifts, may sustain wear damage in the most heavily trafficked areas. Water ponding on the deck may be a sign of damaged stringers below. If the timber is covered with a layer of asphalt, inspect the asphalt for cracks, holes, or other obvious damage that may indicate distress of the underlying decking. Pay close attention to locations with expansion joints, railings, mooring equipment, drainage hardware, and other features of or attachments to the deck. These locations are vulnerable to damage and deterioration. The inspection team should look for missing, broken, or loose connections; obstructions; and other hazardous conditions of curbs, handrails, and

Fig. A-6. The deck of a typical timber wharf; note the numerous steel patches placed over worn, damaged, or deteriorated deck locations
Source: Courtesy of Simpson Gumpertz & Heger, Inc., reproduced with permission.

catwalks. Steel patches, as shown in Fig. A-6, placed over damaged deck areas are only cosmetic and do not provide any protection for the deck members. Patches should be removed as necessary to assess the extent of damage hidden underneath.

A.2.3 Concrete Structures

Concrete can provide a low-cost durable material for marine structures. Concrete open-pile structures are typically constructed with driven piles supporting a monolithic deck or framed deck system (Fig. A-7). Driven concrete piles can be prestressed to increase strength and performance. The deck of a typical concrete marine structure may be constructed of precast or cast-in-place elements, or some combination of the two. Table A-2 provides a summary of what to look for when inspecting the condition of concrete open-piled structures.

A.2.3.1 Concrete Piles Inspect concrete piles for structural cracks and spalls, corrosion, honeycombing, chemical deterioration, and abrasion damage. Check for vertical, lateral, or rotational displacement that may indicate underwater structural damage or overstress. Structural cracks or spalls can typically be found in areas of maximum moment for the piles, at the connection of the piles to the pile cap or deck, or at a location close to the

Fig. A-7. Open-pile mooring dolphin with monolithic deck and prestressed piles Source: Courtesy of CH2M HILL, Inc., reproduced with permission.

middle of the exposed length of the pile. Horizontal or diagonal cracking may indicate overstress of the pile in either bending or shear, respectively. Corrosion damage and deterioration is typically found in the splash zone and other areas where water may intermittently contact the piles. Longitudinal corner cracking is a common deficiency, where the corner reinforcing has corroded and expanded, popping off the unrestrained concrete corner. Check for scour and undermining at the mudline, especially for piles along the berthing area subject to propeller wash and to strong currents. Check exterior piles, particularly corner piles, for damage from vessel contact (Fig. A-8).

A.2.3.2 Concrete Pile Caps, Beams, and Deck Elements Concrete pile caps, beams, and deck elements form the superstructure of an open-pile concrete structure (Fig. A-9). Concrete pile caps are typically cast in place to accommodate construction and pile-driving tolerances. Concrete beams and decks can be either precast or cast in place. Some precast elements may also be prestressed. Precast beams supporting flat deck panels and spanning between cast-in-place pile caps is typical, simple to construct, and very cost effective. Hollow core panels may also be used to save weight with increased span of deck planking. Cast-in-place concrete decks are typically used to form continuous monolithic deck slabs for structures supporting large deck loads, such as container wharves.

Inspect all concrete components of the superstructure for structural cracks and spalls, corrosion, honeycombing, chemical deterioration, and

Table A-2. Open-Piled Concrete Structures: Checklist for Inspections

Section or Part	What to Look for	Comments
Piles	Damaged or missing piles, spalling, alignment (straightness) of piles from top to bottom, scour pits at mudline, corrosion, spalling, impact damage, cracking	Accelerated rates of deterioration in the splash zone and wet areas
Pile caps, stringers, and braces	Damaged or missing members, alignment of members along length (rotation), signs of distress at bearing areas, corrosion, spalling, impact damage, cracking	Underside of low decks may need to be inspected by diver Undersides of high decks may need to be inspected by man lifts (see Fig. A-2), snoopers, or other inspection access equipment
Deck	Damaged or missing members, alignment of members along length (rotation or sagging), corrosion, spalling, impact damage, cracking, expansion joint condition	Underside of low decks may need to be inspected by diver Undersides of high decks may need to be inspected by man lifts (see Fig. A-2), snoopers, or other inspection access equipment
Over-dredging	Excessive dredging at the face of the structure	Measure mudline depths at the structure face and compare with design dredge depths for the structure

abrasion damage. For concrete deck and beam elements, note size of cracks, spalls (open and closed), areas with leakage, staining, exposed reinforcing bars, delamination, or other signs of corrosion of the reinforcement. For reinforced concrete decks, also inspect the underside of the deck, as this area is especially vulnerable to corrosion damage (Fig. A-10). The underside of the deck should be sounded at any locations that are suspected

Fig. A-8. Severely damaged concrete pile from vessel impact
Source: Courtesy of Simpson Gumpertz & Heger, Inc., reproduced with permission.

to be hollow. The concrete cover from representative closed spalls should be removed to observe the level of corrosion of the underlying reinforcing bars.

Connections of precast elements require special attention. Connections are typically vulnerable to corrosion deterioration and require special attention during inspection. Loss of cover, spalling, and heavy streaking from connection locations may warrant further investigation to confirm the adequacy of a connection.

Fig. A-9. Below deck of a concrete deck showing piles with capitols
Source: Courtesy of Simpson Gumpertz & Heger, Inc., reproduced with permission.

A.2.4 Steel Structures

Steel structures are typically constructed with piles supporting pile caps, deck beams, and steel grating for decking (Fig. A-11). On a typical steel-framed dock, steel beams may be bolted perpendicular to and between the steel pile caps and used to support the deck. The structural members are typically connected by welding or bolting. Steel piles might be supported by bracing to reduce the effective length of the piles for vertical loads. Steel structures are subject to corrosion, abrasion, and other environmental factors. Table A-3 provides a summary of what to look for when inspecting the condition of steel open-piled structures.

A.2.4.1 Steel Piles Steel piles can be found in a wide range of sizes, shapes, and grades of steel. Pipe piles and H-piles are the most common sections used. Inspect all steel piles for vertical, lateral, or rotational displacement. Check for scour and undermining at the mudline, especially for piles along the berthing area subject to propeller wash and piles in strong currents. Check exterior piles, particularly corner piles, for damage from vessel contact.

Check steel piles for corrosion (Fig. A-12), local and global buckling, and cracks or damage at the connection of the steel piles to other members. Use calipers and scales to determine the remaining thickness of flanges, webs, and stiffeners of H-piles. Use ultrasonic testing to determine the remaining thickness of pipe piles or to record more accurate thickness of

Fig. A-10. Corroded underside of concrete deck
Source: Courtesy of CH2M HILL, Inc., reproduced with permission.

H-piles. If the structure has a cathodic protection system, test and document the system's condition with an underwater voltmeter after removing marine growth. Key inspection elevations for corrosion deterioration are at MLW and MHW levels. These areas typically experience the highest rate of corrosion metal loss, especially in seawater. Other locations vulnerable to corrosion include periodically wet locations, welded connections with poorly matched materials, or connections where dissimilar metals can cause

Fig. A-11. Steel ocean pier; note height of deck that cannot be adequately inspected from water or shore
Source: Courtesy of CH2M HILL, Inc., reproduced with permission.

galvanic corrosion processes. The latter condition can often be found at metallic appurtenances, for example, a stainless steel ladder connected to a carbon steel pile. Also inspect connections for evidence of overstress or damage, for example, fracture of welds.

A.2.4.2 Steel Framing, Bracing, and Decking Perform a general observation of the steel framing and bracing for severe damage or deterioration, misalignment or rotation, and evidence of overloading. At the caps and beams, evidence of overloading may appear at points of maximum bending stress and maximum compression stress as buckling or sagging at mid span between piles or bents and buckling or crushing directly over piles. Inspect welded or bolted connections between the piles, pile caps, and deck beams. Typically, these members are located above the waterline and can be inspected from a workboat as part of the above water inspection. However,

Table A-3. Open-Piled Steel Structures: Checklist for Inspections

Section or Part	What to Look for	Comments
Piles	Damaged or missing piles, alignment (straightness) of piles from top to bottom, scour pits at mudline, corrosion, pitting, impact damage, condition of coatings and wraps	Accelerated rates of deterioration in the splash zone and wet areas
Pile caps, deck framing, and bracing	Damaged or missing members, alignment of members along length (rotation), signs of distress at bearing areas, corrosion, pitting, impact damage, condition of coatings	Underside of low decks may need to be inspected by diver Undersides of high decks may need to be inspected by man lifts, snoopers, or other inspection access equipment
Over-dredging	Excessive dredging at the face of the structure	Measure mudline depths at the structure face and compare with design dredge depths for the structure

if the deck is located significantly above the water, other means of accessing these areas for inspection may be required.

Check all steel members for corrosion (Fig. A-13). Use calipers and scales to determine the remaining thickness of flanges, webs, and stiffeners. Use ultrasonic testing to determine the remaining thickness of hollow steel section (HSS) elements or to record more accurate thickness of other steel elements. If the structure has a cathodic protection system, test and document the system's condition. Locations vulnerable to corrosion include wet locations, welded connections with poorly matched materials, and connections where dissimilar metals can cause galvanic corrosion processes. The latter condition can often be found at metallic appurtenances, e.g., a stainless steel ladder connected to a carbon steel pile. Also check connections for evidence of overstress or damage, e.g., fracture of welds.

Steel decks are used on some structures and often include steel grating. For steel grating, areas of severe corrosion, overloading, or loss of paint or

Fig. A-12. Pitting and splash zone corrosion of steel pile
Source: Courtesy of Simpson Gumpertz & Heger, Inc., reproduced with permission.

Fig. A-13. Corrosion of steel bracing
Source: Courtesy of Simpson Gumpertz & Heger, Inc., reproduced with permission.

other protective coatings should be documented, especially at grating connections, which are easily damaged.

A.2.5 Composite Structures

Composite piles and beams have entered the market as a viable alternative to timber for the load-bearing parts of light structures and in other areas where timber is commonly used. Composite materials have the advantages of resistance to corrosion and marine borers, strength greater than that of timber, and low maintenance costs. Composite members are usually built up from a recycled plastic matrix with glass fiber reinforcement bars and a low friction skin. Table A-4 summarizes what to look for when inspecting the condition of composite structures.

Composite piles can be used as fender piles, load-bearing piles for light structures, floating camels, or as elements in pile cluster dolphins. Composite beams can be used as load-carrying members in light structures, rubbing surfaces to protect structures, or as elements in large built-up camels.

Composite members should be inspected for signs of overloading, chemical degradation, abrasion, and general wear. Vulnerable areas include connections and locations where the structural elements have been cut, drilled, or otherwise modified. Elements with significant exposure to sunlight may show signs of UV deterioration. Composite decking elements and panels often show signs of deterioration at support points,

Table A-4. Open-Piled Composite Structures: Checklist for Inspections

Section or Part	What to Look for	Comments
Piles	Damaged or missing piles, alignment (straightness) of piles from top to bottom, scour pits at mudline, impact damage, abrasion, wear, UV damage	
Other structural elements	Damaged or missing members, alignment of members along length (rotation), signs of distress at bearing areas, impact damage, abrasion, wear, UV damage, connections	Connections are vulnerable to deterioration The composite decking elements are vulnerable to deterioration at support points

frequently requiring removal of restraining clips and select elements for closer examination.

A.3 RELIEVING PLATFORMS

A.3.1 General

Relieving platforms are a variation on the open-pier structure (see Fig. A-14). A typical open pier has a high deck at the elevation of the working surface of the pier; however, a relieving platform has a low deck, usually located in the tidal zone. Soil or sand is placed over the low deck and filled to the working deck elevation. A working surface is then placed over the top of the soil. The seaward edge of the relieving platform has a seawall to retain and protect the fill against erosion. This type of structure can be used for wharf or pier construction. Vertical live and dead loads are usually supported by vertical piles. Materials used to construct relieving platforms include steel, concrete, and timber. When used to build a wharf, a sheet pile wall is usually either at the face of the wharf or at the inshore side of the wharf. Lateral earth pressure from the retained soil of the sheet pile is resisted by batter piles; an anchorage system, for example, a tie rod or deadman system; or drilled and grouted earth anchors.

Fig. A-14. Deteriorated relieving platform
Source: Courtesy of Childs Engineering Corp., reproduced with permission.

Relieving platforms inherently have high dead loads due to the soil fill. This type of structure has some advantages, such as the wide distribution of wheel loads and point loads through the fill. Also, for timber structures built in freshwater, the entire structure can be built under water or just above the low tide mark, thus helping to preserve the timbers. At the beginning of the 20th century, this type of structure was quite popular for pier and wharf construction. Many timber relieving platform structures are more than 100 years old and still in use.

A.3.2 Typical Components and Problem Areas

Relieving platforms should be inspected in a manner similar to open-piled structures. However, unique considerations for relieving platforms are presented in the following sections. Table A-5 summarizes what to look for when inspecting the condition of these structures.

A.3.2.1 Access Due to the low deck nature of this type of structure, inspection of the exposed components can be difficult and often requires the use of divers using penetration diving techniques (see Fig. A-15). On older timber structures, pile spacing is typically very tight, limiting diver access. A tendency also exists for debris to be entrapped under these structures, further restricting access.

A.3.2.2 Lateral Stability This structure type resists lateral loads from earth pressure and is susceptible to sudden collapse. On timber structures, signs of lateral instability include the presence of nonbearing piles, overstressed batter piles, crushing of pile caps, and separation of pile cap splices. On all relieving platforms, monitor the alignment and settlement of the seawall or face of the structure for movement that would indicate impending failure. Document cracking in paved deck surfaces. Cracks running parallel to the structure face indicate lateral movement.

A.3.2.3 Over-Dredging Determine the design dredge depth at the face of the structure and then check for compliance. Take soundings along the wall to determine that the mudline at the toe is at the proper elevation. A lower dredge elevation than the design increases the effective column length of the piles, resulting in overstressed piles. Over-dredging also increases lateral loading on structures with sheet piles retaining fill. Timber relieving platforms are particularly susceptible to failure as a result of over-dredging.

A.3.2.4 Settlement and Sinkholes Localized settlement and/or formation of sinkholes on the deck of a relieving platform occur when fill migrates through the deck. On timber structures, this is often caused by failure of a deck plank or separation of two adjoining planks allowing fill to

Table A-5. Relieving Platforms: Checklist for Inspections

Section or Part	What to Look for	Comments
Piles	Corrosion, spalling, impact damage, cracking, cathodic protection, coating, pile head bearing conditions (timber piles), fungal rot	Look for overstressing at bearing areas and indicators of lateral movement and determine cause of deficiencies
Deck	Spalling, cracking, fungal rot, separation, fill loss	Excavation will be required for examination
Seawall	Alignment, settlement, spalling, cracking	Check the face for plumbness and check joints for alignment and settlement
Sheet pile	Corrosion, spalling, interlock separation, impact damage, cracking, alignment, cathodic protection, coating, fungal rot	Look for gaps and spaces between concrete or timber sheets, check for interlock separation on steel sheets, and check for corrosion holes and associated sink holes
Pavement	Sinkholes, cracking, settlement	Cracking parallel to the structure face indicates lateral movement
Over-dredging	Excessive dredging at the face of the structure	Measure mudline depths at the structure face and compare with design dredge depths for the structure

be lost. On concrete decks, the fill could migrate through an expansion joint or possibly a weep hole. Excavation may be required to determine the cause of the sinkhole.

A.4 BULKHEADS AND RETAINING WALLS

A.4.1 General

Bulkheads are tension-retaining wall structures constructed of vertical interconnected sheets driven into site soils. The sheets are backfilled on one

Fig. A-15. Underside of relieving platform at extreme low tide; access and inspection of deck components can be difficult and often requires penetration diving techniques
Source: Courtesy of Childs Engineering Corp., reproduced with permission.

side and can be either anchored or cantilevered. Anchored sheets rely on an anchorage system combined with the strength of the sheet to maintain stability. The toe of the sheet pile relies on passive earth pressure to maintain stability. Anchored bulkheads have an anchor rod connected to the sheet, typically as far below the top of the sheet as practical for constructability, usually in the tidal zone for waterfront structures. Anchor systems can consist of steel tie rods connected to a deadman or drilled anchors set in earth or rock. Deadman anchors are often constructed from concrete in the form of blocks or cast-in-place walls. A deadman can also be constructed from piles. Drilled anchors consist of either a steel rod or steel strands placed in drilled holes and grouted to mobilize soil or rock resistance. Helical anchors can also be used to anchor a bulkhead. The cantilever bulkhead (Fig. A-16) does not have an anchor system and instead relies on the bending strength of the sheet and the embedment of the sheet into the bottom for stability. Bulkhead sheets have been constructed from steel, concrete, fiber-reinforced polymer (FRP), vinyl, and timber.

Soldier-beam retaining walls are considered bulkheads as they are a flat, vertical surface and are tension structures. Typically, these structures consist of steel H-piles driven at regular intervals along the bulkhead line with panels or slats placed between the flanges of the H-piles to retain soil. This type of structure is often used as shoring for deep excavations.

Fig. A-16. Steel sheet pile bulkhead structure with concrete cap beam
Source: Courtesy of Childs Engineering Corp., reproduced with permission.

Some bulkheads are constructed of combined systems incorporating a combination of steel Z-sheets and H-piles, pipe piles, or box piles. This type of system may be chosen for increased bending capacity or for increased axial load-bearing capacity.

Typically, the exposed components of a bulkhead are limited to the sheet piles and exterior components of the anchorage system, such as wales and tie rod ends. The overall stability of the structure should be checked for stability issues such as rotational failure, general settlement, or anchor system failure.

A.4.2 Typical Components and Problem Areas

The inspection of retaining walls and bulkheads should be performed using a method similar to that of the inspection of open-piled structures, by inspecting as much of the wall as possible during the above water inspection at low tide and performing an underwater inspection of the remainder of the wall. Make a general observation of the wall for misalignment of the overall structure and plumbness of individual elements making up the bulkhead or wall system. Document differential settlement between elements and displacement or severe damage by vessel impact or other means. The general observation of the wall should include an observation of the fill behind the wall, noting any signs of loss of fill such as depressions or sinkholes. Table A-6 provides a summary of what to look for when inspecting the condition of these structures.

Table A-6. Bulkheads and Retaining Walls: Checklist for Inspections

Section or Part	What to Look for	Comments
Sheet piling	Corrosion, interlock separation, impact damage, cracking, local overstressing, alignment, cathodic protection, coating, clear weep holes, rot	Identify component sizes, quantify deficiencies noted, and determine cause of deficiencies
Anchorage system	Corrosion, cracking, local overstressing, displacement	Excavation may be required for examination
Backfill	Sinkholes, settlement	Look for associated holes or damage on adjacent sheet piles
Geometry	Plumbness of face, bulges, over-dredging, scour	Changes in structure geometry are indications of failure of one or more structural systems
Concrete cap	Spalling, cracking, alignment	Cracking and misalignment are indications of structural failure

A.4.2.1 Corrosion Corrosion is a major cause of failure or loss of strength to bulkhead and retaining wall structures (Fig. A-17). Steel components of bulkheads should be investigated for loss of a section due to corrosion. Measure the steel thickness using nondestructive methods, such as ultrasonic testing, using a procedure that will result in a representative view of the steel losses due to corrosion. Give special attention to high-stress areas such as the exposed anchorage system components like tie rods and wales. Key inspection elevations are at MLW and MHW levels. These areas typically experience the highest rate of corrosion metal loss, especially in seawater. Also, check the condition of coatings and other measures to slow corrosion, for example, anodes, cathodic protection potentials, etc.

A.4.2.2 Anchorage System The anchorage system for a bulkhead is critical to its function. The tie rods and wales, if exposed, should be examined to determine loss of steel, distress such as localized buckling, and deformation. Hidden components, such as tie rods, interior wales, and

Fig. A-17. Severely deteriorated steel sheet pile bulkhead
Source: Courtesy of CH2M HILL, Inc., reproduced with permission.

deadman anchors, require excavation to examine. Bolts attaching interior wales should be closely examined.

A.4.2.3 Geometry Observations should be made of the structure's plumbness and alignment. Variations in the geometry of the structure can indicate failure of one or more vital components. If the face of the sheet pile is out of plumb, it could indicate a failure at the toe of the wall or a failure of the anchorage system, depending on the direction of the movement. Bulges in the alignment of the top of the bulkhead can indicate failure of one or more tie rods.

A.4.2.4 Settlement Settlement and/or the development of sinkholes directly behind a bulkhead indicate loss of fill through the structure. This could be caused by corrosion holes in the sheets with the fill washing out or possible separation of the sheets. In these areas, the sheets should be investigated for anomalies that could result in loss of fill.

A.4.2.5 Concrete Cap Defects Cast-in-place concrete caps are often used to maintain alignment at the top of a bulkhead. The concrete should be checked for corrosion-related spalling. Also check the concrete cap for cracking and misalignment at cracks that may be an early indication of settlement, lateral failure, anchor system failure, or impact.

A.4.2.6 Over-Dredging Bulkheads are very sensitive to over-dredging at the toe of the wall. One of the purposes of conducting an underwater inspection of a bulkhead or retaining wall is to investigate the condition at the base of the wall. Loss of foundation support at the toe of the structure from over-dredging or excessive scour can initiate instability and excessive stresses in the wall, resulting in bulging and overstressing in sheet piling. Soundings should be taken along the wall to determine that the mudline at the toe is at the proper elevation. Over-dredging can cause failure of the bulkhead by increasing soil pressure beyond design limits.

A.4.2.7 Impact Damage Because bulkheads are used on the waterfront as berthing structures for ships, impact damage is common, particularly when the ships have bulbous bows. Typically, this will result in cracking of the concrete cap or dented, deformed, or broken sheets.

A.4.2.8 Hydrostatic Relief Ports Some bulkheads are designed with hydrostatic relief ports or weep holes. These ports are used to relieve water pressure from behind the sheets and thereby reduce the overall pressure on the wall. The ports should be observed to ensure that they are not clogged and allow water to freely vent through the port.

A.5 SEAWALLS AND REVETMENTS

A.5.1 General

Seawalls and revetments function as barriers against the sea to prevent erosion of land area or damage to structures (Fig. A-18). Typically, this type of structure needs to be substantial to resist wind, wave, and ice forces. The outside shape of seawalls varies and can be designed to reflect or redirect the energy of the waves away from the shoreline. Revetments are protected slopes typically consisting of riprap or gabions (rock-filled wire baskets).

Types of structures used to build seawalls include gravity retaining walls, cantilever retaining walls, and pile-supported retaining walls. Many seawalls have a sheet pile cutoff wall incorporated into their foundations to prevent undermining and to maintain stability. The design also accounts for overtopping of waves and the associated drainage issues to allow water to drain back to the sea without causing damage to the structure. Many seawalls incorporate several types of construction such as a combination of a gravity retaining wall and armor stone at the toe.

The most common material used to build seawalls is concrete. In the past, stone was used extensively due to its durability. Stone is also used at the toe of many seawalls to prevent scour and dissipate wave energy. Alternatives to armor stone are often precast concrete shapes that are placed at the toe of a seawall.

Fig. A-18. Mass concrete seawall
Source: Courtesy of Childs Engineering Corp., reproduced with permission.

A.5.2 Typical Components and Problem Areas

The inspection of seawalls and revetments should be performed using a method similar to that of the inspection of retaining walls and bulkheads, by inspecting as much of the structure as possible during the above water inspection at low tide and performing an underwater inspection of the remainder. Make a general observation of the wall for misalignment of the overall structure and plumbness of individual elements making up the bulkhead or wall system. Note differential settlement between elements and displacement or severe damage by vessel impact or other means. The general observation of the wall should include an observation of the fill behind the wall, noting any signs of loss of fill such as depressions or sinkholes. Perform a general inspection of the revetment slope for alignment, signs of settlement or instability (slip failures), areas missing the protection layer, and signs of erosion at the toe of the slope. Where gabions are used, note the general condition of the wire baskets. The baskets are susceptible to corrosion and abrasion, potentially causing unraveling of the revetment. Table A-7 summarizes what to look for when inspecting the condition of these structures.

A.5.2.1 Access Many seawalls are located in very exposed locations, subject to significant wind, current, and wave action. Underwater inspection of these structures can be extremely hazardous, requiring specialized diving techniques.

Table A-7. Seawalls and Revetments: Checklist for Inspections

Section or Part	What to Look for	Comments
Seawall face	Erosion, spalling, cracking, missing blocks, cracked blocks	Assess the material condition for structural integrity; additional testing, such as concrete coring, may be warranted
Seawall top	Plumbness of face, bulges, misalignment, settlement	Identify causes of deficiencies Additional investigation, such as survey, soil borings, or other testing, may be required Monitoring over time may be required to determine if the anomaly is active or stable
Seawall toe	Scour, undermining, armor stone displacement	The mudline in front of the seawall should be evaluated to ensure that design parameters are maintained; survey and document loss of material in front of the seawall
Backland or paved areas	Sinkholes, settlement, drainage	The deck surface behind a seawall is susceptible to loss of fill through openings in the wall or erosion of soil by overtopping water; drains and scuppers should be inspected to make sure they are able to vent floodwater
Weep holes	Clogging	Weep holes are placed to relieve hydrostatic pressure on the wall and should be observed to make sure they are free-draining

A.5.2.2 Seawall Face The exposed face of a seawall is typically a flat or curved surface. Concrete seawalls are susceptible to erosion and corrosion-related spalling.

A.5.2.3 Seawall Toe The toe of the seawall is susceptible to wave action and moving water and should be observed for the effects of scour and undermining. Take soundings along the wall to determine that the mudline at the toe is at the proper elevation.

A.5.2.4 Armor Stone Armor stone, if present, should be observed for displacement. For the armor stone to be effective, it needs to be maintained in position. If settlement is present due to scour or if the stone is being moved by wave forces, document the locations. General size and type of stone should also be determined to verify that the planned protection has not been replaced by unplanned deposits.

A.5.2.5 Pile Foundation Pile foundations for seawalls should not be exposed. If scour and undermining exposes the piles, take measurements to monitor further erosion.

A.5.2.6 Backland Areas Signs of settlement and sinkholes behind the seawall should be looked for. This is evidence of loss of expansion/construction joint fillers or broken/displaced drainage piping, which allow the fill to wash away.

A.5.2.7 Alignment and Settlement Seawalls should be checked and monitored over time for changes in alignment and settlement. Any significant movement of the structure indicates failure and, if not corrected, could lead to the eventual loss of the structure.

A.6 GRAVITY BLOCK WALLS

A.6.1 General

Gravity structures are systems that rely on their weight for stability. The structures can be formed with a wide variety of materials but are often constructed with stone or concrete masonry units or "blocks." Utilizing its own weight for stability, gravity block systems typically are founded directly upon the bearing substrate or on a mat or crib-type foundation, distributing the somewhat large dead load of the structure to the underlying bearing stratum. Gravity block walls are traditionally used as retaining structures to form seawalls or quay walls but can be used to form piers, jetties, marginal wharfs, breakwaters, and numerous other applications in the marine environment. A typical gravity wall section is shown in Fig. A-19.

Throughout the 19th century, stone masonry was generally used in constructing graving docks, seawalls, quay walls, and wharves. Gravity block walls were historically built with cut granite stone founded on placed or sunken timber mats or cribs but more recently are constructed with cut granite, limestone, or precast concrete. As late as the 1850s, cut stones of granite were set in lime mortar; after that, they were set in portland cement mortar.

This type of structure was widely considered more appropriate in areas subject to severe wind, wave, ice, and other environmental conditions

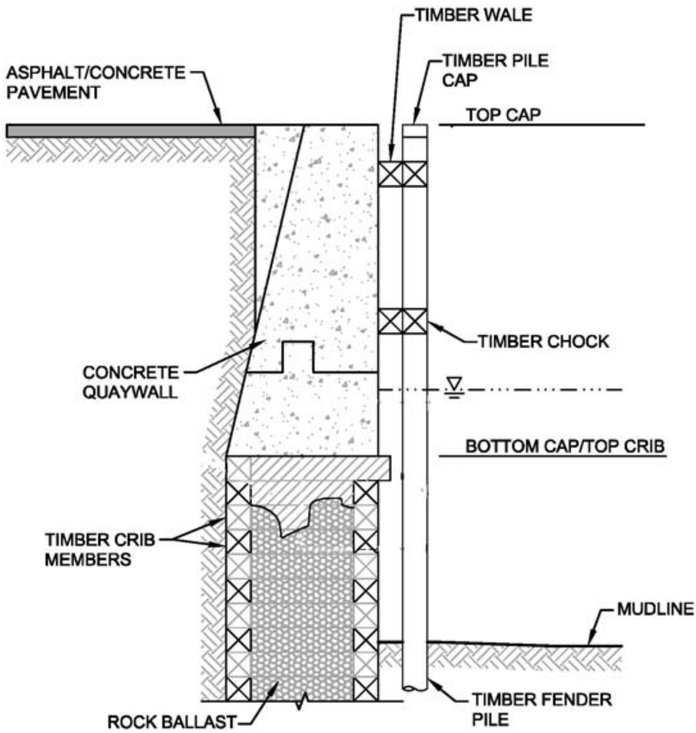

Fig. A-19. Cross section of a typical gravity structure
Source: Courtesy of Marine Solutions, Inc., reproduced with permission.

considered too harsh for timber or steel bulkheads. Prior to techniques allowing bulkhead type walls to accommodate greater freestanding heights, gravity type walls were commonly used for walls more than 40 ft in height and were often used for graving docks when significant below-grade construction was necessary. Modern steel, precast concrete bulkheads, and cast-in-place concrete construction technologies have extended their applicability into areas that, in the past, required gravity type construction.

A.6.2 Typical Components and Problem Areas

As with other marine structures, deterioration of gravity block walls directly depends on the material used in the construction, construction techniques, and the environment to which it is subjected. However, some of the typical problem areas that are common to this specific type of structure, and not necessarily related to material degradation, are briefly described in the following sections. Table A-8 summarizes what to look for when inspecting the condition of these structures.

Table A-8. Gravity Block Walls: Checklist for Inspections

Section or Part	What to Look for	Comments
Wall system	Sweeping, bowing, leaning, misalignment, settlement, localized collapse	If identified, the cause should be determined and the inspection should specifically look for secondary damage such as cracking and loss of blocks Consider the landward area affected by the loss of lateral support; a survey and periodic monitoring may be required to determine if wall movement is active
Backfill	Depressions, sink holes, surface tensile cracking parallel to wall, joint separation, drainage conditions	Causes of backfill problems may not be evident by visual inspections of the wall; excavations, geotechnical borings, or ground-penetrating radar may be utilized
Blocks	Weathering, cracks, common precast concrete defects, erosion, displacement, reinforcement corrosion, interlock shear	Cracking and displacement of blocks are often the secondary result of other problems; conditions that may affect block interlock or friction should be considered
Mortar	Loss, degradation, shrinkage, crushing, leakage	The results of settlement, unleveling, and differential stresses placed on blocks from mortar loss should be considered
Drains	Obstructions, evidence of activity, direction, adequacy	Drain conditions may be a contributing factor to other problems
Joints	Separation, displacement, leakage, filler condition, vegetation	Water staining at joints may indicate the extent of hydrostatic levels behind the wall; loss of fill through joints may be the cause or contributor to backfill problems

Table A-8. Gravity Block Walls: Checklist for Inspections *(Continued)*

Section or Part	What to Look for	Comments
Channel bottom	Backfill deposits, scour, undermining, heaving	The depths and general contours of the channel bottom should be considered to at least 1× the wall height outboard from the wall The actual or likely original design elevation of the channel bottom at the toe of the wall should be compared with current elevations
Foundation	Integrity of members, loose or missing members, voids, loss of ballast, settlement, bearing contact	Both vertical and lateral stability and load-bearing capacity should be considered; degradation of foundation members should also be considered

A.6.2.1 Sweeping, Bowing, Leaning, and Settlement Due to the nature of gravity structures, problems with global stability, differential settlement, and foundation support are some of the most common causes of failure. These problems often first manifested as vertical (bowing) or horizontal (sweeping) bulging, misalignment, and/or a change in the plumbness (leaning) of the wall, and they can occur gradually over time or suddenly at any point in the structure's life. Figure A-20 shows a masonry block wall that has settled and is bowing.

The elevation, alignment, and plumbness of the wall should be specifically monitored during periodic inspections such that small movements can be monitored. The landward area supported by the wall should be monitored for settlement, depressions, and sinkholes. Lateral movement can often be observed first by increases in the width of the joint between the upland surface and cap or top course of the wall. Often, tensile cracking parallel to the wall will also develop in the pavement or ground surface.

A.6.2.2 Weathering The general appearance of the blocks should be considered to indicate how well they have resisted weathering. Quality stone and concrete will retain their sharp edges and corners and, in some cases, stone tool marks may be present.

Fig. A-20. Settlement and bowing of masonry block seawall
Source: Courtesy of Marine Solutions, Inc., reproduced with permission.

Fig. A-21. Erosion of masonry blocks at the water surface
Source: Courtesy of Marine Solutions, Inc., reproduced with permission.

A.6.2.3 Block Erosion Erosion of the blocks near the water surface, especially when subjected to heavy surface water currents and freeze/thaw cycles, is common (see Fig. A-21). The condition can cause significant section loss at the waterline, often referred to as "necking," creating an hourglass type shape.

Fig. A-22. Loss of mortar between masonry block units
Source: Courtesy of Marine Solutions, Inc., reproduced with permission.

A.6.2.4 Loss of Mortar Mortar loss between units can produce minor settlements and displacements affecting the weight distribution of the block matrix. Mortar is generally less durable than the stone or concrete block material and, as such, generally requires maintenance. Figure A-22 shows the loss of mortar between blocks in a masonry block wall.

A.6.2.5 Localized Displacement Loss of foundation support, loss of mortar, changes in load distribution, and other factors can lead to localized displacement or collapse of blocks. In cold regions, damage to blocks by ice pile-ups or movement of masonry units by surface ice may also be a concern.

A.6.2.6 Washout Evidence of undermining or piping of backfill material through the wall contributing to washouts may not always be detectable outboard of the wall, which is underwater. As such, these conditions are not realized until depressions or sink holes are formed landward.

A.6.2.7 Block Cracking Cracks through blocks should be observed for weathering to evaluate if the cracking is due to a recent condition or is ongoing. Vertical or diagonal cracks forming through blocks are often due to differential settlement, changes in loading or load distribution, or failure of lower masonry courses (see Fig. A-23). For interlocking precast concrete

Fig. A-23. Cracking through masonry blocks
Source: Courtesy of Marine Solutions, Inc., reproduced with permission.

blocks, visible cracks may be evidence of shear of the block's key or interlock, which are typically not visible.

A.6.2.8 Vegetation Vegetation can grow from ledges and voids created from mortar or block loss when soil collects in these areas. Vegetation with significant root structures can be very detrimental, inducing stresses and even causing block displacement.

A.6.2.9 Drainage Backfill drainage is an important concern but is often overlooked until a change in subsurface conditions, surface drains, or inadequate drainage leads to more visible damage. Differential head pressures created by fluctuating tides or river levels and storm water drainage can contribute significant lateral forces to the wall. The permeability of backfill material and effectiveness of drains can also change over time. Therefore, the surface and subsurface drainage conditions should be considered, and signs of leaking water through cracks or joints should be evaluated.

A.6.2.10 Foundations Foundations for block walls typically consist of a timber mat or timber crib type that may be filled with stone ballast. However, some gravity block walls may not have a separate foundation, only having a base masonry course laid directly on a leveled bearing

Fig. A-24. View of a collapsed section of masonry block wall due to insufficient foundation support
Source: Courtesy of Marine Solutions, Inc., reproduced with permission.

stratum. Exposure of the foundation of a gravity block wall beneath the waterline is not uncommon. Timber mats or cribbing should be observed for common types of timber deterioration but should also be specifically observed for loose or missing members, direct bearing contact between the mat or crib and the lowest block course, and loss or settlement of ballast material. Figure A-24 shows a collapsed masonry block wall where the foundation no longer provides sufficient support.

A.7 CAISSONS, COFFERDAMS, AND CELLULAR STRUCTURES

A.7.1 General

Caissons, cofferdams, and cellular structures are used to form wharves, piers, seawalls, quays, and freestanding mooring dolphins. These types of structures are also commonly encountered as exposed foundation members, supporting the deck of a pier or wharf.

A caisson is a retaining, watertight structure constructed of reinforced concrete or a solid steel plate lowered or driven in place to form an enclosure that is filled with an engineered material. Caissons can be formed in many shapes but are often referred to as two main types: (1) box caissons, which are prefabricated with sides and a bottom, and (2) open caissons, which do not have a bottom.

Fig. A-25. Typical steel sheet pile cellular structure
Source: Courtesy of Marine Solutions, Inc., reproduced with permission.

Cofferdams form a water barrier most often used to temporarily provide a dry work area. However, the reinforced concrete, steel plate, or steel sheet piles used to form the barrier may be left in place and can be integrated as a permanent member.

Cellular structures are generally formed by interlocking steel sheet piles, creating independent or connected closed or open cells (see Fig. A-25). Differing from a bulkhead, a cellular structure gains its strength and stability from the shear strength and weight of the contained infill or backfill material and does not depend completely on wall embedment or an anchor system. Closed cellular systems depend on their own weight to resist applied loads, functioning as gravity structures. Open cellular systems have diaphragm walls extending landward, utilizing the lateral pressure of the wall backfill to anchor the cell.

A.7.2 Typical Components and Problem Areas

Many of the components and common problem areas associated with concrete and steel sheet pile bulkheads are similar for caissons, cofferdams, and cellular structures. However, a few considerations are specific to these types of elements. Some of the typical problem areas are described in the following sections. Table A-9 provides a summary of what to look for when inspecting the condition of these structures.

Table A-9. Caissons, Cofferdams, and Cellular Structures: Checklist for Inspections

Section or Part	What to Look for	Comments
Foundation	Misalignment, bowing, plumbness	Settlement and lateral movement should be considered by observing and monitoring overall structure position
Steel sheet piling or plates	Corrosion, deformation, interlock separation, splitting, cracking, impacts, dents	Identification of the nominal steel section and thickness, interlock separation, and corrosion or damage to interlock is critical
Deck or backfill	Depressions, sink holes, cracking parallel to wall, joint separation, drainage conditions	Causes of backfill problems may not be evident by visual inspections of the wall; excavations, geotechnical borings, or ground-penetrating radar may be utilized
Cell cap	Settlement, cracking, drainage, edge spalling	If hatch in cap exists, it should be opened to observe fill level and composition; cap cracking can indicate settlement or loss of infill
		Edge spalling and deterioration can compromise the cap connection to the supporting wall
Reinforced concrete walls	Cracks, common precast concrete defects, reinforcement corrosion, joint displacement	Caisson or cofferdam walls may exhibit evidence of differential settlement
Channel bottom	Fill loss, scour, undermining, heaving	The depths and general contours of the channel bottom should be measured considering lateral stability if embedment is decreased

Fig. A-26. Collapse of the concrete cap due to settlement of infill material
Source: Courtesy of Marine Solutions, Inc., reproduced with permission.

A.7.2.1 Settlement Gravity structures not founded directly on competent bedrock are particularly susceptible to settlement and foundation failures, as they inherently apply a somewhat large dead load onto the bearing stratum. Settlement of the infill or backfill material can also occur independently of the foundation soils, especially if nonengineered fill is used (see Fig. A-26). As such, elevations and the verticality, or plumbness, of the structure should be checked with each inspection. The alignment and configuration of the structure should also be recorded for monitoring through successive inspections. Differential settlements between the cell infill and concrete or steel walls should also be considered.

A.7.2.2 Scour and Lateral Stability Deepening of the channel bottom at the structure from scour, dredging, or propeller wash can undermine these types of structures; however, this is uncommon as the loss of lateral support provided by embedment usually leads to leaning (see Fig. A-27) or failure before the structure is actually undermined. Therefore, the design embedment, intended design channel depth, and critical channel bottom elevations should be determined and evaluated during an inspection.

Fig. A-27. Leaning of a cellular structure due to scour and slope instability Source: Courtesy of Marine Solutions, Inc., reproduced with permission.

A.7.2.3 Steel Sheet Pile Interlock Separation Cellular structures depend on the interlock of the steel sheet piles forming the skin of the system to carry the lateral pressures applied by the infill or backfill material. Failure of the interlocks reduces the load-bearing capacity of the entire cell system by reducing the available tensile ring strength and, if fill material is released, by loosening and reducing the shear capacity of the confined fill (see Fig. A-28). Failure of the interlocks is often the result of corrosion and section loss at the interlocks, impacts, increase in loading or fill pressure, or some combination of these occurrences. Often, once the interlock is separated, the length of separation will gradually increase over time, commonly referred to as "unzipping." Removal of steel coupon samples of steel sheet pile interlocks can be performed after bracing the joint to closely observe the condition of the interlock and perform tensile strength testing.

A.7.2.4 Corrosion Corrosion of steel sheet piling can cause or contribute to a number of failure mechanisms (see Fig. A-29). It is important to recognize that if corrosion is occurring on the seaward side of the sheet piling, some corrosion is likely also occurring on the backside of the sheet piling, although it may be less due to lower levels of oxygen. Steel ultrasonic

Fig. A-28. Broken and separated sheet pile interlock resulting in the loss of infill material
Source: Courtesy of Marine Solutions, Inc., reproduced with permission.

thickness measurements are critical to the evaluation of steel components. For steel caisson, cofferdam, and cellular structures, thickness readings should be taken in a procedure that allows mapping of the corrosion by elevation and area such that the risk of interlock separation, splitting, or cracking due to impact or yielding can be determined.

A.7.2.5 Concrete Cap Deterioration Reinforced concrete caps covering closed circular cells are often designed to be supported by the cell walls,

Fig. A-29. Underwater photograph showing a hole in a cellular structure due to corrosion
Source: Courtesy of Marine Solutions, Inc., reproduced with permission.

but may be supported by the cell infill as well. Cracking parallel to the cell walls may indicate shear failure of the concrete at the walls. A somewhat large section of reinforcing steel combined with multiple corners and a cantilevered edge tends to result in corrosion-induced spalling. Common nondestructive and destructive testing techniques for reinforced concrete can provide valuable information to evaluate the condition and thickness of reinforced concrete caps. Coring and geotechnical borings may be necessary to determine the thickness of cell caps and the level and composition of cell infill.

A.8 PAVING ADJACENT TO QUAYWALLS, BULKHEADS, AND OTHER RETAINING STRUCTURES

A.8.1 General

Pavements located directly adjacent to waterfront retaining structures are particularly vulnerable to subsidence due to loss of supporting soil through the retaining structure. The telltale indicator of this condition is usually a distinct localized depression (or hole) in the pavement located above and behind the retaining structure, similar to those shown in Fig. A-30 and Fig. A-31. The depressions may be dramatic or subtle, but the resultant

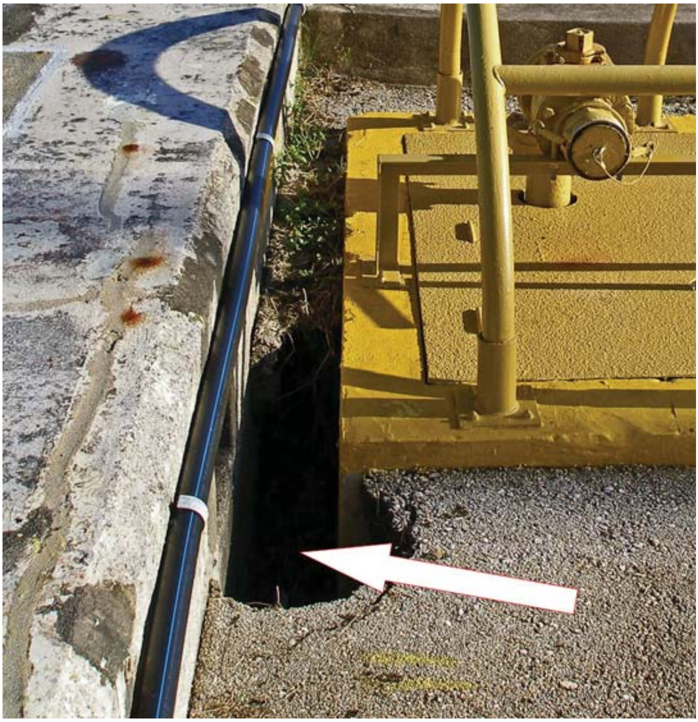

Fig. A-30. Hole in pavement (arrow) due to erosion behind sheet pile bulkhead Source: Courtesy of Moffatt & Nichol, Inc., reproduced with permission.

ponding is easily visible when the pavement is wet. The following structures are commonly associated with this phenomenon:

- Steel or concrete sheet pile bulkheads,
- Timber bulkheads,
- Wharf/pier retaining pendant walls,
- Relieving platforms, and
- Pipes or storm drains.

Pervious retaining structures are more vulnerable to soil loss in waterfront applications, as they are subject to the erosive forces of water movement influenced by tides, wakes, currents, etc. Repetitive pumping action associated with wind chop and boat wakes can be particularly problematic.

When distinct depressions (or holes) are noticed in the pavement for which topside causation is not obvious, the reason for the subsidence can usually be determined by a careful above and/or below-water investigation of the adjacent retaining structure.

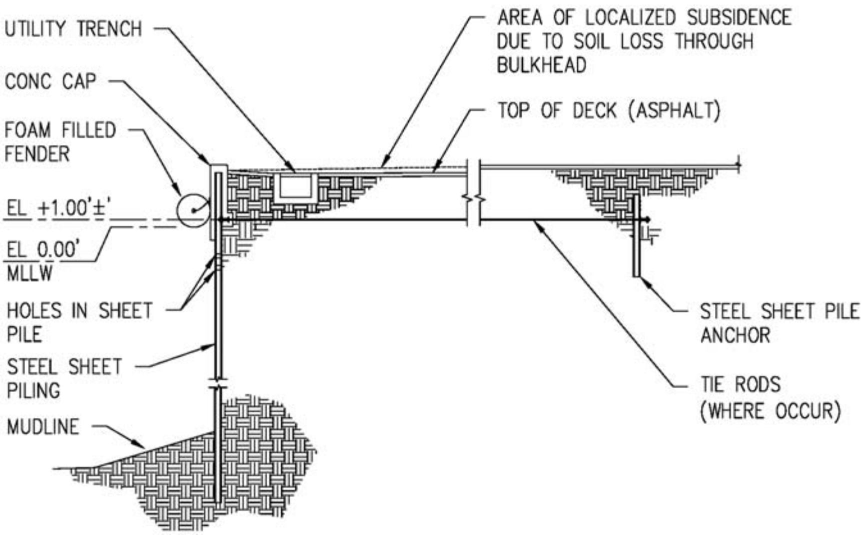

Fig. A-31. Section of a typical bulkhead arrangement showing soil loss and pavement subsidence through a sheet pile bulkhead
Source: Courtesy of Moffatt & Nichol, Inc., reproduced with permission.

Table A-10. Paving Adjacent to Quaywalls, Bulkheads, and Other Retaining Structures: Checklist for Inspections

Section or Part	What to Look for	Comments
Pavement	Localized settlement, depressions, or holes in pavement, ponding when wet, open cracking in the pavement parallel to the face of the retaining structure	An under-deck or underwater inspection will probably be needed to determine the exact cause of the pavement failure; use caution when inspection is close to these areas

A.8.2 Typical Components and Problem Areas

Table A-10 summarizes what to look for when investigating the condition of pavement behind the variety of bulkhead structures discussed in the following sections. Refer to Sections A.4, A.5, A.6, and A.7 to understand

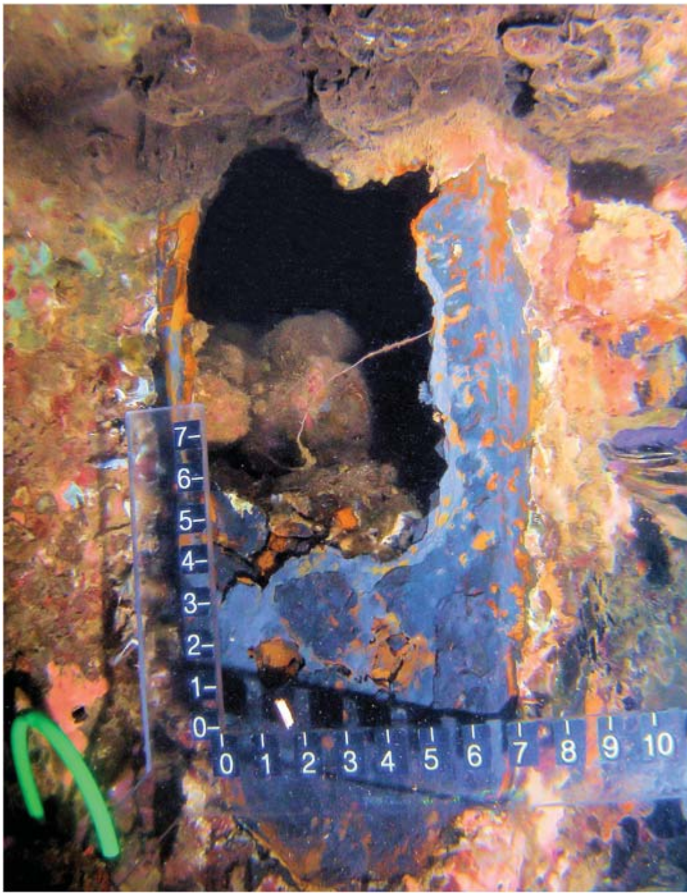

Fig. A-32. Corrosion-related hole in steel sheet pile near mean sea level elevation Source: Courtesy of Moffatt & Nichol, Inc., reproduced with permission.

what to look for in inspection bulkheads, seawalls, gravity walls, and caissons, respectively.

A.8.2.1 Steel Sheet Pile Bulkheads The primary cause of soil loss through steel sheet pile is through corrosion-related holes. Such holes are typically found in the splash zone where active corrosion is known to be most aggressive, although corrosion-related holes can sometimes be located deeper in the water column. Fig. A-32 depicts this type of hole, located in the splash zone region directly below the pavement hole and subsidence seen in Fig. A-30.

Stress-related "unzipping" of adjacent steel sheets can also be an avenue for soil migration through the bulkhead. This is commonly located deeper in the water column where soil pressures are higher.

Other pathways for soil loss include horizontal joints in sheet piles where a "follower" section of sheet pile has been placed on top of an overdriven sheet pile and locations where storm drains penetrate the bulkhead.

A.8.2.2 Concrete Sheet Pile Bulkheads Prestressed and conventionally reinforced concrete sheet pile retaining structures have proven to be problematic because of loss of retained soil, particularly when the backfill material is a fine-grained, cohesionless material such as hydraulically placed dredged material. The typical pathway for migration of the fill material through the bulkhead is via tongue-and-groove joints between adjacent sheets, as shown in Fig. A-33. As indicated in the discussion for steel sheet pile bulkheads, when subsidence is in the topside pavement, the reason can usually be determined by a careful above and/or below-water investigation of the adjacent retaining structure.

In the case of concrete sheet piles, an obvious indicator of soil migration through the joints is the presence of soil accumulation in a "talus cone" fashion at the bottom of the joint, as seen in Fig. A-34. Presence of this material can only be determined by underwater inspection. Generally, the presence of the accumulated soil is of a different character than the adjacent bottom. If sufficient propeller-wash or other scour-type activity occurs along the wall, the material may not accumulate in the manner shown.

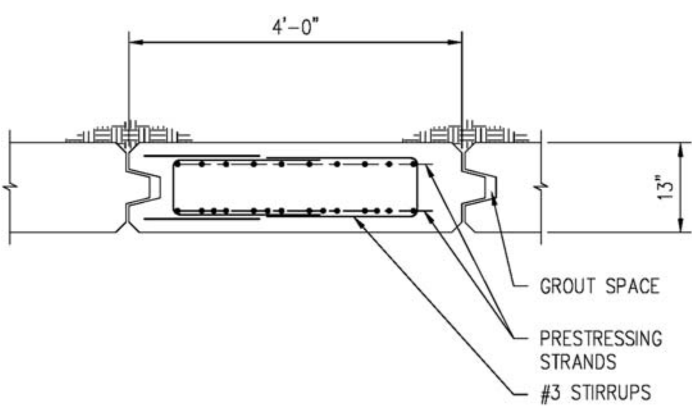

Fig. A-33. Plan section of a prestressed concrete sheet pile with tongue-and-groove joints—a common pathway for soil migration
Source: Courtesy of Moffatt & Nichol, Inc., reproduced with permission.

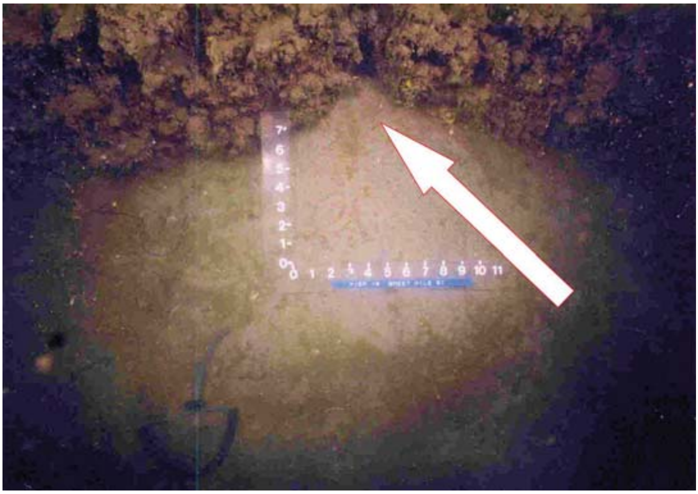

Fig. A-34. Looking down at the bay bottom adjacent to a bulkhead, a "talus cone" accumulation of fill material has leaked through the joint between concrete sheet piles
Source: Courtesy of Moffatt & Nichol, Inc., reproduced with permission.

A.8.2.3 Pendant Wall Structures "Pendant wall" elements are typically associated with wharf construction, where a retaining element is needed to delineate the transition from landside to waterside, as shown in Fig. A-35. The design intent for these structures is for the pendant wall to be sufficiently embedded in the rock revetment so that backfill material behind the pendant wall is retained. For this design to be effective, the rock revetment must be designed with an adequate filter material to prevent migration of the backfill material (usually fine-grained, cohesionless hydraulically placed fill) through the revetment. Subsidence of the backfill material placed behind the pendant wall, in a manner similar to that shown in Fig. A-31, is a common phenomenon with structures of this type. Subsidence is typically caused by one or more of the following (Fig. A-35):

- Settlement or movement of the revetment slope, undermining and exposing the bottom of the pendant wall;
- Improper design of the revetment filter material; and
- Backfill leaking through the pendant wall, typically at the location of drains or construction joints.

Evidence of soil migration underneath the pendant wall is shown in Figs. A-36 and A-37. The resultant void beneath the surface typically results in depressions in the pavement and ultimately pavement failure. Careful examination of the topside surfaces is warranted with these structures. If

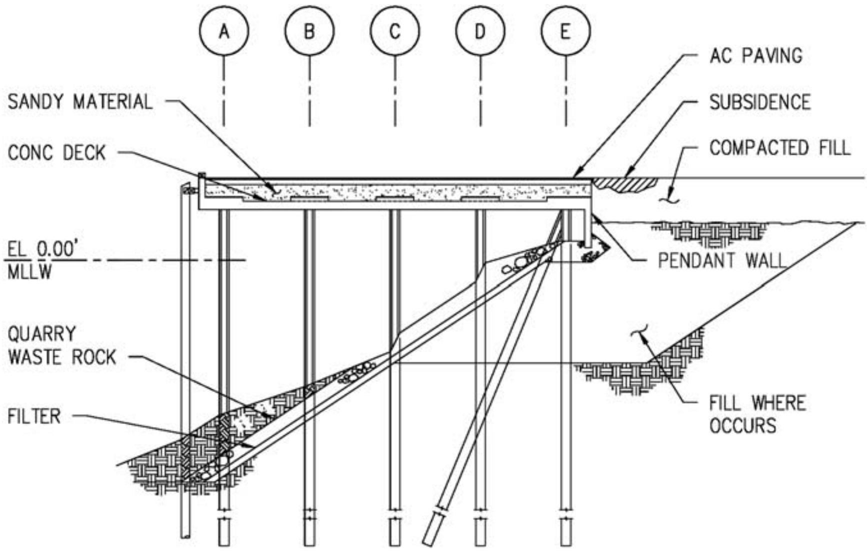

Fig. A-35. Marginal wharf cross section of pendant wall configuration; movement of the rock revetment slope often leads to exposure of the bottom of the pendant wall, resulting in subsidence of the soil behind the wall
Source: Courtesy of Moffatt & Nichol, Inc., reproduced with permission.

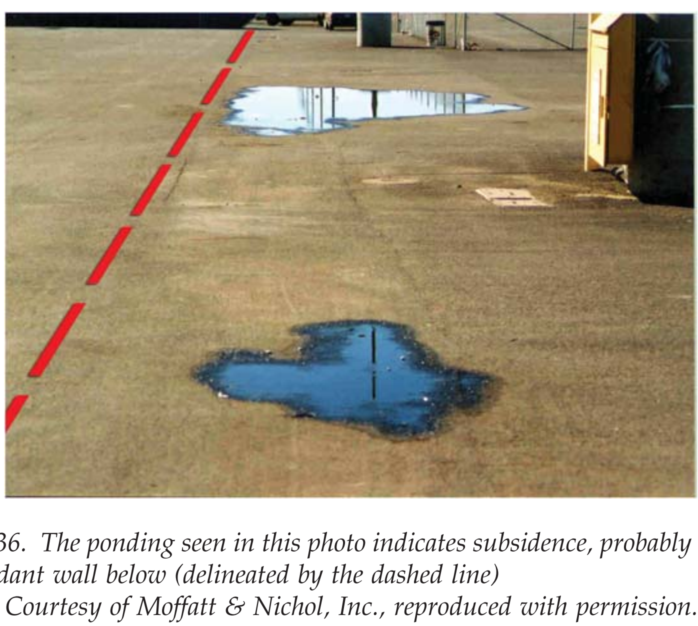

Fig. A-36. The ponding seen in this photo indicates subsidence, probably through the pendant wall below (delineated by the dashed line)
Source: Courtesy of Moffatt & Nichol, Inc., reproduced with permission.

Fig. A-37. The pavement has failed entirely as a result of soil migrating from beneath the pendant wall below (indicated by the dashed line)
Source: Courtesy of Moffatt & Nichol, Inc., reproduced with permission.

subsidence is suspected, special care should be taken with below-deck/underwater inspections in and around the affected area. Periodic monitoring of the pavement surfaces by topographic survey is an effective means of monitoring changes in condition.

A.9 FLOATING STRUCTURES

A.9.1 General

Floating structures are defined as any structure that is intended to remain floating during their service life. They can be moored or self-propelled. Examples of floating structures are large storage containers, drydocks, ferry slip docks, guide walls for navigation locks, breakwaters, bridges, and piers. Floating structures are used when great water depths and/or poor channel bottom conditions preclude the use of ordinary substructure units, or at sites where large water level fluctuations need to be accommodated. Typically, the material used to construct these structures is composed of concrete or steel.

Floating bridges, ferry slip docks, breakwaters, and guide walls for navigation locks typically consist of concrete pontoons at the water surface.

Most concrete pontoons are designed and constructed as a series of long, rectangular barges, with interior egg-crate bulkheads both longitudinally and transversely. The pontoons provide the superstructure for the bridge (or ferry slip dock) or serve to carry a bridge (or ferry slip dock) superstructure. In the case of the guide walls for navigation, the pontoons serve as the entry channel wall(s). The position of the pontoons is either maintained by anchor cables that inhibit movement by working against the buoyancy of the hollow design of the pontoons or are held in place by open pile clusters with a concrete cap.

Floating piers and docks typically consist of a deck that comprises one or more concrete or steel pontoons; however, timber, aluminum, and composite materials have been used as the pontoon material. Steel pontoons are typically required to have double-walled construction throughout the structure. Pontoons are anchored to the channel bottom and connected to the shore via bridges or ramps. Typically, the spud piles of floating piers are made of steel, concrete, or timber, and the connection hardware generally comprises hot-dip galvanized steel, marine grade stainless steel, or aluminum.

The anchor cables of floating structures are typically structural strand made up of small-diameter, stranded steel wires or large-diameter chain. An anchor cable may either consist of a single run between pontoon and anchor or two runs resulting from a cable that is looped through the anchor. The cables are either attached to the anchors by means of a cable socket along with various pins, eyebars, and pin plates or threaded through the anchor with jewels around the cable to protect it. The cables enter the pontoons through ports, and within the pontoon is a means of tensioning the anchor cable to draw the pontoon downward and thereby stabilizing it.

A wide variety of anchor designs are used for floating structures, including drag-embedment anchors, pile anchors, deadweight anchors, suction pile anchors, and direct-embedment anchors. A comprehensive description of these anchor types can be found in Section A.11.

A.9.2 Typical Components and Problem Areas

Table A-11 summarizes the specific components of the floating structures that are typically inspected and the typical items of concern for each component of the structures.

A.9.2.1 Floating Concrete Pontoons Floating concrete pontoons are normally constructed of segmental precast, prestressed concrete, utilizing either standard-weight concrete or lightweight concrete. Lightweight concrete is typically 25% less in unit weight than standard-weight concrete, which results in a shallower draft but requires additional reinforcement in the concrete. The concrete interior and exterior surfaces of the pontoon need to be inspected for typical concrete deficiencies. Of particular concern is any

Table A-11. Floating Structures: Checklist for Underwater Inspections

Component	Section or Part	What to Look for	Comments
		Floating Bridges	
Pontoon	Submerged surfaces	• Cracks, spalls, and loss of section; waterlogged filler material between steel double walls	• Cracks or deep section loss may allow water infiltration
	Joints	• Torn, loose, or bulging rubber membrane • Exposed and/or deteriorated grout • Excessive pontoon misalignment	
Anchor cable	Pontoon port	• Misalignment and cable abrasion	
	Cable	• Coating condition, corrosion, wire section loss, broken and/or braided wires, and potential sources of cable abrasion	• Exterior wire breaks related to stress may suggest comparable numbers of interior broken wires; stress breaks may also indicate end of cable's useful life
	Anchor attachment assembly or jewels	• Corrosion, misalignment, looseness, and cable abrasion or strain	
Anchor	Anchor assembly	• Misalignment or movement, instability, undermining, and inadequate embedment or ballast quantity	

		Floating Piers	
Pontoon	Submerged surfaces	• Material deterioration • Waterlogged Styrofoam filler	• Cracks or deep section loss may allow water infiltration
	Joints	• Damaged and/or deteriorated joint filler and connections • Excessive pontoon misalignment	
Spud pile	Submerged surfaces	• Ordinary pile considerations • Wear or abrasion related to misalignment	
Tension line	Pontoon or anchor attachments	• Corrosion, misalignment, looseness, and line abrasion or strain	
	Cable or chain	• Corrosion, cathodic protection anode consumption (chains), breaks and/or abrasion, and potential sources of abrasion	• Catenary chains may be subject to wear at mudline
Anchor	Anchor assembly	• Misalignment or movement, instability, and inadequate embedment	

cracking or deep section loss that could allow water to infiltrate the concrete and, thus, the inner compartment of the pontoon. Floating pontoons will sometimes experience dynamic excitation due to the waves travelling obliquely to the axis of the bridge, thus lengthening the effective span between crests to much longer than the wavelength. This, in turn, leads to harmonic response by the pontoon. Any cracking in the concrete can become a through crack; then the opening and closing sucks in water and closes, leading to hydraulic fracture. Therefore, a sufficient steel area must cross all potential cracks to stay below yield at the ultimate tensile strength of the concrete. Where a series of pontoons is employed, the rubber membranes and/or grout that are typically used in the joints between pontoons should be inspected for indications of a lack of integrity. Pontoon alignment across the joints should also be examined for indications of excessive differential movement.

The access hatch or point of entry to the pontoon should be inspected for degradation of the sealing material and degradation of the surrounding concrete or steel material. When in the closed position, the hatch door should be watertight; check for gaps around the edges. If the pontoon has multiple compartments, the bulkhead portal doors should be inspected in a similar manner to the access hatch. These types of inspections are most likely confined space inspections and require proper training, specialized equipment, and compliance with local and federal regulations. Refer to Section 34 of USACE (2008) for guidance on confined space inspections.

In some cases, the pontoons may have utility conduits, plumbing, duct banks, and/or cathodic protection systems. The overall condition of these systems should be inspected to identify general deterioration and to determine if the utility conduits and plumbing are broken or detached. Beyond the general condition inspection of these systems, a specialized inspection may be required.

A.9.2.2 Floating Pontoon Anchor Cables and Chains Anchoring cables should be inspected for condition of protective coatings, extent of corrosion, and amount of individual wire section loss. In a strong current flow environment (2 to 3+ knots), vibration of the anchor cable can occur and further cause cyclic dynamic oscillations that can lead to fatigue, both in the cable and at the connection hardware. Cable misalignment and wire abrasion should also be checked at the pontoon ports. At the anchors, the attachment assemblies or jewels should be examined for any deterioration, looseness, or misalignment and for any adverse effects to the anchor cable. Of particular importance is the identification of any broken individual wires along the cable. When possible, determine the source of wire breakage that is abrasion or stress related, because exterior stress breaks typically suggest a comparable number of interior broken wires and also indicates that the end of the cable's useful life is approaching. The inspection of each anchor cable should also identify any potential sources of cable abrasion, such as items hung on the cable (netting, anchor ropes, etc.) or obstructions at the channel bottom. See Section A.11 for additional inspection considerations.

Anchor chains should be inspected routinely for corrosion and section loss of the individual links, the amount of wear between adjoining links, possible stretch of the chain over five continuous links, and alignment with the anchoring system. The anchor chains should be routinely inspected at critical locations throughout the chain assembly, including the riser section, catenary section, dip section, and the ground section. See Section A.11 for additional inspection considerations. In some cases the anchor chain will have cathodic protection throughout the system and should be inspected as described in Section A.14.

A.9.2.3 Floating Steel Pontoons The steel portions of the pontoons should be inspected for the typical material deficiencies. Of particular importance is any cracking, holes, or deep section loss that may allow water to infiltrate the interior cavities of a pontoon. In some cases, the steel pontoons will have double walls along the exterior portion of the hull. Therefore, both interior and exterior examinations of the walls are necessary. Where Styrofoam filler is used in steel pontoons, any exposed filler should be examined for material integrity and any indications of being waterlogged. The joints between pontoons and related connections and/or fillers should be inspected for deterioration, damage, missing or deficient items, and other considerations, as described in Section A.9.2, where applicable.

A.9.2.4 Floating Pier Spud Piles or Tension Lines Floating pier spud piles should be examined for the conditions associated with piles, as described in Section A.2. In addition, the piles should be checked for any excessive wear or abrasion resulting from misalignment. The top of the spud piles should be checked for a protective cap or coating that minimizes deterioration and water accumulation. Where tension lines are involved, the lines and attachment assemblies at either end should be examined for deterioration, breaks, abrasion, and other considerations, as described in Sections A.10 and A.11, where applicable.

A.9.2.5 Floating Drydocks This section covers the basic components of a floating drydock system. For comprehensive inspection techniques related to floating drydocks refer to ASCE (2010). A floating drydock consists of a pontoon with stabilizing wing wall(s) and mechanical and electrical equipment to permit the controlled flooding and emptying of the ballast tanks. A floating drydock is most conveniently inspected by having it drydocked as a unit and by performing the inspection in the dry. Self-docking may be an alternative for some floating drydocks, whereby portions of the structure are removed and drydocked on the remaining structure. In some cases, access to submerged portions of the pontoon is possible by creating controlled list or pitch of the drydock through the flooding of selected ballast compartments.

Those portions of the floating drydock that may require underwater inspection include the pontoon hull and water intakes.

A.10 MOORING HARDWARE AND FENDER SYSTEMS

A.10.1 General

Mooring hardware and fender systems are the primary components in the berthing of vessels at any waterfront facility. The fender system is vital to providing protection for the waterfront structure and for the vessel. The fender system must be able to resist a strong impact when a vessel first makes contact with the structure and for it to be able to withstand continuous loading from environmental conditions such as wind, current, and waves. Once a vessel is alongside the structure, the vessel's mooring lines are connected to the mooring hardware that is mounted to the structure. Typically, onboard winches allow the mooring lines to be adjusted to position the vessel. As with fender systems, mooring hardware must be able to withstand constant environmental forces in addition to strong gusts increasing tension on individual mooring hardware.

A.10.2 Typical Components and Problem Areas

Mooring hardware and fender systems are no different from typical structural components, with common problem areas stemming from fatigue (cyclic loading), sudden high impact (overloading), and prolonged environmental exposure. Table A-12 and Table A-13 summarize what to look for when inspecting the condition of mooring and fender system components, respectively.

A.10.2.1 Mooring Hardware Mooring hardware is comprised mainly of bollards, bitts, cleats, and hooks, which have various functions on the wharf structure to secure vessel mooring lines. A general overall inspection of the mooring system should be performed, noting location and type of mooring components; typical use of the system; and obvious deterioration, damage, or missing components.

A.10.2.1.1 Bollards, Bitts, and Cleats Most bollards, bitts, and cleats are of steel construction and subject to the same deterioration causes and

Table A-12. Mooring Hardware: Checklist for Inspections

Section or Part	What to Look for	Comments
Bollards, bitts, and cleats	Coating loss, corrosion, abrasion, displacement, cracking	• Make sure to check in high-wear areas, such as the base of the hardware where the mooring lines sit. These areas are often the first to experience coating loss and corrosion. It is important to look under mooring lines while no vessels are berthed, as this is the area of most concern.
Fasteners	Corrosion, deformity	• May need to conduct Level III inspection to determine full extent of fasteners' deterioration. Check both above and below deck level if fasteners can be accessed from both sides, especially for timber structures.
Supporting structure	Cracks, spalls, displacement	• Check below deck level if fasteners go through deck, especially for timber structures.

Table A-13. Fender Systems: Checklist for Inspections

Section or Part	What to Look for	Comments
Absorption element	Deformation, cracking, abrasion, tears	Connections are vulnerable areas
Fender panels	Deformation, deterioration, debris accumulation, blocked drainage, loose or missing hardware	Connections to fenders or chains are vulnerable areas
Supporting piles	Buckling, impact damage, broken sections, material specific deterioration	Not found on all fender systems
Rub surface	Abrasions, impact damage, protruding bolts, missing elements	

Fig. A-38. Typical mooring hardware: a single bitt bollard with ears (upper left), a cleat (upper right), an angled double bit bollard (lower left), and a double low bit bollard (lower right)
Source: Courtesy of CH2M HILL, Inc., reproduced with permission.

symptoms of steel structural elements, as shown in Fig. A-38. Typically, the mooring hardware is a cast steel or iron and is secured to the structure with bolts that either are anchored into or bolted though the structure. The actual cast fitting will have various wall thicknesses based on its capacity. As noted in Table A-12, problems arise from abrasion of the mooring lines, as this can remove the coating and leave the areas open to the marine atmosphere, which ultimately leads to corrosion. Corrosion will lead to loss of section and, therefore, a reduction in the strength of the fitting. In addition, the fitting can be subject to cracking and deformation. Hardware should be inspected for overall condition. Welds should be inspected for cracks. Base plates should be inspected for bending or uplift indicating a previous overload. Hardware coatings and surfaces should be examined for damage and/or wear, especially from mooring lines. Surfaces should be smooth and free of defects that could catch or tear mooring lines.

A.10.2.1.2 Quick-Release Hooks Quick-release hooks (QRH), as shown in Fig. A-39, require a high degree of maintenance. Detailed maintenance efforts are required to maintain the operational life of these units. However, a visual inspection of the hook can determine if further inspection is required. Hook coatings and surfaces should be examined for damage and/or wear, especially from mooring lines. Hook surfaces should be smooth and free of defects that could catch or tear mooring lines. All exterior surfaces should be coated, especially base plates and anchor bolts. The inspection should verify that unloaded hooks freely rotate and that the release mechanism is functional. Check for evidence of excessive lubricant loss, especially at the pins such as streaking or pooling on the hardware on the deck below. Many QRH units are equipped with motorized capstans. These units should also be inspected for overall condition; signs of distress may require further review by a specialist experienced in these types of units.

A.10.2.1.3 Anchorage Anchorage of all mooring hardware should be carefully inspected and the condition documented (Fig. A-40). Load path of the hardware is critical to safe use of these items. Hardware should not be loose fitting. Common signs of anchorage damage include missing bolts or nuts, loose bolts, bolts that have been partially pulled through timber structural elements, or cracking of the grout pad or concrete deck supporting the hardware. When observations such as these are noted, attempt to document the cause of the damage. Recessed bolt holes should be filled with mastic, silicone, or a similar material to prevent water ponding and bolt corrosion.

A.10.2.2 Fender Systems Fender systems typically comprise two to three critical elements:

- An absorption element absorbs the energy from the impact of a vessel and minimizes the forces that are transmitted directly to the structure.
- The supporting elements either support the absorption element, provide a contact face, or provide a reaction surface—although not all systems have these.
- The rub surface typically comprises an ultra-high molecular weight (UHMW) polyethylene, or timber rub face or strip, and framing to secure it to the supporting piles or absorption elements.

A.10.2.2.1 Absorption Elements Two typical types of absorption elements are elastomeric fender units that are normally directly attached to a structure and pneumatic or foam-filled fender units that float in front of the structure or fender pile system.

Fig. A-39. A double quick-release mooring hook with a manual quick-release mechanism and cleat (left) and a quadruple quick-release mooring hook with electric capstan and tension monitoring equipment (right)
Source: (left) Courtesy of Simpson Gumpertz & Heger, Inc., reproduced with permission; (right) Courtesy of CH2M HILL, Inc., reproduced with permission.

Fig. A-40. Severe anchorage corrosion of a cleat (top) and a bollard (bottom)
Source: Courtesy of Simpson Gumpertz & Heger, Inc., reproduced with permission.

A.10.2.2.2 Elastomeric Fender Units Elastomeric fender units come in many shapes and sizes and are typically the connection between the structure and a fender frame or rub surface, as shown in Fig. A-41. Rubber compounds are subject to deterioration or damage from physical and chemical reactions, such as heat aging, sunlight, abrasion, fatigue, and heavy or excessive berthing. Rubber also reacts poorly to contact with chemicals or petroleum products, which can cause hardening and cracking with exposure.

Fender units should be checked for rubber deterioration in the form of cracking, hardening, abrasion, tears, and compression set. If fender panels are not properly supported, fender cracking may occur. This can be either circumferential around the fender at the connection with the supporting structure, or longitudinal on top of the unit due to excessive tension associated with self-weight and/or the fender panel. Often the fender unit will sag, and the panel will no longer be plumb. Radial cracking on the sides of the unit may indicate excessive angular loading. Look for dirt, sand, and debris accumulation.

A.10.2.2.3 Pneumatic or Foam-Filled Fender Units Pneumatic and foam-filled fenders are located on the seaward side of pile-supported fender systems or connected directly to the side of the structure. They are typically cylindrical-shaped objects with large eyelets on either end that allow a chain to be attached to secure the fender to the fender system structure, as shown in Fig. A-42.

As shown in Table A-13, pneumatic and foam-filled fenders should be visually checked for overall signs of obvious deterioration and damage, such as rubber disfiguration, cracking, tears, sagging, or permanent distortion. Urethane covers should be checked for signs of damage like tears, ribs, or holes. Fittings at the ends of these units should be checked for splitting or separation from the fender and for corrosion, deformation, or abrasion damage.

A.10.2.2.4 Steel Frames and Structural Supporting Members Rubber fenders often support a steel frame, a fender pile system, or some other structural system that will be the contact point for the berthing vessels. These structural systems should be checked for the deterioration based on the material composition.

Steel fender panels should be checked for corrosion, cracks (especially at the connections to the elastomeric fender units), deformation, and condition of coating (Fig. A-43). Check all connection hardware (bolts, nuts, washers) for intactness and corrosion. Also check that all connection hardware is tight fitting and in place. Some fender panel designs are prone to collecting debris and water, accelerating the corrosion process. Inspect these areas for signs of localized deterioration damage.

Timber pile systems should be checked for rot, checking, splitting, abrasion, displacement, and structural failure. Also check connection hardware for corrosion and damage (Fig. A-44).

Fig. A-41. Leg/element-type elastomeric fender unit (left) and a cone-type unit (right)
Source: (left) Courtesy of Childs Engineering Corp., reproduced with permission. (right) Courtesy of CH2M HILL, Inc., reproduced with permission.

Fig. A-42. Foam-filled fender unit with concrete backing piles (left) and similar units with timber and steel backing (right) Source: (left) Courtesy of Simpson Gumpertz & Heger, Inc., reproduced with permission; (right) Courtesy of Childs Engineering Corp., reproduced with permission.

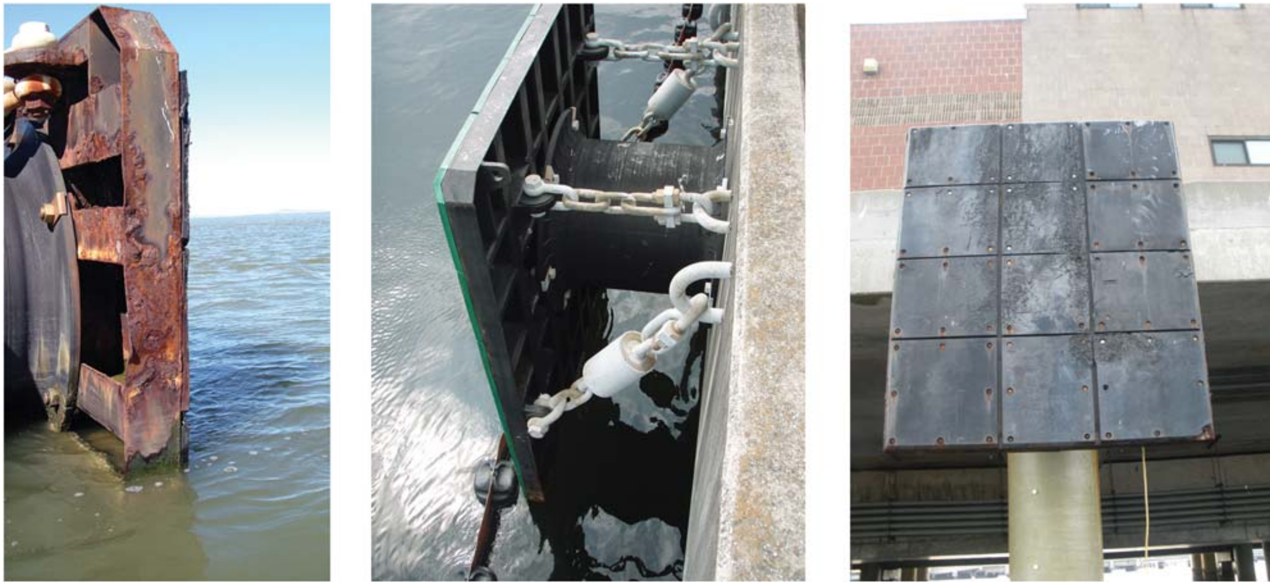

Fig. A-43. Severely corroded steel fender framing (left), typical chains supporting the fender framing and panel (center), UHMW fender panels with typical wear (right)
Source: (left) Courtesy of CH2M HILL, Inc., reproduced with permission. (center, right) Courtesy of Childs Engineering Corp., reproduced with permission.

Fig. A-44. Steel H-piles supporting a timber fender framing and rub strip (top left), timber fender pile system (top right), clusters of timber fender piles banded together with wire rope (bottom left), composite fender pile system with a broken wale (bottom right)
Source: Courtesy of Childs Engineering Corp., reproduced with permission.

Concrete fender pile systems should be checked for spalling, cracking, displacement, and corrosion. All connection hardware should also be checked.

A.10.2.2.5 Fender Chains and Fittings As a result of constant movement, chain links may wear considerably at the contact points between them, decreasing the chain's overall strength. Chains and fittings should be checked for corrosion, wear, permanent deformation, and signs of overloading. Check all connections to fenders, panels, and supporting structure for signs of overloading. See Section A.22 for a more comprehensive discussion of chain inspection.

A.10.2.2.6 Synthetic Facing Materials Fender panels and fender piles might be covered with a synthetic facing material to provide a low-friction surface for the vessel hull to bear against. This material is usually some kind of UHMW) polyethylene. Synthetic facing materials should be checked for normal wear and tear and possible chemical deterioration. Check connecting bolts for corrosion and proper recess in the facing material to avoid damage to the vessel hulls from the bolts. Older installations should also be checked for deterioration associated with UV exposure, such as fading, cracking, or embrittlement of the material.

A.11 MOORING BUOY SYSTEMS

A.11.1 General

Mooring buoys are standard means of mooring vessels or floating structures to the sea floor by laterally leading lines to anchors. Different types of buoys used in moorings include the drum buoy, the peg top buoy, the drum nonriser buoy, and the cylindrical buoy (see Fig. A-45). Mooring buoys provide primary, temporary, or contingency berthing. A mooring buoy system generally consists of a floating buoy, anchor chain(s) (or cables), anchor(s), and the connecting hardware. Standard types of mooring buoy systems currently in use include the free-swinging mooring, the bow and stern mooring, the spread mooring, the Mediterranean mooring, and the buoy dolphin mooring. Specialized moorings are used in a nonstandard configuration and are designed to satisfy a unique mooring application or a specific operational requirement. Mooring buoy systems are classified by their respective holding power. The U.S. Navy classification ranges from holding capacities of 50,000 to 300,000 lbs (222 to 1,340 kN).

A.11.2 Typical Components and Problem Areas

Unless a mooring can be completely lifted out of the water for assessment, an underwater inspection normally forms an essential part of a mooring inspection. Given that mooring buoys are typically difficult to access and are located in less than ideal conditions, experienced personnel and reliable equipment are required to accomplish these tasks. Table A-14 summarizes the specific components of common mooring types and the most common areas of concern for each component. The inspection of mechanical and electrical equipment that may form part of the mooring system is beyond the scope of this manual.

Consistent measurements and inspection of the accessible portions of a mooring generally provide a good indication of the overall condition of the mooring. However, if portions of the mooring are buried, such as anchors and chain anchor legs, they are usually not uncovered during the inspection. Pop-up buoys may be attached to chain anchor legs where they disappear into the mud to permit survey crews to determine location.

A.11.2.1 Buoys Most mooring buoys have steel hulls protected with several coats of paint or with fiberglass coating (see Fig. A-45). To protect

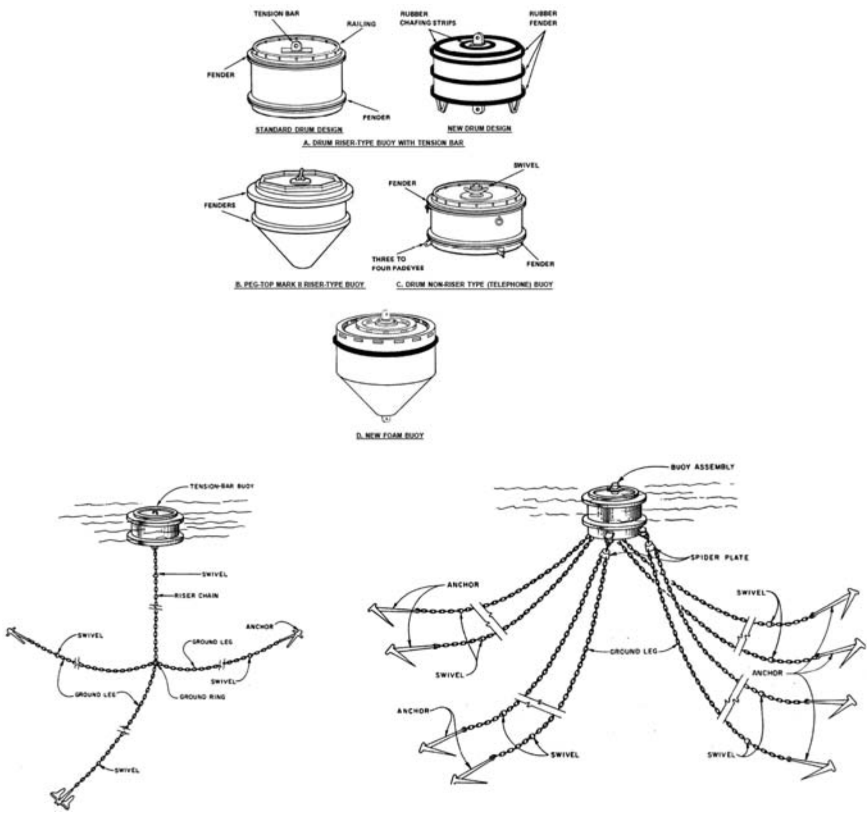

Fig. A-45. Types of mooring buoys (top) and types of mooring buoy arrangements, riser-type (lower left) and nonriser type (lower right)
Source: U.S. Navy (1987).

the coating from damage during the underwater inspection, not attempting to remove any marine growth from the buoy may be advisable.

The buoy should be examined to determine its overall condition. The upper jewelry should be inspected for excessive wear and corrosion. In addition, any excess top jewelry or wire rope cables attached to the buoy should be reported. Physical damage to the hull of the buoy, such as holes, dents, metal distortion, or listing, should be documented. The buoy's freeboard should be measured and documented. The condition of fiberglass on fiberglass-coated buoys should be inspected and any cracks, wear, peeling, or rust bleeding identified. The condition of paint on painted buoys should be checked for cracking, chipping, and/or peeling. The condition of water drains should be examined for broken parts, surface rust, and surface pitting. The condition of fenders and chafing strips should be checked for

Table A-14. Mooring Buoy Systems (Riser and Nonriser Type Moorings): Checklist for Inspections

Component	Section or Part	What to Look for	Comments
Buoy, upper portion	General	Size; freeboard; physical damage (dents, holes, list); coating condition	
	Fenders, chafing rails or strips	General condition	
	Top jewelry	General condition of tension bar, hawse pipe, manhole covers, etc., as applicable	• Check for hardware wear and corrosion, damage, etc.
Buoy, lower portion	Hull	General condition, physical damage (dents, holes, etc.)	• Check condition of coating
	Bottom jewelry	Condition of tension bar, hawse pipe, etc., as applicable; condition of chain padeyes (for nonriser moorings)	• Tension bar: Check eye and retaining plate for wear/distortion • Hawse pipe: Check chain for wear/corrosion, rubbing casting for wear

(Continued)

Table A-14. Mooring Buoy Systems (Riser and Nonriser Type Moorings): Checklist for Inspections *(Continued)*

Component	Section or Part	What to Look for	Comments
Riser chain subassembly	Chain links, connecting hardware, swivel, ground ring	Type and general condition, wear/corrosion, distortion	• Measure chain links at three locations for each shot of chain, i.e., each end and midway between; at each location, take single and double link measurement
Anchor chain subassembly	Chain links, connecting hardware, swivel (if applicable)	Type and general condition, wear/corrosion, distortion, compass bearing of each chain	• Check for pitting corrosion
Anchor subassembly (if visible)	Anchor, connecting hardware	Type and general condition	• Note orientation of anchor flukes if visible
Cathodic protection system, buoy and chain	See Section A.14		

physical integrity and secure connections to the buoy's surface. Fender/chafing strip brackets or studs should be inspected for corrosion and/or cracks.

A.11.2.2 Riser Chain Subassembly The riser chain subassembly normally consists of chain, swivel, ground ring, and connecting hardware such as shackles and special links. The swivel permits the buoy to turn 360 degrees without twisting the anchor chains. The ground ring connects the riser chain to the anchor chain legs.

The mooring chain is susceptible to two basic forms of corrosion: uniform and fretting. Uniform corrosion occurs over the entire chain link. The links initially corrode at a somewhat fast, uniform rate, which decreases with time. Therefore, the diameter of the chain should be measured at several locations throughout the assembly, typically accomplished using calipers and a tape measure. Fretting corrosion, which is more damaging and more difficult to prevent, occurs at the crossing of two adjoining links (called the grip area). It results when movement of the chain links under load grinds away the outer corroded layer of steel in the grip area. This process continuously exposes new, noncorroded surfaces of the steel, which are then corroded at the initial, faster corrosion rate. Loss of chain diameter is accelerated in the grip area, and the useful life of the chain is reduced. The amount of corrosion at the grip area can be determined by measuring the overall length of the two adjoining links, called a double link measurement.

Additional areas of concern of the chain assembly are overall alignment and possible stretch. Stretching can be determined by a measurement over five continuous links, which is compared with the original construction measurement over five links. A tolerance of 2.5% variation in the five-link measurement is typical. Alignment and orientation of the chain legs can be checked using an underwater compass, and catenary measurements are made using an inclinometer at predetermined locations along the chain.

A.11.2.3 Anchor Chain Subassembly Anchor chain assemblies consist of the multiple legs of chain and connecting hardware that connect the ground ring (in the case of riser moorings) or the buoy (in the case of nonriser moorings) to the anchors. The chain should be checked for wear and corrosion as described previously for the riser chain subassembly and should be inspected at critical locations throughout the chain assemblies, such as the catenary section, the dip section, and the ground section.

The catenary section is the portion of the chain that maintains constant curvature and is located between the riser section and the touchdown point of the chain. The dip section is the portion of the chain leg that initially comes in contact with the bottom. This section is the part of the chain leg that receives the most wear, abrading the sea bed as it moves. The ground section is the portion of the chain leg that is static on the sea floor. Vertical movement of the buoy does not move the chain leg at this section.

The Kenter link, which is a special link used to connect two lengths of chain, should be inspected for the connection stud, keeper pins, and lead pellets (plugs). A Kenter link that connects different size diameter chain lengths may have a studless link to allow for the connection; however, the keeper pins and lead pellets are still required.

A.11.2.4 Anchor Subassembly A pop-up float may be attached to an anchor so that the position of the anchor relative to the mooring buoy can be observed from the surface. Buried anchors are normally not uncovered for inspection. However, wherever possible, the connection between anchor and anchor chain should be inspected for wear, corrosion, and alignment. If possible, the type of anchor and connecting hardware should be identified. Also, the reason for it being uncovered should be investigated. Some mooring designs have two anchors in tandem that are separated by one shot of chain. The anchor closest to the buoy is called the buoy anchor, and the one farthest from the buoy is called the tandem anchor. The buoy anchor is connected to the ground section at the shank end and to the chain at the crown end of the anchor. The chain at the crown end of the anchor is located at the opposite end of the shank end and also connects the flukes.

A.11.2.5 Anchors and Anchor Chains Several types of anchors can be used in moorings, including drag-embedment (conventional) anchors, pile anchors, deadweight anchors, suction pile anchors, and direct-embedment anchors.

A.11.2.5.1 Drag-Embedment Anchors Drag-embedment anchors are the most commonly used anchors in moorings (see Fig. A-46). Drag-embedment anchors have an anchor shank that is used to transfer the mooring-line load to the anchor flukes, which have large surface areas to mobilize soil resistance. The leading edge of a fluke, called the fluke tip, is sharp so that the fluke will penetrate into the sea floor. Tripping palms, located at the trailing edge of the flukes, cause the flukes to open and penetrate the sea floor (see Fig. A-47). The shank-fluke connection region is called the crown of the anchor. Some anchors have stabilizer bars located at the anchor crown oriented perpendicularly to the shank. Stabilizers resist rotational instability of the anchor under load. Drag-embedment anchor performance is sensitive to sea-floor soil type and drag angle. Drag-embedment anchors are designed to resist horizontal loading. A near-zero angle between the anchor shank and the sea floor (shank angle) is required to ensure horizontal loading at the anchor. Sufficient scope in the mooring line will result in a near-zero shank angle. (Scope is defined as the ratio of

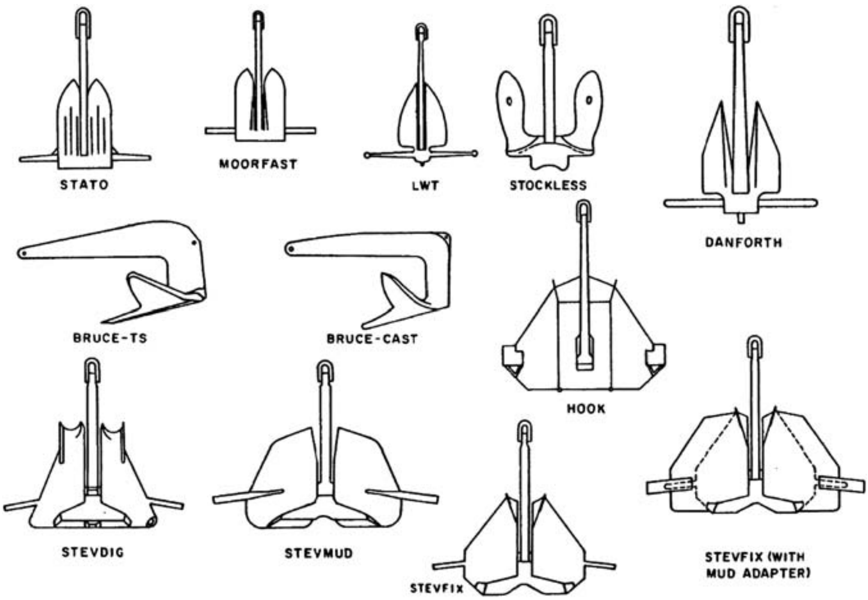

Fig. A-46. Types of drag embedment anchors
Source: U.S. Navy (1985).

the length of the mooring line from the mooring buoy to the anchor to the water depth.) As the shank angle increases from zero, the vertical load on the anchor increases, and the holding power of the anchor decreases. Anchors' general condition and whether they are properly deployed should be inspected.

A weight called a sinker, usually made of concrete, may be placed on a mooring leg in a location to ensure horizontal loading at the anchor end and to aid in energy absorption. A steel rod (called a hairpin) is cast into the sinker to provide for connection to a mooring chain. The connection between the mooring chain and the sinker is critical; if this connection fails, the sinker will be lost, and the entire mooring may fail. Therefore, certain precautions must be observed. First, the connection must allow free movement of the chain links to avoid distortion and failure of the links. Second, a sinker must not be cast around the chain itself.

A.11.2.5.2 Pile Anchors A pile anchor consists of a structural member, driven vertically into the sea floor, designed to withstand lateral (horizontal) and axial (vertical) loading (see Fig. A-48). Pile anchors are generally simple structural steel shapes fitted with a mooring-line connection; however, they may be composed of concrete, timber or composites, or steel helical shapes

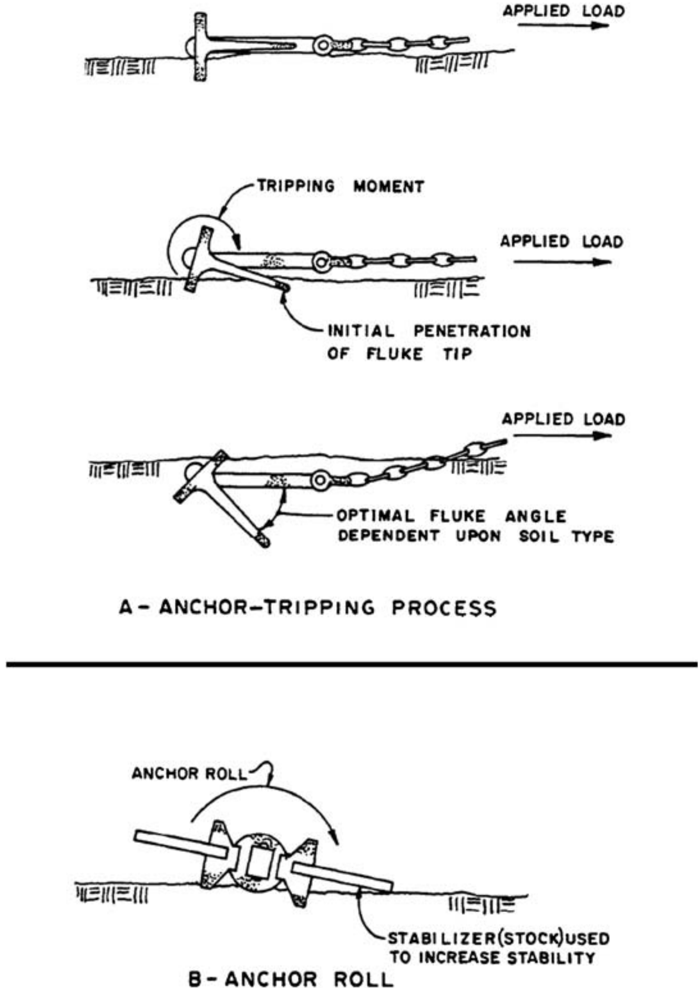

Fig. A-47. Performance of drag embedment anchors under loading Source: U.S. Navy (1985).

screwed into the ground. Pile anchors are installed by driving, drilling, jetting, or screwing. High installation costs usually preclude their use when drag-embedment, deadweight, or direct embedment anchors are available. Pile anchors are particularly well suited when a short-scope mooring is desired, when rigid vessel positioning is required, when sea-floor characteristics are unsuitable for other anchor types, or when material and installation equipment are readily available. Piles achieve their lateral and axial holding capacity by mobilizing the strength of the surrounding sea-floor soil. The

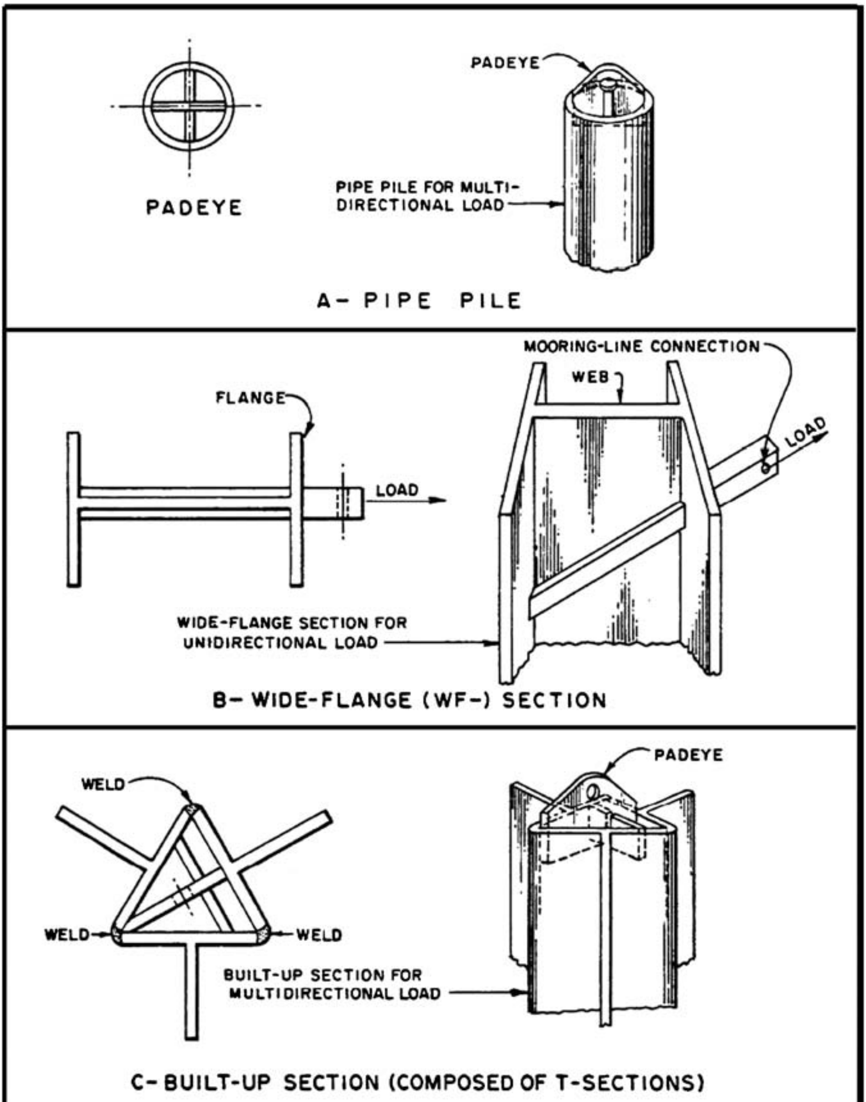

Fig. A-48. Types of pile anchors
Source: U.S. Navy (1985).

lateral strength of a pile anchor derives from lateral earth pressure and its axial strength derives from skin friction.

Pile anchors can fail in three ways: by pulling out of the sea floor, by excessive deflection, or by structural failure. In the first, the anchor pile may pull out of the sea floor when uplift loads exceed the axial capacity offered by skin friction. In the second, lateral loads applied at the upper end of the pile generally cause the pile head and surrounding soil to deflect. Excessive and repeated deflections of the pile head and surrounding soil will cause a reduction in soil strength and may result in failure of the pile anchor. Finally, large lateral loads on a pile may result in stresses in the pile that exceed its structural strength. Typical structural steel shapes of pile anchors consist of pipe piles, wide flange sections, or built-up sections composed of T-sections. A pile anchor must be fitted with a mooring line connection, and pipe piles are well suited as anchors, because they can sustain loading equally in any direction (although the mooring-line connection may not). In contrast, wide-flange sections possess both a weak and a strong axis against bending. Built-up sections may be fabricated with other structural shapes to resist either multidirectional or unidirectional loading.

A.11.2.5.3 Deadweight Anchors A deadweight anchor is a large mass of concrete or steel that relies on its own weight to resist lateral and uplift loading (see Fig. A-49). Lateral capacity of a deadweight anchor will not exceed the weight of the anchor and is more often some fraction of it. Deadweight-anchor construction may vary from simple concrete clumps to specially manufactured concrete and steel anchors with shear keys.

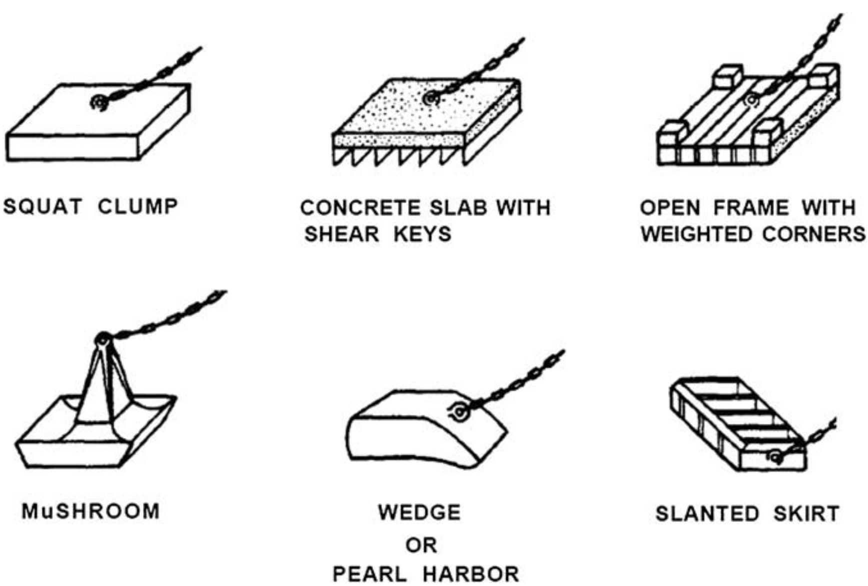

Fig. A-49. Types of deadweight anchors
Source: U.S. Navy (1985).

Deadweight anchors are generally larger and heavier than other types of anchors. Deadweight anchors are designed to withstand uplift and lateral loads and overturning moments. Uplift loads are resisted by anchor weight and by breakout forces. Lateral capacity is attained by mobilizing soil strength through a number of mechanisms, depending on anchor and soil type. In its most simple form, the lateral load is resisted by static friction between the anchor block and the sea floor. Static-friction coefficients are generally less for cohesive sea floors (clay or mud) than for cohesionless sea floors (sand or gravel). Friction coefficient values are often very small immediately after anchor placement on cohesive seafloors. However, these values increase with time as the soil beneath the anchor consolidates and strengthens. Deadweight anchors should not be used on sloped seafloors.

A deadweight anchor will drag when the applied load exceeds the resistance offered by static friction. Once dragging occurs, the anchor tends to dig in somewhat as soil builds up in front of the anchor. Under these circumstances, the lateral capacity of the anchor results from shear forces along the anchor base and sides and from the forces required to cause failure of the wedge of soil in front of the anchor. The lateral capacity of a deadweight anchor on cohesive seafloors may be increased with shear keys. Shear keys are designed to penetrate weaker surface soil to the deeper, stronger material. Shear keys may be located on the perimeter of the anchor to prevent undermining of the anchor. Shear keys are not used for cohesionless soils because they provide minimal additional lateral capacity.

A.11.2.5.4 Suction Pile Anchors Suction anchors gain their vertical capacity from the weight of the plug inside and the friction (shear) on the outer surfaces and the negative end bearing, which is the force required to separate the lower end of the soil plug from the undisturbed soil. Because taut moorings impose large lateral loads, chains are attached approximately halfway down the length of the anchor. This is a point of very high stress and potential fatigue on the cylinder, which must be heavily reinforced.

Typically, suction anchors are greater than 15 ft (5 m) in diameter and 60–90 ft (20–30 m) long. The suction anchor is lowered to the sea bed with a valve on the top in the opened position and allowed to initially penetrate the sea bed surface under its own dead weight. Once on the sea bed, the top valve is closed and the water pumped out to create an under-pressure in the cylinder. This gives extra driving force equal to the net differential hydrostatic pressure over the cylinder's area. The under-pressure is limited by soil heave, which plugs the cylinder and prevents further penetration. If the top is sealed in service, the capacity increases with time.

For removal, the water is forced into the top of the anchor. By keeping the pressure on for several hours, the pour pressure in the soil is raised and the shear reduced. Suction anchors are mostly used in deeper water; they can be used in depths as shallow as 300 ft (92 m).

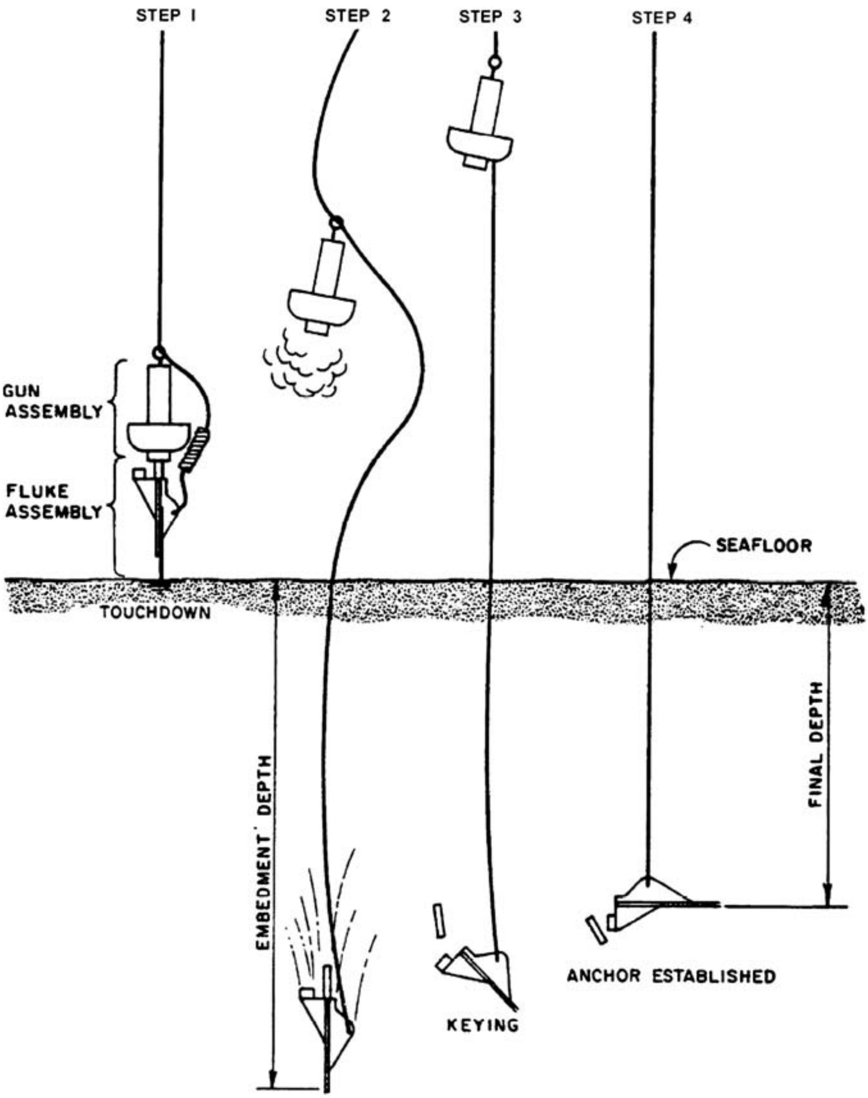

Fig. A-50. Propellant-embedded anchor
Source: U.S. Navy (1985).

A.11.2.5.5 Direct-Embedment Anchors A direct-embedment anchor is driven, vibrated, propelled, or screwed into the sea floor, after which the anchor fluke is expanded or reoriented to increase pullout resistance (see Fig. A-50). Direct-embedment anchors are capable of withstanding both uplift and lateral loading. Direct-embedment anchors achieve their holding capacity by mobilizing soil-bearing strength. Shallow anchor failure is characterized by removal of the soil plug overlying the anchor fluke as the anchor is displaced under loading. A deep anchor failure occurs when soil flows from above to below the anchor as the anchor is displaced under load. The tendency toward the shallow or deep anchor-failure mode depends on the size of the anchor fluke and the depth of embedment. Direct-embedment anchors are sensitive to dynamic loading. Therefore, design procedures must include analysis of anchor capacity under cyclic and impulse loadings.

A.11.2.6 Cathodic Protection System Many buoys are cathodically protected by sacrificial zinc anodes attached to the hull. The condition, dimensions, and connection of the anodes need to be checked during an underwater investigation. To increase the protection for chains, continuity cables are attached to the anode and woven through the chain and connected at every eighth link by means of clamps or U-bolts. In this fashion, a shot of chain can be protected by a single anode and should be inspected. Electrical potential readings should be taken to determine the effectiveness of the cathodic protection system. The inspection of the cathodic protection system is further covered in Section A.14.

A.12 WAVE SCREENS AND ATTENUATORS

A.12.1 General

Many marinas and small harbors include wave attenuation structures to reduce the effects of wave action and wake on moored vessels. These structures can be fixed or floating and are typically installed where a rubble mound breakwater is too costly or has too much of an environmental impact to be practical. These structures can be integrated into other components of a marina or harbor, or can be stand-alone structures. The orientation of these structures is designed to block waves from a specified direction, typically dictated by the prevailing wind direction.

The typical construction of a fixed wave screen includes piles that support wave screen panels or vertical planks. The panels or planks extend a specified depth below sea level to disrupt the natural formation of waves as they travel toward the facility. The panels are connected together with beams or wales that span between the support piles. The panels or planks typically have gaps between one another to allow water to flow through the structure.

The typical construction of a floating wave attenuator is similar to a floating dock. The floats are designed to extend a specified depth below sea level to disrupt the formation of waves. The floating units are either fixed in place by guide piles or by an anchorage system. The floating units are typically connected to each other with hardware specifically designed by the wave attenuator manufacturer.

A.12.2 Typical Components and Problem Areas

Because wave screens and wave attenuation structures are designed to block waves and wakes, they are typically oriented in the path of waves. As such, they are subject to impact from debris and heavy loading during storm conditions. If these structures are not integrated into other elements of the marina or harbor, such as an access dock or mooring float, their structural integrity is not as critical as other structures that support pedestrian or vessel loads. Table A-15 summarizes what to look for when inspecting the condition of these systems.

A.12.2.1 Fixed Wave Screens

A.12.2.1.1 Piles The piles that support fixed wave screens should be inspected for damage and deterioration similar to other piles in the marine environment (refer to Section A.2 for additional information). Additional attention should be paid to a few elements unique to these structures. The vertical alignment of the piles should be verified. Some wave screens are designed with a batter, and some are designed with vertical piles. Design and as-built drawings should be available prior to the inspection. If the piles were originally designed to be vertical and they are not, this could indicate that the allowable lateral loads on the piles are being exceeded. The exposed length of the pile should be measured during inspection of these structures to verify that the sea bed or mudline has not changed significantly. A greater exposed pile length can have a significant effect on the lateral capacity of the piles supporting the wave screen.

A.12.2.1.2 Beams and Wales The beams and wales that span the support piles and support the wave screen panels or planks should be inspected for damage and deterioration as described in Section A.2. Attention should be paid to the connection between the beams and the piles and between the beams and the panels or planks. These structures are exposed to significant lateral loads, and connections may be the first element to show signs of damage or deterioration.

A.12.2.1.3 Panels or Planks The panels or planks that provide the wave screening should be inspected for damage and deterioration. The length that these elements extend below water should be verified against the design or

Table A-15. Wave Screens and Attenuators: Checklist of Inspections

Type	Component	What to Look for	Comments
Fixed wave screens	Support piles	Damaged or "missing" piles, deterioration, alignment (straightness) of piles from top to bottom, exposed length	Check for "ice jacking" in colder climates
	Beams and wales	Damaged or "missing" elements, deterioration, connecting hardware condition	
	Panels or planks	Damaged or "missing" elements, deterioration, connecting hardware condition, length of element below water	Check for fouling from floating debris
Floating wave attenuators	Guide piles	Damaged or "missing" piles, deterioration, alignment (straightness) of piles from top to bottom, exposed length	Check abrasion at pile guides
	Floats	General alignment, condition of attached wave attenuation devices, connection between floats, bottom surface condition	See Section A.9 for general float inspection
	Anchor chain or cables	General condition, wear/corrosion, distortion, connection to float, connection to anchor	
	Anchors	Location of anchor, embedment, general condition	

as-built drawings. The depth these elements extend below water is critical in their effectiveness in attenuating waves. In addition, the wave screens should be inspected for debris that may be trapped between the panels or planks. A buildup of debris adds load to the overall system by preventing flow through the system.

A.12.2.2 Floating Wave Attenuators

A.12.2.2.1 Guide Piles Guide piles can be of timber, steel, or concrete and should be inspected for damage and deterioration similar to other piles in the marine environment. In floating wave attenuation structures, the guide piles are subject to significant lateral loads and wear from the vertical travel of the floats they support. Abrasion in the tidal zone should be inspected. Guide piles are always installed vertically, and plumbness should be verified in the field. If the piles are not vertical, it may be an indication that the allowable lateral load of the pile has been exceeded.

A.12.2.2.2 Floats Similar to marina floats, the float units that make up a wave attenuation structure should be inspected for alignment, damage, and deterioration. Listing or partial submersion may indicate that the flotation system is damaged. The floats should be inspected based on their material composition and their design details. These floats may be either timber or steel with flotation units integrated into the structure or concrete box construction. Flotation units may be constructed of Styrofoam, closed cell foam, polystyrene units, or various other flotation systems. The integrity of the flotation should be visually inspected for soundness. Concrete box construction may rely on the buoyancy of the box to maintain flotation and should be inspected for leakage, cracks, or spalls.

The pile guides on float systems may be cast into the units or external guides mounted on the face of the units. These should be inspected to verify they are operating as designed. Many have rollers or elastomeric units to provide protection to the guides. These elements should be inspected to verify they are operating as designed.

A.12.2.2.3 Anchor Chain or Cables For systems that are secured by anchor chains or cables, these elements should be inspected to verify the integrity of the anchorage. Chains should be visually inspected, and links should be measured to check for corrosion. Cables should be inspected for frays and integrity of the strands making up the cable. Connections between the anchor chain or cable and float unit should be inspected. If a winch system is used to maintain tension on the anchor's lines, it should be inspected for function and condition. Winch stands that are bent out of alignment may indicate impact damage or overloading. The connection between the anchor line and the anchor block at the mudline should be inspected for damage and deterioration.

A.12.2.2.4 Anchor For anchored systems, the location of anchor blocks should be verified. Movement of the anchor blocks may indicate that the design loads have been exceeded. This may also be indicated by a change in orientation of the overall system. Anchors may be constructed of concrete block, helical piles, mushroom anchors, or drag anchors. These anchors may be buried and cannot be visually inspected. In this case, the orientation of the overall system should be verified to investigate possible movement of the system. Proper alignment of the wave attenuation system is a key factor in the effectiveness of the system.

A.13 WATERFRONT SECURITY BARRIERS

A.13.1 General

Waterfront security barriers are becoming common for Department of Defense installations and major ports worldwide. Typical waterfront security barriers (WSB) use a continuous floating "fence" that protects maritime assets located within its perimeter. It also serves as a "line of demarcation" to separate controlled areas from commercial and public water traffic. The WSB fence is very much like a common chain link fence on land, except that it floats on the water. Instead of fence posts, it has moored buoys that anchor it into position. Instead of chain link, the WSB has a series of connected modular floats that hold up a net.

Having been through many revisions, WSBs have taken on a different appearance in the many locations where they are deployed. Early designs utilized entirely steel construction, whereas more recent upgrades have transitioned to fiberglass and high density polyethylene (HDPE) components. Regardless of construction materials, the WSB comprises the same primary components: buoys, floats (pontoons and beam), connectors, and netting.

The WSB's moored (anchored) buoys are used to hold the barrier strings (multiple floats connected together) in place on the water at most sites. Some shallow-draft locations have anchors attached directly to WSB floats. Other locations have only the end of the barrier attached to a vertical wire rope instead of a buoy. Function and construction of buoys may vary.

A.13.2 Typical Components and Problem Areas

Several different WSB float designs are used at various barrier sites. The older WSB floats typically have steel pontoons and round-pipe trusses, whereas the newer floats have plastic HDPE pontoons and square-tube trusses. The WSB connectors are used to attach the WSB floats to each other and to the buoys. Most of these are static connectors; once installed, they are not disconnected from the floats and buoys. However, some connectors are designed for frequent opening and closing at barrier gates to allow ships and other vessels to pass.

Conditions that degrade the ability of any portion of the barrier to stop a craft should be reported immediately to Harbor Control so that they can arrange back-up security. These conditions include floats or buoys that are close to sinking, the failure of both primary and secondary connectors, and significant damage to the netting. Table A-16 summarizes what to look for when inspecting the condition of these barriers.

A.14 COATINGS AND CATHODIC PROTECTION SYSTEMS

A.14.1 General

Marine structures constructed with steel or reinforced concrete components are subject to corrosion. To prolong their service life, these structures can be fitted with a cathodic protection system. Cathodic protection is simply a means of making a structure the cathode in an external electrochemical cell. This transfers the uncontrolled corrosion of the structure to controlled corrosion of external anodes, which can be replaced. Cathodic protection causes an electrochemical reaction that can result in an alkaline film forming on the cathode. The reaction is called polarization of the structure.

Waterfront structures are typically divided into corrosion zones. These include the atmospheric zone, the splash zone, the tidal zone, the immersed zone, and the embedded zone. Corrosion rates are typically highest in the splash zone and at the lower end of the tidal zone.

Three types of typical cathodic protection systems exist: coatings; the galvanic anode system, also known as the passive or sacrificial system; and the impressed current system, also known as the active system.

To provide proper cathodic protection to an entire marine structure, all submerged steel members and components must be bonded together metallically to ensure electrical continuity. For instance, on pile structures, each bent of a pier would typically be tied together electrically by means of welded cross bracing. For steel sheet piling, electrical continuity may be achieved by welding across interlocks. Continuity may be achieved on concrete structures by bonding the reinforcing steel or by providing supplemental wire connections.

A.14.2 Typical Components and Problem Areas

Cathodic protection systems for waterfront structures often include both above- and below-water components. The below-water portion of the structure may experience the largest demand on the cathodic protection system. Therefore, an underwater investigation may be required for complete verification of system performance. Table A-17 summarizes what to look for when inspecting the condition of these systems.

A.14.2.1 Coatings Inspection of coatings could be considered a specialty discipline. The coating industry trains and certifies coating inspectors.

Table A-16. Waterfront Security Barriers: Checklist for Inspections

Section or Part	What to Look for	Comments
WSB floats	Verify floats are intact, not showing signs of advanced corrosion, and not taking on water internally	The freeboard of multiple floats should be compared to determine if any one buoy is significantly lower in the water, indicating possible water intrusion issues
WSB buoys	Verify buoys are intact, not showing signs of advanced corrosion, and not taking on water internally; verify buoy locations have not changed from the original configuration and mooring chains are not showing greater than 80% wear	Compare the freeboard of multiple buoys to determine if any one buoy is significantly lower in the water, indicating possible water intrusion issues. Typically diving will be required to inspect mooring chains. See Section A.11 for additional information.
Nets	Verify all nets are intact, properly connected to structural members, and hung properly	The lifespan of the WSB nets may be decreased with exposure to natural outdoor environments
Connectors	Verify all connections, both primary and back up (if applicable), are intact and operating properly; verify connections on both ends are secure and properly tightened	Periodically check urethane connectors for cracking and interior deterioration
Kayak guards	Verify all kayak guards are intact and properly connected to the WSB	Kayak guards should be positioned to prevent small vessels from transiting under the WSB
Navigational lights	Verify all navigation lights are properly working and connected securely to the WSB; verify the power supply, if solar, isn't covered by bird guano	Navigational lights may need to be periodically cleaned to prolong life
Warning signs	Verify warning signs are legible, properly mounted to the WSB, and appropriately positioned	Warning signs may need to be periodically cleaned to ensure legibility

Table A-17. Cathodic Protection Systems: Checklist for Inspections

Element	Component	What to Look for	Comments
Coating	Overall	General condition, amount of coverage, amount of bare steel exposed, dry film thickness, adhesion/disbondment	
	Zones	Atmospheric zone condition	
		Splash zone condition	
		Tidal zone condition	Include description of marine growth
		Submerged zone condition	Include description of marine growth
	Edges	Condition of coating at edges of flanges and other members	
	Welds and connections	Condition of coating at welds and other connections	Look for disbondment at welds, bolt heads, and other connections
Galvanizing	Overall	General condition, layer thickness	
	Zones	Atmospheric zone condition	
		Splash zone condition	
		Tidal zone condition	Include description of marine growth
		Submerged zone condition	Include description of marine growth
	Welds and connections	Condition of galvanizing at welds and other connections	

Galvanic cathodic protection system	Anodes	Size	Record dimensions and % remaining
		General condition	Describe appearance
	Connection	Welded	
		Bolted	
		Hanging	
		Sled	
		Cables	
Impressed current cathodic protection system	Rectifier	AC power supply to unit	
		AC power across transformer	
		DC power across rectifier	
		DC power at output taps	
		Voltage and current to anodes	Record voltage and current levels
	Cables	General condition	
		Connections	
		General condition	
	Anodes	Size	

The reader is referred to the National Association of Corrosion Engineers (NACE), the Society for Protective Coatings (SPC), and the American Galvanizers Association (AGA) for information related to certified coating inspectors and important standards and reference materials. It is beyond the scope of this manual to summarize the large body of knowledge surrounding this topic. This manual is concerned with some of the basic concepts associated with coating inspections.

Visual inspection of coatings should include a description of the coatings at various zones of the structure and an estimate of the amount of bare steel exposed and/or of the remaining coating. For example, "85% of the coating appears to be intact." Check edges of members, the area around fasteners and connections, and areas that retain water for coating disbondment. The inspector should look for cracking, peeling, or blistering of the paint, and report chalking, which is deterioration from UV light.

Coatings can be tested for dry film thickness. Magnetic pull-off gauges and ultrasonic instruments exist for this task. Coatings can also be tested for adhesion. Typically, a disk is glued to the surface of the coating, and a special hydraulic instrument is used to pull a divot of coating from the base metal. This instrument is calibrated to measure coating adhesion.

Visual inspection of galvanizing should include a description of the coatings at various zones of the structure and of the thickness, appearance, and level of marine growth. It should also include an examination and description of whether the coating is continuous or has bare steel patches exposed. Fresh galvanizing typically has a complete and continuous thick silver coating and has little or no marine growth. As the galvanizing is consumed, the coating becomes thinner. At some point, marine growth starts to adhere to the coating. Once the coating nears the end of its service life, gaps in the galvanizing will appear and bare steel will be seen in patches. Observing different conditions of the galvanizing at different zones on the same structure occurs frequently. For example, galvanizing may be nearly consumed in the intertidal zone but be in good condition in the atmospheric zone.

A.14.2.2 Galvanic Cathodic Protection System Galvanic anode systems are subject to various types of deterioration. The three most common types are consumed anodes, broken connection wires, and coating failure (see previous section). Impact forces, abrasion, and environmental factors can cause these types of damage.

A.14.2.2.1 Anodes Anodes should be visually inspected for even consumption. No evidence of consumption indicates the system is not effective. Observe and record the physical condition of the anodes, including the general dimensions, such as cross-section dimensions and length. If the original dimensions are known, the percentage of remaining material can be estimated. Report the presence or absence of marine growth. Typically, an active anode has little or no marine growth attached and will have a chalky, flaky exterior. An anode with marine growth and a hard exterior may be passivated and may not be working. Anodes should be replaced before they are completely consumed to ensure continued effective functioning of the system.

A.14.2.2.2 Connections The connections and attachments of the anodes should be inspected, and the condition reported. Attachments often provide the electrical connection to the structure. This connection is critical to the operation of the anode and should be identified, described, and reported. If the electrical connection is made by a mechanical clamp, the clamp must be in firm contact with the structure. Galvanic anodes typically have very low driving voltages, often less than 1 volt, so any resistance at the connection can have a large effect on the performance of the anode. All connections in the system should likewise be examined to ensure they are sound, e.g., welded cross-bracing, connection wires, support wires, straps, and conduits. These components ensure the electrical continuity of the structure; breaches can affect the performance of the system. Wave action, debris, ice, severe weather, and impact can damage these components.

A.14.2.2.3 Potential Survey A potential survey can be conducted to verify cathodic protection is adequate by conducting a potential survey using a reference cell and a voltmeter to take readings at regular intervals along members. The readings also are used to verify that all of the members in the structure are continuous and are protected. See the following section for more information.

A.14.2.3 Impressed Current Cathodic Protection System As with the galvanic cathodic protections system, the impressed current system should be inspected to ensure proper operations.

A.14.2.3.1 Rectifier Significant voltage and current may be present at the rectifier, and detailed inspection should only be done by an electrician or trained individual. Having an electrician turn the power off for a visual inspection may be appropriate in some situations. Some rectifiers have an indicator light to signify that the power is on. In this case, the condition of the indicator light should be noted. Some rectifiers have voltage and amperage meters located on the front panel. If so equipped, document the voltage and amperage. These items may indicate that the power is on and current is flowing to the anodes. Rectifiers are subject to electrical failure and broken wires, which can result in maladjustment of the system and lead to under or overprotection of the structure and to stray current corrosion on adjacent structures. Insufficient current results in under protection and corrosion. Excessive current leads to over protection, failure of protective coatings, and the potential for both hydrogen embrittlement of high-strength steel prestressing wire and stray current corrosion on adjacent structures.

Anodes, connections, and protective coatings should be examined for damage and deterioration as described previously for the galvanic system. A typical mode of failure for an impressed current anode system is cable failure. If the anodes are visible, the size and condition should be noted. Also perform a potential survey to verify the cathodic protection adequacy.

A.14.2.3.2 Potential Survey One of the most common methods of evaluating cathodic protection is to measure the potential or voltage of the structure with respect to a reference electrode. The reference electrode is referred to as a half cell, because it acts as one pole; the structure acts as the other pole in the cell. Various types of standard reference electrodes exist. For field investigations, the two most common are the copper-copper sulfate (Cu-CUSO4) and the Ag-AgCl reference half-cells. Cu-CUSO4 electrodes are commonly used in above water surveys to take potential readings on decks and on the ground over buried structures. Ag-AgCl electrodes are commonly used to take potentials on submerged structures.

Ag-AgCl readings of −0.85 Volts or more negative typically indicate adequate cathodic protection in seawater. Readings of about −1.1 volts are typical near active sacrificial anodes. Readings of up to about −2.0 volts sometimes indicate active impressed current anodes. Because the most important thing is not the voltage at the anode but the voltage at the structure, readings should be taken in areas distant from the anodes. Impressed current systems should be turned off just prior to taking readings. In this case, the polarized or residual potential of the structure will be taken. Corroding steel in seawater with no cathodic protections typically produces readings of between −0.5 and −0.7 volts.

A.14.2.3.3 Stray Currents Stray electrical currents promote corrosion by accelerating the electrochemical process. These currents can originate from a variety of sources including welding activity, faulty grounds from vessels or other structures, cathodic protection systems for neighboring structures or pipelines, transit systems, DC industrial generators, power stations, or substations. This type of accelerated corrosion and member deterioration also results in damage similar to that encountered in steel and concrete structures.

A.15 MARINA AND SMALL CRAFT HARBOR COMPONENTS

A.15.1 General

Marinas and small craft harbors may comprise various marine structures, many of which are common to other types of waterfront facilities. Open-piled piers, bulkheads, timber cribs, wave attenuators, breakwaters, and gangways are all structures that may form part of a marina and are described elsewhere in this appendix. This section deals specifically with those marine components that are parts of marinas such as floats, anchor systems, fenders, roofs, gangways, appurtenances, and utilities. Table A-18 summarizes some of the more common problem areas associated with the specific above water components for marinas.

A.15.2 Typical Components and Problem Areas

A.15.2.1 Floats Floating docks at marinas typically consist of floating units that are anchored by piles or by chain and anchors. Floats come in various materials such as timber, concrete, aluminum, metal, and composites. Other materials used in float construction include foam and rubber; these materials are also used in conjunction with some of the other materials noted previously. Foam billets may need to be coated to protect against deterioration caused by the environment or exposure to fuel and oil in the water. Plastic tubs are often used in lightweight applications such as floats for residential recreational craft. Hardware or rubber sheets are often used to connect the float modules. Where finger floats attach to main floats, steel or aluminum knee braces or triangles are used to provide connectivity and stability. Hardware used for floats is generally hot-dip galvanized. Figure A-51 depicts a typical marine float with tall guide piles to accommodate a wide range of water level elevations.

Inspections of floating dock components above the water can be performed by individuals familiar with these types of structures. Divers must be used to inspect the undersides of floats. Typical problems encountered on floats generally relate to deterioration of the specific float material.

Floats should not have a visible list and must float high enough to keep walers out of the splash zone, typically no less than 12 in. for small craft. The timber float in its simplest form consists of a timber deck supported on log or timber framing. Loss of buoyancy from waterlogging of the timbers can become a problem. Modern timber floats may incorporate polystyrene flotation billets to improve buoyancy. However, these systems may lose buoyancy due to leakage associated with shell cracking or deterioration; impact damage (particularly for concrete and fiberglass floats, which may be more susceptible to cracking), manhole openings, accumulation of marine growth on floats and anchor chains, and deterioration of foam buoyancy units. Float hardware should be inspected for wear, stress/fatigue damage to float connecting components, loosened float waler nuts, or missing hardware components.

A.15.2.2 Anchor Systems Anchors for marina floats secured by chains or lines usually consist of precast concrete blocks or mushroom anchors placed directly on the bottom. They are most suitable for soft bottom

Table A-18. Marinas and Small Craft Harbors: Checklist for Inspections

Component	Section or Part	What to Look for	Comments
Floats	General	Excessive float misalignment, tilt, reduced freeboard	Misalignment may suggest anchor slippage; tilt or loss of freeboard could be caused by leakage, excessive marine growth, etc.
	Decking or surface	Worn, uneven, spalled, loss of nonslip surfacing, corrosion, loose deck members	May result in a tripping or slipping safety hazard
	Shell	Surface deterioration; physical damage (dents, holes, etc.); loose or leaking access hatch covers	Check for waterlogged filler
	Joints between float units	Damaged, loose, and/or deteriorated connecting hardware; excessive float misalignment	
Anchor systems and piles	Anchor chain and connecting hardware	General condition, wear/corrosion, distortion	
	Anchor cable winches	Secure attachment to deck, verify cables are not binding within winch	
	Pile system	Damaged or “missing” piles, alignment (straightness) of piles from top to bottom	Check for “ice jacking” in colder climates
	Pile surfaces	Deterioration, wear/corrosion, mechanical damage	
	Pile guides	Deterioration, damage, wear/corrosion, missing components, binding	Integrity and condition of pile/float connection

Fenders and appurtenances	Fenders or bumpers	Deterioration, missing/loose members, condition of attachment hardware	Check corner bumpers
	Cleats	Damage, missing connecting hardware	
	Ladders	Damage, missing connecting hardware	
Roofs and covers	Roof panels	Holes, tears, missing connectors	
	Trusses and columns	General condition, missing or bent members, missing or damaged connecting hardware, column attachments	

Fig. A-51. Timber float on polyethylene flotation billets
Source: Courtesy of Reid Middleton, Inc., reproduced with permission.

conditions where they can achieve improved resistance against sliding. Screwed-in helical piles may also be used as anchors. Chains, cables, or lines are normally used to secure the floats to their anchors.

Guide piles consisting of concrete, steel, timber, or composite piling are another type of float anchorage system. The connection between float and pile is a critical system component subjected to heavy wear and repeated load reversals. Metal or timber guides attached to the float encompass the piles, allowing the piles to move vertically with the changing tides and laterally with wind and wave forces acting on the float. Guides may be internal or external to the float modules. Antifriction blocks or wheels are used to permit the pile to move freely within the guide. Figure A-52 shows a typical steel pile and guide.

If the anchor systems consist of an anchor chain assembly, any above water connecting hardware at the float should be inspected for general condition. Cable winches should be inspected for loose hardware, corrosion, and freedom of movement. For floats that utilize a pile and guide system, guides should be inspected for condition, wear, missing sliding blocks or wheels and hardware, and binding. Float and deck material adjacent to the guides should be inspected for stress cracking.

A.15.2.3 Fenders (Bumpers) Timber walers that are part of the structural unit sometimes serve as fender protection on concrete and timber floats. Timber rub boards (treated or untreated), low-friction UHMW, or vinyl bumpers are often added to protect both the floats and vessels. Attachment to the floats may be with bolts, screws, or nails. Corner bumpers often consist of vinyl bumpers or wheeled assemblies.

Fig. A-52. Galvanized steel pile with UHMW antifriction guides
Source: Courtesy of Ralph Petereit, reproduced with permission.

Fenders are made mainly of timber, vinyl, or rubber. More recently, UHMW has been used, but this provides protection more to the dock than to the vessel. Other material sometimes used includes fire hose, tires, and rubber belts. Depending on the material, fenders should be inspected for missing sections, material degradation, rot, cracks, tears, and missing attachment hardware.

Vinyl bumpers are particularly susceptible to attachment hardware pullout, because galvanized nails are often used, which do not stand up well to heavy vessel impact accompanied by shear forces. Corner bumpers that utilize wheels should be inspected for alignment and freedom of movement.

A.15.2.4 Covers and Roofs Rigid covers and roofs provide weather protection for moored vessels. Roofing material is sloped to provide rain runoff and consists primarily of metal sheeting (panels), although wood or fiberglass are also used. The sheeting is attached to supporting roof trusses with rivets or bolts. Posts or column trusses extend from the roof and attach to the float deck with bolts. In some cases, roof-covered slips may be partially or fully enclosed by walls. Although lightweight materials are often used to reduce the amount of additional flotation needed, they must be strong enough to resist expected winds.

Covers and roofs should be inspected for missing or loose roof panels, missing roof connecting hardware, holes, and general condition. Trusses, columns, and posts should be inspected for missing elements, deterioration or corrosion, missing connectors, and attachment to the float. Walls, if present, should be inspected for general condition.

A.15.2.5 Appurtenances Primary appurtenances consist of cleats and ladders. Secondary appurtenances include float-mounted safety items and amenities such as fire extinguishers, fire hoses and cabinets, float throw rings on stands, telephones, utility pedestals, and dock storage boxes. Some float-mounted appurtenances are shown in Fig. A-53.

Appurtenance condition is determined by age and wear. Appurtenances should be checked for missing connecting hardware, attachment condition, damage, deterioration, and safety. Ladders should be inspected for attachment to the float, deterioration, and missing rungs. Ladder rungs should extend at least two rungs into the water to ease climbing out of the water. If the rungs telescope downward when weight is applied, they should be checked for freedom of movement. Secondary appurtenances should be inspected for attachment to the float and general condition.

A.15.2.6 Utilities Utilities, such as potable water, electrical cables (including cable TV and telephone), fuel stations, piping for sewage

Fig. A-53. Typical float-mounted appurtenances: throw ring, fire hose, and fire pull box
Source: Courtesy of Reid Middleton, Inc., reproduced with permission.

Fig. A-54. Marine growth on utility cable tide loop
Source: Courtesy of Ralph Petereit, reproduced with permission.

pumpouts, and storm sewer outfalls for upland drainage, are normally found at marinas. Utilities transition from the shore to the floats through tide loops lying on the embankment or mounted on the gangway. Once on the floats, utilities may be run outside or inside the floats.

The above water components of these utilities should be inspected as outlined in Section A.21. Internal utilities within junction boxes are not usually checked. Utility tide loops and utilities running under gangways and along the outside edges of floats should be checked, if accessible. Fig. A-54 shows a utility tide loop covered in marine growth. Marine growth adds stress to the cables, couplings, and supports and often hides visible damage.

A.16 GANGWAYS

A.16.1 General

Gangways are transition structures providing access between land and marina floats or between fixed structures and vessels. They are typically hinged on the landward end and are free to move (roll, slide, or pivot) on the float end. Attached to the free end of the gangway are skids or rollers that travel over threshold plates. Occasionally, vessel gangways are used, which are fixed to the vessel and free on the structure side. As gangways can be subject to fatigue damage, a full gangway inspection is beyond the scope of

Table A-19. Gangways: Checklist for Inspections

Component	What to Look for	Comments
Ramp structural members	Missing or bent members, weld cracks, and damaged coatings	See Section A.21 for utilities
Ramp deck, walking surface	General condition and antislip elements	
Skids, rollers	General condition, freedom of movement	
Guardrails	General condition, height, intermediate rail, attachment to deck	Pay particular attention to splinters (if wood) or burrs (if metal), which may cause hand injury
Connections	Deterioration, signs of overstress, fatigue, or leaks	

this manual. Table A-19 summarizes some of the more common problem areas associated with the specific above water components for marinas.

Gangways are typically constructed of aluminum to be lightweight, but they may also be constructed of steel. Guardrails and antislip decking are provided for safety. Gangway slopes vary with the water level but should always slope down toward the float end. Gangway width and length vary. Several manufacturers have standardized designs that can meet the needs of most marina and float owners. Handicapped accessible ramps consisting of electrically operated lifts can also be provided. An 80-ft long heavy-duty marina gangway is shown in Fig. A-55.

Larger gangways, like cruise vessel mobile passenger gangways, are often used to provide access between buildings above the first story and higher decks of vessels. They are typically fabricated from structural steel and are wheel-based mechanical devices that use a combination of electrical and hydraulic power systems. These gangways can be positioned in a particular location to interface with a ship and facilitate the embarkation/disembarkation of passengers and supplies. Structural steel elements should be inspected and assessed in accordance with the recommendations for steel structures described in this manual. Inspection and assessment of the electrical systems, hydraulic elements, and appurtenances is beyond the scope of this document. A mobile passenger gangway is shown in Fig. A-56.

Fig. A-55. 80-ft long heavy-duty gangway
Source: Courtesy of Reid Middleton, Inc., reproduced with permission.

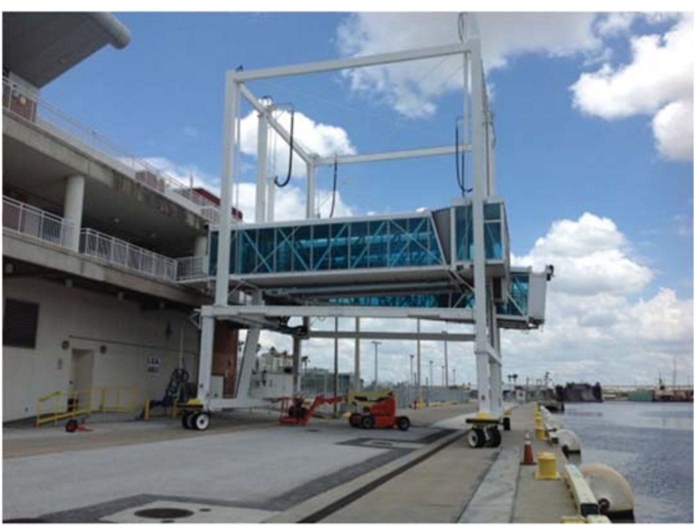

Fig. A-56. Cruise vessel mobile passenger gangway
Source: Courtesy of Tampa Port Authority, reproduced with permission.

A.16.2 Typical Components and Problem Areas

A.16.2.1 Ramp Discussion of typical components focuses primarily on smaller marina-type gangways. The ramp consists of a travel surface and its supporting structure. Depending on the design, the structure may provide its strength from either below or above the deck. Walking surfaces, which should be provided with antislip features or materials, may consist of grating, diamond plating, wood elements, or plywood.

Aluminum and galvanized steel ramps are corrosion resistant. Whereas lighter-duty ramps may have bolted components, heavier-duty ramps are typically welded. Welds should be visually inspected for cracking or other signs of stress and fatigue, and connections should be inspected for corrosion. Inaccessible welds should be noted. Steel connections used on aluminum elements should be inspected for accelerated corrosion caused by contact with dissimilar metals. Steel ramps should be inspected for weld cracks, tight connections, and corrosion. Galvanizing and coatings should be inspected for condition. Skids and rollers at the gangway ends wear over time. Skids' ability to move freely should be verified, and rollers should be inspected for binding and flat spots. The surface that the skids or rollers ride on should be attached firmly to the float and not exhibit signs of excessive wear.

Because the travel surface gets frequent use, the condition of the antislip features should be evaluated for effectiveness. If grating is used, pay special attention to missing or corroded attachment clips. Inspect fiberglass grating for breaks or holes. Inspect wood and plywood deck surfaces for damage, deterioration, and rot. Because wood, when wet, is not very slip resistant, antislip materials or coatings are often added to the top surface; this material should be inspected for wear.

A.16.2.2 Guardrails Guardrails should be inspected for secure attachment to the ramp, including welds and connecting hardware, such as connecting pins. Also verify the height of the top railing and presence of an intermediate rail. Coated railings should be inspected for general condition.

Railings should be a minimum of 42 in. high, have at least one intermediate rail, and be located on each side of the ramp. Rails often extend up to 2 ft beyond the end of the ramp to provide additional safety. The railing material matches the ramp material and is primarily steel or aluminum. In the United States, additional requirements exist for the railing to be compliant with Americans with Disabilities Act (ADA) regulations.

A.16.2.3 Connections Connections from the gangway to the supporting structures include hinges, transition plates, and deck clips. A transition plate and rollers are shown in Fig. A-57. Inspection should focus on missing,

Fig. A-57. Gangway transition plate and gangway rollers
Source: Courtesy of Reid Middleton, Inc., reproduced with permission.

loose, or corroded connecting hardware and clips. Hinges at the top of the ramp should be free to move.

A.16.2.4 Utilities Utilities provided to marina floats are often routed alongside or beneath gangways. Hangars are used to attach the utilities to the structure. Deck lighting may be provided on handrails to increase night safety. These components should be inspected as outlined in Section A.21.

A.17 BOAT RAMPS

A.17.1 General

A boat ramp is an inclined surface that allows for the launch into and removal of a boat from the water. This section covers ramps used to launch boats using hydraulic and vehicle trailers. Ramps may consist of one or more lanes. Elements of a ramp include the toe, ramp, and transition curve.

Constructed primarily of cast-in-place concrete or precast concrete panels, some ramps may also use the natural material in the area, provided it has sufficient traction. Traction for concrete ramps is often provided through the use of roughened surfaces or V-shaped grooves. In freshwater areas, ramps can be constructed of heavy-duty timber planks, where traction is sometimes enhanced by attaching metal chain link or other metal fabric to the top surface. Ramps may have side curbs and end stops to prevent trailers from leaving the ramp. Material for the curbs and stops can include concrete, timber, rubber, or vinyl.

Boarding floats or piers are frequently provided to assist in the launch, retrieval, and queuing of boats. A transition plate spanning between the float and an abutment at the top of the ramp makes the float more accessible. In locations where water levels fluctuate, grounding skids or blocks are provided on the underside of the floats that may ground to prevent damage.

A.17.2 Typical Components and Problem Areas

Because boat ramps are located at the water's edge and consist of in-water and out-of-water elements, above water components are best inspected during low water levels. Table A-20 summarizes some of the more common problem areas associated with boat ramps.

A.17.2.1 Ramps Ramp surfaces are the most important component of a boat ramp; if the surface is in good condition a boat could be launched or retrieved even if it had damaged curbs or boarding floats. Therefore, inspection should focus on the general condition of the ramp. For ramps on natural ground, surfaces should be checked for potholes, buildup or drifting of aggregate, and loose deep soil. Concrete ramps should be inspected for undermining, spalls, cracks, reinforcing steel corrosion, and excessive aggregate exposure. Evaluate traction features, such as V-grooves and surface roughing. Asphalt ramps should be inspected for potholes and cracking. Document evidence of sediment accretion. Figure A-58 shows a boat ramp and boarding floats at low tide, exposing sediment buildup at the lower reaches of the ramp. Curbs should be inspected for damage. Concrete abutments rarely suffer damage but should be examined for evidence of vehicular impact.

Table A-20. Boat Ramps: Checklist for Inspections

Type	Component	What to Look for	Comments
Boarding floats	Grounding skids or blocks	Presence, condition	See Sections A.9 for floats and A.21 for utilities
Ramps	Ramp surface	Concrete condition, undermining, cracking, surface traction	
	Curbs	Damage	
	Abutment	Damage	

Fig. A-58. Boat ramp with sediment covering lower reach of ramp
Source: Courtesy of Ralph Petereit, reproduced with permission.

Propeller wash can scour the soil below the base of the ramp if it is not properly protected. This type of damage can typically only be observed by underwater inspection.

A.17.2.2 Boarding Floats Boarding floats should be examined in accordance with float inspections outlined in Section A.9. One advantage of observing floats out of the water is that all sides of each out-of-water float module can be examined. Damaged concrete, torn flotation material, holes and punctures, and deformations will be readily visible. In addition, the presence of grounding skids or blocks should be verified and their conditions noted. Inspect float connections to the abutment and transition plates.

A.18 MARINE RAILWAYS

A.18.1 General

A marine railway is a cradle-and-track system used to lift vessels out of the water. They can be used at dams, locks, portages, shipyards, and marinas. Typical operation consists of positioning the vessel over the cradle, raising the cradle carefully to allow the floating vessel to rest in a stable position on the cradle, and then winching the cradle and boat up out of the water or lowering down into the water.

A.18.2 Typical Components and Problem Areas

The main components of the marine railway are the track structure, the cradle, and the winching system. The track structure typically consists of two or more pile-supported track beams that are connected transversely to prevent the track gauge from changing. The cradle rests on either a system of free rollers or a wheel system built into the cradle. The cradle is typically raised and lowered by a cable winch system.

The pile supports, transverse beams, and track beams can be fabricated from timber, concrete, or steel members and should be inspected as described for open-piled structures with additional attention paid to the rail-to-track beam fastening system.

The cradle may also be fabricated from concrete, timber, or steel members; however, steel and timber are more commonly used. The inspection of the cradle system should be performed as described for typical above water structures with particular attention paid to the connections. The cable connection at the cradle should be thoroughly inspected for damage and corrosion.

The winch and braking system may be complex and, depending on its physical condition, may require inspection by a mechanical engineer experienced in winch design and inspection.

A.19 BULLRAILS, LADDERS, AND SAFETY FEATURES

A.19.1 General

Bullrails are the nosings or vertical projections at the waterward edge of a pier or wharf deck. They may be permanent, as in the case of a cast-in-place concrete structure, or removable, as in the case of a heavy timber cross section. Bullrails are essentially a safety measure installed to reduce the likelihood of a person or piece of moving equipment inadvertently going over the edge of the structure.

Ladders allow a person in the water near the face of the structure to climb out of the water to the top of the structure. Ladders are typically placed intermittently along the wharf or pier face to reduce swimming distance. To work as intended, a wharf-side ladder must extend below the lowest anticipated water surface by several feet. Constant wetting and drying of the ladder and connections by tidal action can accelerate corrosion if the materials are not treated to account for this.

In addition to bullrails and ladders, safety features on a waterfront facility may include Type IV (throwable) personal flotation devices (PFD), pedestrian refuges, hazard and pedestrian area striping, and audible alarms for moving equipment.

Fig. A-59. Split timber bullrail
Source: Courtesy of Simpson Gumpertz & Heger, Inc., reproduced with permission.

A.19.2 Typical Components and Problem Areas

A.19.2.1 Bullrails A visual inspection of the bullrails should focus on corroded connections, chipped or spalling elements, and areas damaged by equipment (see Figs. A-59 and A-60). Some bullrails are considered sacrificial, which should be considered when evaluating the extent of damage sustained. Take care to note defects or elements that could inhibit the bullrail from serving in its capacity as a safety feature.

A.19.2.2 Ladders Wharf-side ladders are a means of emergency egress from the water (see Fig. A-61). Wharf-side ladders typically do not have standard fall protection features. An inspection of a wharf-side ladder should include climbing the ladder, assuming the ladder appears safe. Field personnel should follow all appropriate safety precautions when climbing up the ladder.

A.19.2.3 Miscellaneous Safety Features Safe operation of a waterfront facility depends on the users of the facility. Examples of items to look for include improper stowage of dockside materials, missing or damaged safety equipment, inaccessible or hindered access to pedestrian refuge, and tangled or frayed mooring lines.

Inspectors of safety features should familiarize themselves with Occupational Safety and Health Administration (OSHA) documentation regarding

Fig. A-60. Concrete bullrail with integrated mooring points
Source: Courtesy of Port of Tacoma, reproduced with permission.

Fig. A-61. Wharf-side ladder
Source: Courtesy of Port of Tacoma, reproduced with permission.

safe conduct at marine terminals. Current OSHA information on traffic safety in marine terminals can be found in the document titled "Traffic Safety in Marine Terminals," which may be downloaded from the OSHA web site (OSHA 2007). This document is advisory in nature and is intended to assist employers in providing a safe and healthy workplace. At the time of publication of this manual, OSHA is considering revisions to the document.

A.20 CRANE RAILS, TRENCHING, AND CABLES

A.20.1 Crane Rails

Crane rails transfer gravity loads from a shore-side crane to the supporting structure. Crane rails run parallel to the longitudinal face of the supporting structure. Contemporary crane rails are installed using a continuous welded rail section; older installations may utilize jointed rail. They may bear on shim plates and flowable grout, or on cross ties on a ballasted substrate.

Crane rails are attached to the structure by mechanical anchors. In the case of concrete ties or a concrete substrate, these are typically metallic clips or clamps that hold the rail base in place by applying a compression force. In the case of timber cross-ties, standard rail spikes are used. Often crane rail anchorages are encased in asphalt or low-strength cementitious grout, making a visual inspection impossible.

A.20.2 Trenching and Cables

Power is supplied to shoreside cranes via an electrical cable or a collector bar system. Electrical cables can either be in an open trench (see Fig. A-62) or in a covered trench such as a Panzerbelt (see Fig. A-63).

Cable trenches run parallel to the wharf face, typically near the waterside crane rail. Crane cables are typically stored on the crane and played out from the crane on a self-return cable reel. Cables are laid out in the trench and connected to the power supply in a subsurface vault either on the wharf or on the uplands. Cables feed through the wharf via cable horns that allow the cables to lie in the trench in either direction along the face of the wharf. Cable horns allow the cables to penetrate the wharf structure and then run under the structure transverse to the crane rails and back to the power supply at an upland transfer station or substation. Cables may be visually inspected from the structure deck from a splice to the cable horn. In the case of an open-face wharf or pier, any other visual inspection of cable or conduit must occur below the deck structure. In the case of a closed-face wharf, power cables are either run in an accessible utility trench or buried and, therefore, unavailable for visual inspection.

Fig. A-62. Cable trench (to the right of the crane rail)
Source: Courtesy of Port of Tacoma, reproduced with permission.

Collector bar systems utilize live electrical buss bars in a hinged plate-covered trench parallel to the crane rails. As the crane moves along the rails, a wedge-shaped projection from the crane frame lifts the plates open and exposes the collector bars to the electrical connections feeding the crane.

A.20.3 Typical Components and Problem Areas

Visual inspection of crane rails may not reveal internal structural distress or connection/support issues that warrant attention. However, visual indications of rail or connection fatigue, delamination, and signs that the rail may be at the end of its useful life are often apparent. Visual inspection of electrical cables only reveals cracks in the insulation casing, or pinched or kinked cables. Shorts in the cable must be investigated by a qualified electrical equipment inspector. Table A-21 summarizes some of the more common problem areas associated with crane rails and associated components.

A.21 WATERFRONT UTILITY SYSTEMS

A.21.1 General

Utility systems are often essential components of military, industrial, commercial, or recreational waterfront facilities. They provide safe lighting, electrical power, water, sewer, and fire protection for people and equipment utilizing the structure.

Fig. A-63. Cable trench protection system
Source: Courtesy of Cavotec SA, reproduced with permission.

The most common waterfront utility systems are

- Potable water: Freshwater for drinking and washing.
- Nonpotable water: Freshwater or seawater for washing, flushing, or fire protection.
- Fire protection: Typically nonpotable water for containing fire-related emergencies. For flammable liquid handling facilities, fire protection may consist of foam or other medium in conjunction with water or dry chemical systems.

- Electrical power: Power transmission from source (power plant, generator, or local utility feed) to destination on pier (shore power station, disconnect, electrical panel, etc.). The final destination may provide power to vessels (cold ironing) or other large equipment (gantry cranes), or provide feeds for local services such as lighting, aids to navigation, security, or cathodic protection systems.
- Grounding system: Provides grounding for operational and personnel safety for all electrical systems, apparatuses, machinery, electrical conduit, and all accessories that are a part of the power distribution system. Grounding systems are also provided for structural supports, frames, towers, safety fencing, hardware, equipment enclosures, system neutrals, and buried ground cable networks and counter-poses used in substations and similar areas. Grounding systems also provide lightning protection.
- Communications: Provides speech or data transmission via wire or cable over distances (telephone, data transmission, coded transmission, cable TV, and signal or alarm circuits).
- Steam service: Provides steam along piers and other waterfront structures typically used for active military berthing and ship repair and at the perimeter of graving drydocks.
- Compressed air: Provides pressurized air for control or operation of pneumatic systems.
- Sewer/sanitary waste: Removes sewer/sanitary waste from the facility and/or from ship connections.
- Oily waste/waste oil: Removal of bilge or ballast water from vessels.
- Product lines: Provides petroleum, oil, lubricants, or chemicals that may be part of ship supply or part of commercial storage and transport operations.

Utility systems can be located directly on pier decks, within utility trenches, alongside piers, or underneath piers on pipe hangers. The specific location depends on the quantity and type of utility lines and the installation time. For example, new container facilities will likely be designed to accommodate the utilities in preformed conduits or trenches during construction. However, utility retrofits or upgrades for facilities with inadequate space may require new runs under or alongside the structure.

This section addresses the physical condition of visible utility components such as conduits, pipes, hangers, etc. Although testing the performance or code compliance of these systems is also important, this is beyond the scope of this manual.

A.21.2 Typical Components and Problem Areas

Inspectors should comply with all safety precautions, including lockout/tag-out for relevant systems. These precautions are particularly

Table A-21. Crane Rails, Trenching, and Cables: Checklist for Inspections

Element	Component	What to Look for	Comments
Crane rail	Head	"Mushrooming" or plastic deformation of running surface	Thin layers of steel may be seen as "sliding off" the rail head
		Uneven wear	
		Lateral, out-of-plane deformation	
	Web	Cracking at connection to head	
		Rotation	Indicates rail is insufficient size for loads applied or crane wheels are misaligned
	Joints	Worn connection plates	Look for widened bolt holes
		Loose bolts	
	Support	Cracking or spalling in grout under crane rail base	
	Connection to base	Loose clips or clamps	Rail attachments to concrete
		Loose or missing spikes	Rail attachments to timber ties

(Continued)

Table A-21. Crane Rails, Trenching, and Cables: Checklist for Inspections *(Continued)*

Element	Component	What to Look for	Comments
Trench, cable, and collector bars	Cable	Cracked insulation	Refer to facility operator immediately
		Burn marks, other signs of an electrical short	STOP! Initiate lockout/tagout process
		Kinked or bent cable	
		Cable in water (on deck or under deck)	
	Trench	Corrosion, concrete spalling	
		Operation of cover plates	
		Cover plates broken, buckled, or corroded	
		Debris in trench	
	Collector bars	Burn marks, other signs of an electrical short	STOP! Initiate lockout/tagout process
		Frayed or worn collector elements	
		Debris in collector trench	

important for grounding systems because grounding wires may or may not be in conduits and relatively low currents (approximately 5 mA) can be extremely dangerous. Table A-22 summarizes some of the more common problem areas associated with various utility systems.

A.21.2.1 Utility Supports

A.21.2.1.1 Pipe/Conduit Hangers Hangers, brackets, bolts, and specially fabricated supports and braces should be inspected for corrosion, damage, loose hardware, or other signs of connection failure. In addition, missing, broken, or structurally failed supports should be documented, as the conduits or piping may not be designed for the increased spans. Sagging or deflection of these lines is obvious signs of locations where hangers have completely failed. In addition, wood burning or charring at hanger contact points could indicate a grounding deficiency.

A.21.2.1.2 Trenches Utility trenches should be inspected for water intrusion or standing water, specifically at valves and connections. Trenches designed to be self-draining should be inspected for blocked drain outlets. Trenches with automatic pumps for drainage should be tested for proper operation by testing the float switch, if accessible.

A.21.2.1.3 Cover Plates, Access Hatches, and Manholes Plates, hatches, and manholes in decks should be inspected for flush-mounted covers to reduce tripping danger. These elements can also snag and damage mooring lines during line handling if they are damaged. In addition, corrosion, leakage, distortion, elongation, distorted holding clamps, and misalignment should be noted during the inspection.

A.21.2.2 Utility Systems

A.21.2.2.1 Piping Inspection of piping systems should generally be limited to visual inspection. Defects to note include obvious leakage; strain or torsion; excessive corrosion; failed coating; misalignment; lack of support; excessive vibration; broken, loose, deteriorated, or strained connections; and cracks or other breaches. In addition, inspectors should note worn or illegible identification markings and failed piping enclosures, such as insulation or heat tracing. Finally, obviously broken valves or gauges should be identified for further testing.

A.21.2.2.2 Conduit Visual inspection of conduit is similar to that of piping systems. Inspectors should note breaks, visible wires, corroded or mechanically damaged conduit, loose or missing attachments to structures, or failed conduit inspection plates.

A.21.2.2.3 Grounding Systems Grounding systems for lighting protection or electrical service may or may not be in conduits. In general, inspection

Table A-22. Waterfront Utilities: Checklist for Inspections

Type	Component	What to Look for	Comments
Utility support	Pipe or conduit hangers	Missing, broken, or structurally failed supports; corrosion; bending or distortion; loose hardware or other signs of connection failure	Sagging pipes or conduits are a sign of missing hangers
	Trenches	Water intrusion or ponding, failed drainage or pump systems	
	Cover plates or manholes	Improper seating on the frame, corrosion, leakage, distortion, elongation, distortion of holding clamps, and misalignment	
Utility runs	Piping	Obvious leakage; strain or torsion; excessive corrosion; failed coating; misalignment; lack of support; excessive vibration; broken, loose, deteriorated, or strained connections; and cracks or other breaches	
	Conduits	Breaks, visible wires, corroded or mechanically damaged conduit, loose or missing attachments to structures, failed conduit inspection plates	
	Fittings	Discontinuity from loose, missing, or broken connections; signs of burning or overheating; corrosion	

of these systems should be limited to visual review for discontinuity from loose, missing, or broken connections and signs of burning, overheating, or corrosion.

A.22 ANCHORS AND CHAINS

A.22.1 Routine Above Water Inspections

Routine inspection of the exposed portions of the anchor-and-chain system primarily consists of assessing the chain and hardware connection that is connected to a structure. The chain should be inspected for wear, distortion, corrosion, and alignment with the attachment point. This is best accomplished at a low water elevation to take advantage of the ability to see as much of the chain as possible. The connection hardware should be inspected for wear, distortion, corrosion, and a secure connection to the structure.

Some anchor system designs involve dissimilar material types connected to each other, such as a galvanized anchor chain and connection hardware attached to an epoxy-coated "black steel" mooring buoy. In this example, if the epoxy coating has deteriorated such that the two dissimilar metals are in contact, increased corrosion rates could occur at the intersection. Another similar scenario involves using nongalvanized (or nonstainless) anchor bolts to secure a galvanized pad-eye to a concrete surface; in this case, increased corrosion will occur on the anchor bolt. The remaining material thicknesses should be measured using calipers to determine the remaining capacity.

A.22.2 Routine Underwater Inspections

Level I inspection efforts for anchor and chain leg assemblies are conducted using visual/tactile means and consist of examining the overall alignment of the anchor and chain leg, the anchor connection components, the anchor position on the ground and surrounding ground material type, orientation of the stabilizers and flukes, and any evidence of drag movement in the surrounding area. The anchor chain inspection should focus on the riser section, catenary section, dip section, and ground section. Level II efforts are also visual upon removal of marine growth in areas to be inspected.

Level III inspection efforts of an anchor consist of measuring the remaining thickness of the connection components and measuring the offset angle of the chain to the shank end.

Level III inspection efforts of the anchor chain legs consist of measuring the single-link diameter to determine the amount of remaining steel (see Fig. A-64). A double-link measurement is used to determine the amount of wear at the adjoining two-link connection. A five-link measurement is used to check for chain stretch. A single-link measurement is used to check the

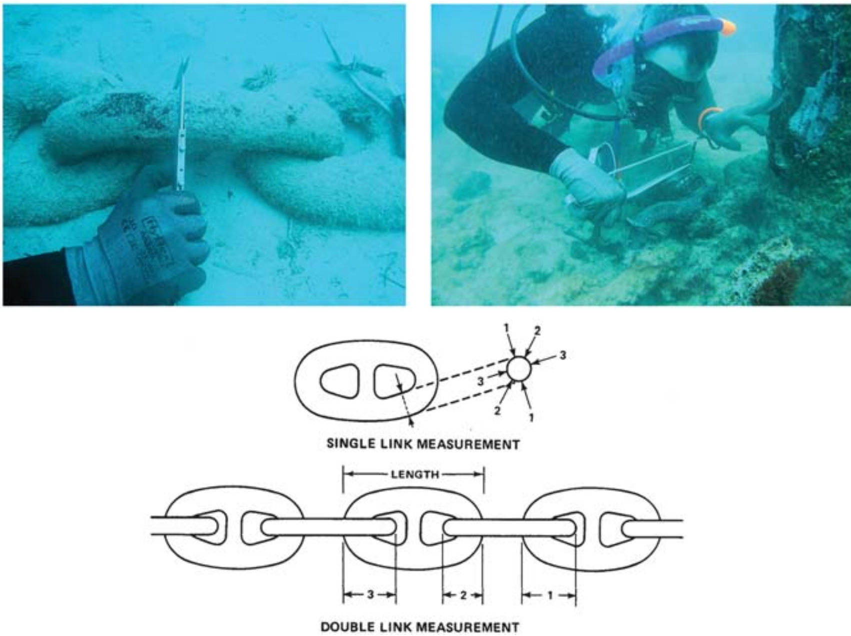

Fig. A-64. Measurement of chain hardware, single link (upper left), double link (upper right)
Source: (top) Courtesy of Moffatt & Nichol, Inc., reproduced with permission. (bottom) U.S. Navy (1987).

individual chain link for stretch and that it falls within the manufacturer's tolerance. In special mooring configurations, measuring the angle of the chain at the catenary and dip sections using an inclinometer device may be necessary. The connecting Kenter link should be inspected for the connection stud, keeper pins, and lead pellets (plugs). See Section A.11 for additional information.

APPENDIX B
TYPES AND CAUSES OF DEFECTS

B.1 INTRODUCTION

This appendix provides general information on various types and causes of material damage and deterioration, collectively referred to as "defects." The types of defects described are those most commonly encountered when inspecting marine structures. Some of the defects discussed may be found in many other types of construction (buildings, roadways, etc.); however, all types and causes of defects discussed stem from practices commonly used in marine construction, exposure to the marine environment, or applied forces specific to waterfront facilities.

The intent of this appendix is to overview the most commonly encountered defects. Although some defects discussed are complex in nature, the subjects are only briefly discussed, providing a short summary of the information that is useful in identifying, assessing, and addressing these conditions. The reader is encouraged to pursue additional sources to further explore the scientific and engineering aspects of these conditions.

B.2 CONCRETE STRUCTURES

Most types of defects that are found on concrete waterfront structures are common to all concrete structures. However, certain types of defects are more commonly found on waterfront structures and can lead to more severe consequences in the marine environment. Note that these defects typically apply to the various common types of concrete members, including unreinforced, reinforced, precast, prestressed, and fiber-reinforced concrete. Although not specifically addressed in this manual, it is important to consider the differing effects the various defects discussed may have, depending on the type of member.

B.2.1 Cracking

Cracking is a linear separation of concrete into two or more parts caused by induced tensile stresses in the concrete that are greater than the tensile strength of the concrete. The cracking may extend partially or completely through the member. Cracking is often classified as "structural," "nonstructural," and "degradation" type cracking.

For waterfront structures, the forces that induce cracking can be extreme when compared with concrete in other applications and environments. For structural cracks, live loads from cargo, ship berthing and mooring, cargo-handling equipment, and heavy load vehicles often apply large and concentrated forces to the structure. For nonstructural and degradation cracking, marine environments often present large variations in temperatures and moisture and humidity. Perhaps most detrimental is the introduction of chlorides, sulfates, and other elements that can have deleterious effects on concrete members.

Structural cracks caused by stresses from imposed loads can often be identified as "flexural" or "shear" cracks. Flexural cracks often begin at the maximum tension zone and progress toward the compression zone, commonly occurring within the areas of maximum positive or negative moment of force. Shear cracks are often diagonal or vertical cracks that normally occur in the web of a member or near a point of bearing where maximum shear stress is applied. They begin at the side and extend diagonally toward the center (see Fig. B-1).

Nonstructural cracking includes temperature cracks caused by thermal expansion and contraction of the concrete, shrinkage cracks caused by contraction of the concrete during curing, and mass concrete cracks created by thermal gradients in large concrete sections. Shrinkage cracking is common in the marine environment where highly variable temperatures often occur. Various types of shrinkage include plastic shrinkage, drying shrinkage, autogenous shrinkage, thermal shrinkage, and carbonation shrinkage. Although nonstructural cracks are not attributed to insufficient load-carrying capacity, they can be problematic because they provide openings for the intrusion of water, chlorides, sulphates, and other contaminants into the concrete matrix or to internal steel reinforcement (see Fig. B-2).

Degradation cracking of concrete is due to some form of deterioration such as delamination of the concrete surfaces, corrosion of reinforcing steel, or chemical reactions within the concrete matrix. In the marine environment, where many degrading agents exist, degradation cracking often leads to progressive deterioration at a much higher rate than cracks formed in other environments. Additional discussion of the various types of degradation

Fig. B-1. Structural crack on a reinforced concrete pile cap
Source: Courtesy of Marine Solutions, Inc., reproduced with permission.

Fig. B-2. Nonstructural cracking on the face of a concrete bulkhead
Source: Courtesy of Marine Solutions, Inc., reproduced with permission.

that induce this type of cracking can be found in subsequent sections of this appendix.

B.2.2 Corrosion of Reinforcing Steel

Corrosion of internal reinforcing steel is often the limiting factor in service life of reinforced concrete elements placed in the marine environment. The corrosion of reinforcing steel in concrete occurs to a large extent due to a change in the chemical composition of the concrete substrate from exposure to the environment, which eliminates the inherent protection of the embedded steel reinforcement. The steel becomes exposed to the same deleterious environment, allowing the now unprotected steel to corrode.

At an early age, concrete has a very high alkalinity (pH) that results in the transformation of a surface film of ferric hydroxide covering the reinforcing steel. As long as this passivation film is not disturbed, it will keep the steel passive and protected from corrosion. The corrosion process begins with the penetration of deleterious elements, such as chlorides or carbon dioxide, into the porous concrete. Over time, these elements penetrate to the reinforcing steel, at which point the protective film is destroyed, and the steel begins to corrode when oxygen and moisture is present. Abundant amounts of oxygen and moisture are present in the marine environment.

Corrosion is an electrochemical process requiring an anode, a cathode, and an electrolyte. A moist concrete matrix provides an acceptable electrolyte, and the steel reinforcement provides the anode and cathode. Electrical current flows between the cathode and anode transferring electrons and, with the electrons, mass that is particles of steel.

As the steel corrodes, it produces rust scale, delaminating and expanding the oxidized metal with an outward pressure that far exceeds the tensile strength of the concrete. This results in cracking and eventual spalling. Therefore, damage from corrosion of reinforcing steel is most often first observed within the tidal or splash zone. Inadequate concrete cover over the reinforcing steel can be a primary instigator of the corrosion process. Further, damage from corrosion of reinforcing steel is often the most severe at the corners of the members where there are increased exposure to seawater and oxygen, two exposed concrete faces, a concentration of longitudinal and transverse reinforcement, and often less concrete cover over the reinforcing steel.

Cracking and spalling caused by the expansive forces allow increased access by oxygen, chlorides, and moisture, which intensifies the corrosion and accelerates the loss of steel. The intrusion of chlorides into the concrete from rainwater, marine spray, and deicing agents also contribute to the corrosion process. These agents penetrate the concrete either through pores, cracks, and holes, or by diffusion, allowing oxygen and water to attack the reinforcing steel.

Subsequently, the concrete cracking (separation) and spalling (loss of section), and the loss of bonding of the steel reinforcement to the concrete and loss of the steel reinforcement bar section, threaten the structural integrity and load-bearing capacity of the concrete component.

Structural implications of internal corrosion are more acute in prestressed concrete than in conventionally reinforced concrete. This is due to the difference in the quantity of steel in the two types of construction, with the steel strands used in prestressed construction being considerably smaller than the cross-sectional area of reinforcing steel used in nonprestressed construction. The concrete requires the same amount of steel corrosion by-products to crack the concrete surface, but a comparatively larger percentage of the prestressed strand is consumed before the concrete cracks. This reduction in steel area is such that little of the strand's cross-sectional area may be left by the time the initial crack forms and becomes visible.

The rate of corrosion can be very slow in good quality concrete. Accelerated corrosion will occur if the alkalinity is lowered, if aggressive chemicals are present, or if dissimilar metals are introduced into the concrete. Stray electrical currents and concentration cells caused by an uneven chemical environment can also speed corrosion. In addition, concrete structures can also be vulnerable to corrosion of reinforcing steel by the action of sulfate-reducing bacteria found in sediments and discharged production water. This action produces a porous and disintegrating matrix. In each case, the amount of concrete cover over the reinforcing steel is a critical factor in the induction of corrosion of the reinforcing steel. As such, mechanical damage can also reduce the layer of concrete over the reinforcing steel, initiating and accelerating internal corrosion.

B.2.2.1 Corrosion Cracking A corrosion crack is a splitting crack that occurs in concrete due to the expansion of the chemical products generated by the corrosion of steel reinforcement. Corrosion cracks are formed when the internal stresses produced by the expansion of corrosion products exceed the tensile strength of the concrete.

Corrosion cracks appear close to the corroding steel and propagate along the bars. The main characteristic of these cracks is the location, adjacent and parallel to corroding reinforcing. Corrosion cracks can vary in width, with the maximum width at the point of most intense corrosion; leading edges with an opening that gradually reduces until the crack tapers out; and red, orange, or brown corrosion products (rust staining), which often bleed from the crack. Corrosion cracking often first appears at the corner of a concrete member, because the concrete has less restraint and the resistance to the internal pressure of the expansion products is less (see Fig. B-3).

In marine structures, members subjected to seawater spray, such as piling, pile caps, beams, and the underside of deck slabs, are more susceptible to corrosion cracking due to the accelerated increase in chlorides caused

Fig. B-3. Typical corrosion crack on a reinforced concrete pile
Source: Courtesy of Marine Solutions, Inc., reproduced with permission.

by wave action against the structure (i.e., splash, spray, and wicking). The initiation of corrosion cracks accelerates the corrosion process, allowing direct access of oxygen, moisture, and chlorides to the reinforcing steel.

B.2.2.2 Closed Corrosion Spall As corrosion cracking continues, the defect may degrade into a closed corrosion spall. A closed corrosion spall is defined by a slightly raised area of concrete completely or partially surrounded by corrosion cracks. When it is struck with a hammer or steel rod, the spall gives off a hollow sound, indicating the existence of a fracture plane below the surface. It is the intermediate stage in the process of complete separation of a fragment of concrete cover. As such, a closed corrosion spall is often referred to as an "impending spall." Differing from a corrosion crack, a closed spall is often an indication of potentially significant section loss of the affected reinforcing steel bar and a loss of bonding between the concrete and the steel bar (see Fig. B-4).

B.2.2.3 Open Corrosion Spall An open corrosion spall is a recess in the concrete surface with the underlying reinforcing steel or strands clearly visible. The steel is usually covered with corrosion by-products by this stage (see Fig. B-5).

In open spalls, the structural significance of the damage depends on the extent of the steel-reinforcing bar section loss and loss of bonding between the steel bar and concrete. Open spalls can also increase the rate of corrosion

Fig. B-4. Cracking indicating a closed corrosion spall on the corners of a pile cap Source: Courtesy of Marine Solutions, Inc., reproduced with permission.

Fig. B-5. Open corrosion spall on the corner of a reinforced concrete pile cap Source: Courtesy of Marine Solutions, Inc., reproduced with permission.

Fig. B-6. Open corrosion spall on the underside of a reinforced concrete deck Source: Courtesy of Marine Solutions, Inc., reproduced with permission.

of further internal reinforcement through the newly exposed, unfinished concrete surfaces (see Fig. B-6).

B.2.2.4 Delamination Delamination is a separation of layers of concrete along a plane parallel to, and near, the surface of the concrete (see Fig. B-7). Although commonly caused by improper finishing or curing, it can be caused by the expansion of corroding steel reinforcement, most often on flat concrete surfaces. As the rust layer builds, the expansion forces cause the outermost concrete layer to separate.

Delamination can occur on any concrete surface where corrosion of the internal reinforcing steel is possible. It is primarily found on the soffits of pile caps, beams, and decks, but it can also form on the vertical faces and corners of piles, caps, beams, deck members, and retaining structures. Because delamination is the initial stage of spalling, it will ultimately affect the structural capacity of a component due to loss of reinforcing steel and loss of reinforcement bonding.

B.2.3 Chemical Attack

Chemical attack often occurs due to the constituents of the concrete mixture, curing methods and, at times, the ambient environment. The most common types of chemical attack found in marine structures are alkali-aggregate reaction, chloride contamination, sulfate attack, delayed ettringite formation, carbonation, and acid attack.

Fig. B-7. Delaminated area on a reinforced concrete pier deck
Source: Courtesy of Marine Solutions, Inc., reproduced with permission.

B.2.3.1 Alkali-Aggregate Reaction Alkali-aggregate reaction (AAR) can cause expansion and cracking in concrete. The two most common forms are alkali-silica reaction (ASR) and alkali-carbonate reaction (ACR). Both are caused by a reaction between chemical ions in the alkaline cement solution in concrete and reactive forms of aggregate. An expansive gel is produced as a product of the reaction. The resulting increase in volume exerts an expansive pressure-induced cracking. The moisture-rich marine environment can accelerate this reaction. Reactive silica aggregates are much more common than reactive carbonate reactions; therefore, ASR is the more common reaction.

AAR may be typically first observed as patterned or "map" cracking reflecting the expansive cracks forming around aggregate and the internal pressure generated. Over time, bulging and distortion of the concrete member can occur. Cracking due to chemical attack can be differentiated from cracking due to finishing, curing, or volumetric changes by the depth of cracking and by petrographic examination to detect the chemical reactions. If the reactive aggregate is close to the surface, the reaction may create a small pop-out.

B.2.3.1.1 Alkali-Silica Reaction ASR occurs when certain aggregates, such as reactive forms of silica, react with alkalis, typically potassium and sodium, and calcium hydroxide from the cement. When sufficient moisture is present, a gel forms around the reacting aggregates. As the gel develops, it

Fig. B-8. Epoxy-covered cracks formed from ASR
Source: Courtesy of Marine Solutions, Inc., reproduced with permission.

expands, causing microtension cracks to form around the aggregate. The gel continues to form until the reactive aggregate or alkalis are consumed. In the marine environment, where an abundance of alkali occurs, the reaction can continue almost indefinitely.

ASR causes microcracking within the concrete matrix. Damage is often first noticeable where longitudinal cracks develop in areas of least restraint. The damage may progress with macrocracking, pattern cracking, and delamination (see Fig. B-8). ASR may be found above water, but due to the presence of moisture and alkalis found in seawater, the greatest amount of damage from ASR may be found below water. Corrosion of the reinforcing steel exposed by the degradation resulting from the chemical attack is a secondary affect and can sometimes be misdiagnosed as the primary cause of damage.

B.2.3.1.2 Alkali-Carbonate Reaction ACR can cause damage similar to that of ASR. ACR occurs between some of the dolomitic limestone aggregates and alkalis in the cement. The reaction forms a gel, which swells, causing cracking around the reacting aggregates when sufficient moisture is present. As the gel swells, it expands, causing microtension cracks to form around the aggregate. The gel continues to form until the reactive aggregate or alkalis are consumed or the moisture is depleted.

Similar to ASR, ACR cracks are typically oriented vertically and are often found in the submerged zone of a member. Deterioration is believed to take place underwater because the seawater provides additional alkalis for the reaction and intensifies it.

ACR cracks do not significantly reduce a member's capacity, as long as they remain shallow. Deeper ACR cracks have the potential to expose the reinforcing steel to corrosion and, thus, may seriously affect the integrity of prestressed members.

B.2.3.2 Chloride Contamination Chloride contamination is initiated by the presence of chlorides within the concrete mix. They may be introduced by admixtures containing chlorides or seawater, or they can be naturally occurring in certain aggregates. Concrete made with beach sand or mixed with seawater has an increased level of chlorides from the outset. Water-soluble chlorides are the most damaging, because they readily recrystallize within the concrete. The newly formed salt crystals cause the swelling of capillary cavities in the concrete, and the expansive force of the increase in volume can cause microcracking, leading to the disintegration of the concrete.

B.2.3.3 Sulfate Attack Sulfate attack is caused by exposure of the concrete to sulfates; the most common sulfates are sodium, potassium, magnesium, and calcium. The sodium, potassium, and calcium sulfates react with various hydration products, in the presence of moisture, to form ettringite. The magnesium sulfate reacts with the hydration products to break down the calcium silicate hydrate present in cement.

Sulfate attack often leads to softening of the concrete. Damage is often first noticeable at the corners of the members where longitudinal cracks may develop. The damage will progress to degradation of the corners and eventual rounding of the member. Often the concrete will degrade to a soft, chalk-like texture that crumbles and can be removed and broken by hand. Accelerated by moisture and sulfates found in seawater, the greatest amount of damage from sulfate attack is found below water. Corrosion of the reinforcing steel exposed by the degradation resulting from the chemical attack is a secondary effect and can sometimes be misdiagnosed as the primary cause of damage.

B.2.3.4 Delayed Ettringite Formation Delayed ettringite formation (DEF) is a unique type of chemical attack affecting marine structures. A number of as-built factors, such as concrete composition, curing conditions, and exposure, influence the potential for sulfate attack; however, DEF is believed to be a result of improper heat curing of the concrete.

DEF occurs when the concrete is subjected to elevated temperatures during hydration. Ettringite is not stable at elevated temperatures, resulting in the formation of monosulfates. When the concrete returns to normal temperatures, the monosulfates are not stable, thus ettringite is formed;

Fig. B-9. Reinforced concrete pile with loss of section below the high tide level
Source: Courtesy of Marine Solutions, Inc., reproduced with permission.

however, this delayed ettringite is formed while the concrete is in a hardened state and with the presence of moisture. The ettringite forms and, if space is insufficient, the ettringite formation will cause expansion. Due to this expansion, microcracks form around the aggregates and are filled with ettringite. The formation of the ettringite can lead to extensive damage.

Damage is often first noticeable where longitudinal cracks develop in areas of least restraint. The damage may progress with macrocracking, pattern cracking, and delamination. DEF may be found above water in moist or humid conditions, but due to the presence of moisture found in seawater, the greatest amount of damage from DEF may be found below water. Corrosion of the reinforcing steel exposed by the degradation resulting from the chemical attack is a secondary effect and can sometimes be misdiagnosed as the primary cause of damage (see Fig. B-9).

B.2.3.5 Carbonation Carbonation is the reaction between acidic gases (generally carbon dioxide) in the atmosphere and the products of cement hydration. This can occur in industrial areas where the level of carbon dioxide in the air is generally higher than normal. Carbon dioxide enters through pores in the concrete by diffusion, forms a mild carbonic acid, and reacts with the calcium hydroxide dissolved in the pore water. The alkalinity of the concrete is reduced, which, when the carbonation reaches the level of the reinforcing steel, removes the passivation film, resulting in the onset of corrosion if oxygen and moisture are present. Carbonation also causes an increased concentration of chloride ions along the carbonation front, thereby increasing the corrosion.

The process of carbonation requires continuous wet-dry cycles, carbon dioxide, and moisture. At normal levels, such as in rural environments, the reaction is minimal; however, in areas with higher concentrations of carbon dioxide, such as in large cities and industrial ports, the rate of carbonation increases with the increase in carbon dioxide. Carbon dioxide amounts are normally very small in seawater. However, concentrations become higher in the presence of decaying organic matter, causing carbonation to occur. Carbonation can also take place in concrete exposed to water emanating from underground. Carbonation does not occur when concrete is constantly submerged.

B.2.3.6 Acid Attack Concrete is highly alkaline and typically not used in the presence of acids without protection. However, acid attack of concrete is observed in a few instances. The first is in sewers, where sulfuric acid can form. The sulfuric acid creates multiple reactions, including sulfate attack and an attack of the calcium hydroxide and calcium silicate hydrates in the concrete.

The second reaction is a reaction between acidic waters and carbonate aggregates. The carbonate aggregates, typically limestone and dolostone, dissolve in the acidic water. The acidic waters are generally found in swamps and sloughs but may also be encountered in industrial areas.

B.2.4 Mechanical and Other Types of Damage

In the harsh marine environment, mechanical and other types of damage or degradation common to most concrete structures can be amplified by extreme temperature changes, moisture conditions, and exposure to chlorides and sulfates. Somewhat minor cracking or spalling may provide exposure to the concrete substrate and pathways to steel reinforcement, accelerating secondary damage from steel reinforcement corrosion or chemical attack. As such, the secondary effects of even minor damage from somewhat typical defects should be considered.

B.2.4.1 Volumetric Changes Volumetric changes in concrete are caused by thermal expansion and contraction, plastic shrinkage, freezing and thawing, and changes in moisture content. Tensile stresses are often generated in the concrete that result in cracking and spalling. Significant damage can particularly be caused when the concrete member is confined.

B.2.4.2 Impact and Overload Impact damage is caused when ships, boats, or other objects strike a concrete member. The extent of damage depends on the mass and velocity of the object and can range from superficial damage to fracture or failure of the member.

Fig. B-10. Reinforced concrete pile with impact damage
Source: Courtesy of Marine Solutions, Inc., reproduced with permission.

Generally, the consequence of impact is localized structural damage ranging from cracks, voids, chipped corners, and local spalling to major structural distress. This damage is usually located on the berthing face of a marine structure and in the intertidal zone of piles. Impact damage can cause complete failure of a structural element or can accelerate corrosion of reinforcing steel by causing cracks or breaking sections of concrete reducing or removing the concrete cover (see Fig. B-10).

Overload damage is caused when loads are applied to the structures in excess of their capacity, also referred to as overstressing. When applied loads result in stresses in excess of the compressive or tensile stress capacity of the concrete, or when the yield stress of the reinforcing steel is exceeded, damage occurs. As with impact damage, the extent of the damage can range from superficial to failure of the member.

Overstressing damage does not necessarily occur at the point of load application but at locations where the resulting stress meets or exceeds the structural capacity of the structural section. The result is deformation of the member or an overstress crack, which is often characterized by sharp edges and small wedges of missing concrete along the length of the crack.

B.2.4.3 Scaling Scaling is the gradual and constant loss of surface mortar and aggregates from an area of concrete. It is most often found near the waterline and underwater due to a breakdown of the finished surface of the concrete. Improper finishing and curing can often contribute to the early

Fig. B-11. Concrete scaling at the water surface
Source: Courtesy of Marine Solutions, Inc., reproduced with permission.

onset of scaling. Scaling can lead to cracking and spalling and the eventual depletion of the concrete cover (see Fig. B-11).

B.2.4.4 Freeze-Thaw Damage Freeze-thaw damage takes place when freezing and thawing cycles act on porous concrete that has absorbed water. Water contained in the pores expands as it freezes, causing expansion forces that break the surrounding concrete that is comparatively weak in tension. The disintegration occurs in small pieces, working from the outer surfaces inward. Freeze-thaw deterioration typically occurs on vertical surfaces that are near the waterline where they are exposed to wave action and spray (see Fig. B-12).

B.2.4.5 Honeycombing Honeycombs are voids or hollows in the concrete and are a construction deficiency caused by inadequate consolidation of the concrete. The lack of vibration segregates the coarse aggregates from the fine aggregates and the cement paste, creating small voids and pockets within the concrete (see Fig. B-13). Honeycombing can occur on the interior or the surface of a concrete component.

The impact of honeycombing on the structural capacity of concrete components depends on the size and depth of the area affected. These areas will have a high permeability and will be more susceptible to chemical attack. Surface honeycombing has the additional potential of allowing the

Fig. B-12. Freeze-thaw damage along the face of a reinforced concrete bulkhead Source: Courtesy of Marine Solutions, Inc., reproduced with permission.

Fig. B-13. Honeycombing on the side of a reinforced concrete bulkhead Source: Courtesy of Marine Solutions, Inc., reproduced with permission.

penetration of corrosion agents into the reinforcing steel and eventual cracking and spalling.

B.2.4.6 Pop-Outs Pop-outs are shallow, cone-shaped holes in the surface of the concrete. They are formed when conical fragments break away from the concrete surface. A shattered aggregate particle is generally found at the bottom of the hole, and another piece of this particle may still be attached to the small end of the cone that popped out, if present.

Pop-outs are caused by the presence of reactive aggregates and high alkali cement. They can also occur when aggregates that expand with moisture, such as shale, are in the makeup of the concrete or when the ends of internal reinforcing steel corrode, developing localized expansive forces.

B.2.4.7 Abrasion or Erosion Abrasion of the surface of concrete structures is the result of external forces acting on the concrete (see Fig. B-14). Four major causes of abrasion are waterborne solids, friction, propeller wash, and cavitation.

B.2.4.7.1 Waterborne Solids Sand, small rocks, and debris carried in wave or current action can cause abrasion damage at the water line or in the tidal zone. Ice floes can also abrade at this elevation. Abrasion can also occur at the mudline caused by the action of abrasive material carried in the swift current of some rivers.

Fig. B-14. Severe erosion of a concrete sheet pile breakwater
Source: Courtesy of Marine Solutions, Inc., reproduced with permission.

Fig. B-15. Diver measuring severe erosion damage
Source: Courtesy of Marine Solutions, Inc., reproduced with permission.

B.2.4.7.2 Friction The proximity of marine traffic and the continuous friction from attached mooring lines and anchor chains can be a source of abrasion.

B.2.4.7.3 Propeller Wash Wash from vessels repeatedly and quickly starting and reversing their propellers (e.g., tug or ferry boats) can act like an abrasive on underwater components.

B.2.4.7.4 Cavitation Cavitation damage can occur in areas of high water velocity. This is manifested at localized areas of erosion and may be encountered in intakes and spillways. Cavitation damage is similar to scale and is mainly cosmetic, although it does reduce the thickness of the member and decrease the cover over reinforcing steel with its consequential long-term effects. Cavitation damage can be identified in the form of exposed aggregate, cracks, gouges, and cavities (see Fig. B-15).

B.2.4.8 Biological Deterioration Organisms that grow on concrete can affect the condition of the concrete. In fresh and brackish water, algae and hydroids can grow on continuously moist or submerged zones of a structure. They form a dense covering, which tends to seal the concrete and decrease gas permeability and consequently reduce carbonation and the availability of oxygen, thus promoting corrosion.

In seawater, plants of higher orders, such as seaweed, are potentially aggressive agents. They will not grow until carbonation lowers the pH of the concrete. When they do become established, the root systems can break down the concrete. Additionally, the release of carbon dioxide during daylight hours may increase carbonation, and the action of sulfur developed during the decomposition of seaweed can degrade the concrete.

B.2.4.9 Contamination Certain chemical solutions will attack marine structure components. Various acids, alkaline solutions, and salt solutions are all examples of these aggressive chemicals. Chemical reactions on concrete involve the reaction between the acid and the calcium hydroxide of hydrated portland cement. The reaction produces water-soluble calcium compounds, which are leached away. When limestone or dolomite aggregates are used, the acid may dissolve them.

B.2.4.10 Weathering Gradual weathering by sun, wind, and water is usually indicated by erosion or shallow, fine cracking of the concrete surfaces (i.e., erosion, scaling, aggregate pop-outs, rounded corners, or shallow pattern cracking). The location and severity of the weathering often varies by the contributing environmental condition and may be affected by the finishing and curing practices used. For example, weathering may be more severe in areas subject to heavy water currents or underwater, where unfinished surfaces are present.

B.3 STEEL STRUCTURES

B.3.1 Steel Deterioration

Deterioration of steel structures in the marine environment is typically caused by corrosion, fatigue cracking, and impact or overload damage. Often, two or more of these agents work collectively to cause the degradation.

B.3.1.1 Corrosion Corrosion of steel is the deterioration and eventual destruction of the metal due to its reaction with the environment. Chemically, it is the transformation of a metal to its oxide through a reaction involving oxygen, water, and other agents. Corrosion is most advanced slightly above high water (splash zone) and slightly below low water but may also be advanced in the submerged zone of the member, particularly near the mudline. The rate of deterioration in these zones may be greatly affected by tide ranges and other site-specific characteristics. The average rate of corrosion is generally estimated at 0.005 in. per year for mild steel. As corrosion may be greatly affected by local and site-specific parameters, the use of this average value should proceed with caution.

B.3.1.1.1 Progression of Corrosion Numerous factors determine the rate and progression of corrosion. These include environmental conditions, type of steel, surface protection, and other parameters.

Environmental effects include temperature, humidity, and the exposure of the metal. Warm water and higher ambient air temperature increase the rate of corrosion, as does high humidity. Exposure to the drying effects of wind and sun decrease corrosion rates, whereas sheltered areas retaining moisture and corrosion is accelerated. Impurities, such as salt, can make water a more efficient electrolyte and speed corrosion. The presence of organisms in swamps, bogs, heavy clay, stagnant or brackish water, and contaminated water may cause bacteriological corrosion. Movement of water in the splash zone caused by tides, waves, and high-velocity currents also affects corrosion. This type of water movement allows for a greater number of wet-dry cycles, resulting in an increase in the supply of oxygen to the metal. Water movement can also facilitate the removal of the prime layer of corrosion, which normally provides some amount of protection helping to reduce the rate and progression of corrosion.

In addition, the presence of abrading elements in the moving water can also remove the buildup of corrosion by-product and increase the rate of deterioration. Repeated marine growth removal to facilitate inspection of the same steel member or component at the same location may also increase corrosion rates at these areas.

Other factors affecting corrosion include atmospheric pollutants, animal deposits, stray electric currents, galvanic action, and surface growth. Atmospheric pollutants can act similarly to salt in water, and acids formed from atmospheric gases can directly attack steel. Bacteria often destroy the protective film or coating on metals, forming deposits and occasionally attacking the steel itself. Bird droppings retain moisture and form deposits, which chemically attack the steel. Stray electrical currents from adjacent sources may promote corrosion by speeding the rate of the electrochemical process. Galvanic action occurs when other metals are in contact with steel and causes corrosion similar to rust. Marine growth on steel located in seawater can occasionally deter corrosion, but it can also hide areas of damage.

B.3.1.1.2 Characteristics of Corrosion Different types of corrosion are classified according to the manner in which the corrosion attacks the metal. Some of the more common types of corrosion encountered during waterfront facilities investigation include the following.

Uniform corrosion. Uniform corrosion (rusting) is the general thinning of metal in an overall manner. It occurs when bare metal is exposed to the corrosive environment, and it is identified by uniform rust or section loss over the entire surface. It comprises many small pits joined together. The corrosion by-product reduces the corrosion rate by forming a barrier between the metal and the environment.

Microbial-induced corrosion. Microbial-induced corrosion (MIC) is also known as accelerated low water corrosion (ALWC). MIC is a form of localized and aggressive corrosion that typically occurs around low water and is evident by bright orange oxide. Left untreated, MIC may corrode the steel at a rate around 1/32 in. per side, per year.

Crevice corrosion. Crevice corrosion occurs at confined locations with limited exposure to the outside environment. Concentrations of oxygen cells or metal ion cells in these confined areas create an environment conducive to corrosion. Chloride ions are also often trapped in crevices. Crevice corrosion is typically found within gaps between mating surfaces or between back-to-back members. A classic example is the corrosion of metal fasteners embedded in timber.

Pitting. Pitting is localized corrosion that causes the formation of isolated penetrations into steel surfaces. It forms when chemical or physical differences occur such as imperfections in the steel under the paint or debris deposits. Pitting can act as a stress riser and cause failure by cracking. Fig. B-16 is a typical example of pitting of a steel H-pile underwater.

Galvanic corrosion. Galvanic corrosion occurs when two different metals are in contact in the presence of an electrolyte. The difference in their corrosive potential produces an electron flow, with one metal becoming the cathode and the other the anode. This results in an area of thinning and perforation of the steel. Galvanic corrosion can occur in a single piece of

Fig. B-16. Underwater photograph of pitting on a steel pile
Source: Courtesy of Appledore Marine Engineering, Inc., reproduced with permission.

Table B-1. Galvanic Series in Seawater

Material	Electrical Potential (Volts)
Titanium	0.00
Stainless Steel, Types 316, 317	−0.06
Nickel-Copper Alloy 400 (Monel)	−0.07
Stainless Steel, Types 302, 304, 321, 347	−0.08
Nickel-Chromium Alloy 600 (Inconel)	−0.17
Lead	−0.22
Copper	−0.37
Naval Brass, Yellow Brass, Red Brass	−0.38
Low Alloy Steel	−0.61
Mild Steel, Cast Iron	−0.66
Cadmium	−0.71
Aluminum Alloys	−0.88
Zinc	−1.02
Magnesium	−1.61

steel due to differing potentials within the material. Table B-1 illustrates the corrosion potential between common metals.

Stress corrosion. Stress corrosion occurs when member stresses and a corrosive environment coexist. Areas of high stress can lead to accelerated corrosion causing localized areas of section loss. Corrosion causes the initiation of discontinuities in the metal that act as stress risers, leading to section loss and possible cracks.

Erosion corrosion. Erosion corrosion is the attack on a metal caused by the flow of liquid over its surface with sufficient velocity to remove adhering surface corrosion products. It is caused by particle erosion, where particles in water abrade the metal surface, wearing away the surface coating of corrosion protection products. This allows corrosion to continually attack bare metal and, consequently, speeds the rate of deterioration. It is found in areas where river currents, tidal flow, or propeller wash carry particulate matter such as silt and sand. This type of corrosion is usually identified as damage at a particular elevation or band of deterioration on the member.

B.3.1.1.3 Effects of Corrosion Steel components used in waterfront construction that are subject to corrosion are predominantly H-piles, pipe piles, sheet piling, and bracing. Additionally, connections (e.g., bolt, rivets, and welds) are also susceptible to corrosion. Corrosion has four main effects on the structural integrity of these components.

Loss of section. The reduction in member capacity leads to lower bending, axial, and shear capacity. Typically, thinning, knife edging, areas

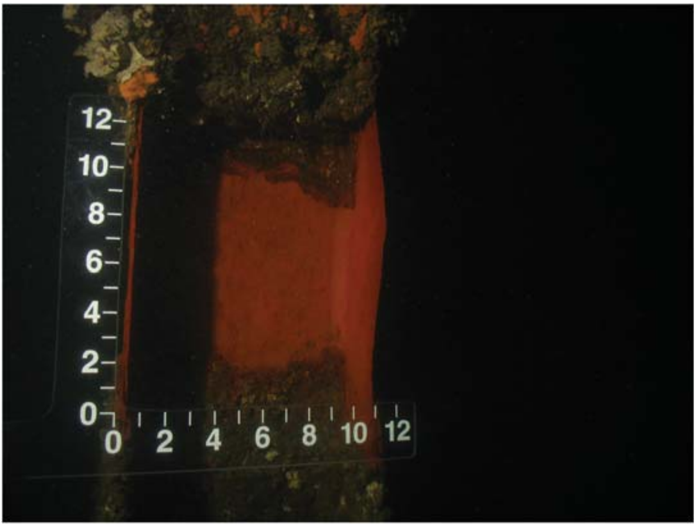

Fig. B-17. Severe corrosion and "knife edging" of a steel H-pile
Source: Courtesy of Appledore Marine Engineering, Inc., reproduced with permission.

of missing section, and localized buckles identify this type of deterioration. Fig. B-17 depicts an H-pile with severe knife edging and localized buckle in flange.

Creation of stress risers. The formation of holes and notches by corrosion causes stress concentrations, providing locations for the initiation of cracks. This type of deterioration can be identified by pitting, corrosion nodules, or other localized imperfections.

Introduction of unintended fixity. When corrosion freezes moving parts of a structure, such as expansion devices or fender systems, the structure behaves differently than originally designed. As a result, members can be subjected to unexpected high stresses and subsequent damage.

Introduction of unintended movement. Corrosion build-up in constricted areas can generate pressure that bends or moves components with damaging effects.

B.3.1.2 Biological Deterioration MIC and ALWC, a severe form of MIC, is caused by the presence of microbes whose metabolism produces acids and sulfides. These microbes and their by-products in the presence of metals can produce a film conducive to accelerated local corrosion. Microbiological involvement in corrosion provides additional means by which aggressive ions can be formed, and it facilitates the acceleration of the

Fig. B-18. Impact damage on a steel brace
Source: Courtesy of Marine Solutions, Inc., reproduced with permission.

corrosion process. MIC can attack ductile iron, steel, stainless steel, galvanized steel, and copper.

MIC can lead to the formation of large, unusually shaped pits, or a corrosion product film, depending on the bacteria involved. It has been observed in recirculating cooling water systems, on the interior of stainless steel storage tanks and aluminum alloy fuel tanks, and in buried pipes. It may also be found on marine structures in certain environments. MIC can be controlled by pH adjustment in certain situations, cathodic protection, or a barrier system such as a coating. An effective prevention and maintenance program for MIC must combine expertise in microbiology and corrosion science.

B.3.2 Impact or Overload Damage

Loads that exceed the capacity of a member or structure may cause deformation or failure. Overloading or impact damage may result in deformation or partial breakage of a component. Deformation of tension members can be identified by elongation and a decrease in cross section (necking). In compression members, the symptoms of plastic deformation are single bow buckling or S-buckling and double-bow buckling, where the component under compression is fixed at the center point. Deformation of flexural members can also be identified by local buckling and elongation and by locations of concentrated corrosion in areas of high stress (see Fig. B-18).

Signs of a one-time overload failure are a fibrous appearance at the point of separation, gross distortion at the point of failure, necking down under tension, and buckling under compression or bending.

Partial breakage of a component occurs when a member is not completely broken but a portion has been severed or is missing. The member may be functional but will have reduced structural capacity.

In severe cases, overloading or impact damage may result in complete breakage of a component. The portions of the member near the break are discontinuous, resulting in failure of the member.

B.4 TIMBER STRUCTURES

B.4.1 Wood Deterioration

Deterioration of timber structures in the marine environment can be caused by biological factors, mechanical means, or chemical agents. Various factors affect the rate of deterioration.

B.4.1.1 Biological Damage

B.4.1.1.1 Marine Borers The two types of marine borers responsible for most damage to structures in the seawater environment are crustacean borers and mollusk borers. The Limnoria is a crustacean borer. The Teredo, Bankia, and Pholad are mollusk borers.

Limnoria. The Limnoria is a waterborne, surface-boring crustacean. It is also known as the wood louse or gribble. It is the only marine borer that is free swimming and can move from member to member. The Limnoria bores into wood, preferably untreated wood, as soon as it hatches.

Adults reach a length of 1/8 to 1/4 in. Limnoria bore a tunnel to a depth of 1/4 in. and then burrow parallel to the surface of the wood. As the tunnel length increases, auxiliary tunnels are bored to the surface to provide access to water for respiration. The end result of Limnoria infestation is a seriously weakened honeycomb-like surface. Wave action and debris then break down this fragile timber lattice. As this occurs, the Limnoria are able to burrow deeper into the member.

The continuous burrowing of Limnoria causes the progressive deterioration of a member's cross section, typically resulting in an hourglass shape to piling in the tidal zone, where sufficient oxygen is present to support the organisms (see Fig. B-19). Damage can also extend to the mudline in shallow waters but generally does not occur below the mudline where oxygen and access is limited to the organisms. Infestation can also occur through construction damage caused by over-driving, open boltholes, or cut member ends left untreated after field cutting. This type of infestation is typically identified as internal cavities in the damaged member and may be very

Fig. B-19. Typical hourglass shape formed in a timber pile due to damage from Limnoria
Source: Courtesy of Marine Solutions, Inc., reproduced with permission.

difficult to locate and assess. Some species of Limnoria are tolerant to creosote at milder levels.

Teredines. Teredo and Bankia are both mollusk borers and members of the teredinideae family of internal marine borers. They are also known by the common name of "shipworms." Teredo and Bankia are clam-like mollusks that burrow by rasping with a pair of finely serrated shells on the head of a worm-like body.

The shipworm begins its life cycle as a free-swimming larva that attaches to wood, preferably untreated, and starts boring. It can only spread from one member to another when it is in this free-swimming larval stage. Once it bores into wood, the wood imprisons it. A small opening is maintained at the surface of the wood to provide freshwater for respiration and to possibly obtain nourishment from seawater. Once the larva enters the wood, metamorphosis occurs and the shipworm acquires its adult form.

Shipworm larvae do not settle on wood that is well treated with creosote or waterborne toxic salts. They do attain access, however, to a member through areas where the protective layer is defective or damaged, such as open boltholes, untreated field cuts, and splits or cracks sustained during construction or during service life. Adult shipworms have been found to penetrate the creosote layer of a pile via a firmly attached piece of untreated wood.

The loss of wood volume caused by the substantial diameter and length of the shipworm can be extensive, and a small number of animals can completely destroy a pile in as little as six to nine months. Damage may occur in the intertidal zone but most commonly is found throughout the submerged and mudline zones. Because shipworm damage is restricted to the interior of a timber member, areas of damage are difficult to visually identify.

When alive and actively boring, the only visible sign is the two slender posterior siphons, which extend beyond the surface at the entry hole. When the animal is dead, the only external sign of damage is the original pinhole point of entry (1/16 in. diameter or less). Wood members with a heavy infestation of shipworm can sometimes be identified by the presence of large internal cavities. Often these cavities are caused by a combination of Limnoria attack and shipworm infestation (see Fig. B-20).

Pholads. Pholads are rock-burrowing clams related to shipworms. These borers have also been found to burrow in wood. Their bodies are entirely enclosed in a pair of shells. Like shipworms, they become imprisoned within the wood. They bore into the surface of the wood making a pear-shaped burrow that enlarges as they grow. The Martesia striata is the species most commonly associated with wood attack. Adults range in size from 2–2 1/2 in. in length and up to 1 in. in diameter.

As pholads grow, they enlarge the entrance hole to 1/4 in., making it more readily detectable than shipworms. Pholad attack is most severe in the tropical waters of Hawaii and Mexico, but sightings have also occurred along the western coast of the United States.

Fig. B-20. Underwater photograph showing hollowing of the interior of a timber pile from Teredo
Source: Courtesy of Marine Solutions, Inc., reproduced with permission.

B.4.1.1.2 Fungi Fungal decay is primarily a problem in the above water portions of waterfront structures (see Fig. B-21). However, it can be of concern from an underwater perspective when a structure is situated on a lake or river with regularly fluctuating water levels.

Fungi require four conditions to grow:

1. Oxygen: Atmospheric air;
2. Favorable temperature range: 21°C to 30°C, although some species grow slowly at temperatures as low as 0°C and as high as 45°C;
3. Adequate food supply: Wood; and
4. Adequate supply of moisture: 20–50%.

Decay is usually found in areas with consistent wet and dry cycles. Moisture is often retained at member interfaces and in the vicinity of steel fasteners, spikes, bolts, or drift pins, which, when temperatures are favorable, provide optimal conditions for fungal attack (see Fig. B-22).

Three groups of fungi are found growing on wood: wood-destroying fungi, soft rot fungi, and stains and molds.

1. Wood-destroying fungi: Two types of these fungi exist: brown rot and white rot:
   a. Brown rot: Brown rot is common in softwoods. The wood becomes brittle, is brown, and displays distinct cross-grain checks. Brown rot significantly reduces wood strength.
   b. White rot: White rot attacks hardwoods. The wood takes on a whitish or tan color, flecked with dark pencil-like lines. The wood is not checked and may be soft or punky. White rot causes less strength loss than brown rot.
2. Soft rot: Soft rot causes the gradual softening and degradation of the wood surface. It occurs at high moisture levels and significantly reduces strength properties.
3. Wood stains and molds:
   a. Stains are spots, streaks, or patches of varying colors, which penetrate the sapwood. They are a superficial phenomenon.
   b. Molds are powdery circular growths of varying colors. They can be brushed off when the wood is dry. Molds do not cause decay.

   Neither molds nor stains cause decay, but they do indicate conditions favorable to the growth of fungi.

B.4.1.1.3 Insects Insect damage is common in timber structures. The inspector should have a basic knowledge of the variety of common wood-destroying insects including termites, carpenter ants, and buprestid beetles. Like their marine borer counterparts, these insects can cause

Fig. B-21. Rot at the top of timber fender piles
Source: Courtesy of Marine Solutions, Inc., reproduced with permission.

Fig. B-22. Severe rot due to moisture located on a timber beam
Source: Courtesy of Marine Solutions, Inc., reproduced with permission.

significant loss of cross section and structural integrity to affected members.

Specific to the marine environment, the caddis fly is an insect that can damage timber members. It is typically found in freshwater, but it can also tolerate brackish water. The caddis fly has been known to burrow into creosote-treated wood. Bacterial and fungal infections in the wood attract the caddis fly. Wood that has been damaged by caddis flies is characterized by the appearance of many, smallpox-like pits.

The caddis fly is closely related to moths and butterflies. As a larva in water, it digs small holes in the wood for protection. It prepares a shelter for the pupa stage by enlarging, deepening, and strengthening the hole. At the end of the pupa stage, the pupa cuts its way out of the hole, swims to the surface, and the adult emerges. The cycle then begins again.

The next generation may use and enlarge the existing holes. A high density of caddis flies on a member, combined with bacterial and fungal decay, and the abrasive action of river or tidal currents, can reduce the cross section of the member and affect its structural strength.

B.4.1.1.4 Cellular Degradation Microscopic organisms are present in wood, particularly in the marine environment. These bacteria are known to attack the cell wall, detoxify preservatives, and increase the permeability of wood. They are highly resistant to many wood preservatives and may aid in the infestation of wood by marine borers. At present, little of their destructive process is known. The continuing study of wood-inhabiting microbes may further define the role of bacteria in the breakdown of wood.

B.4.1.2 Mechanical Damage

B.4.1.2.1 Impact Timber components will split, shear, or fracture under high-velocity impact. Impact at lower velocities can sometimes be absorbed without significant structural damage. However, any impact can result in compression or tearing of the timber surface (see Fig. B-23). This damage can compromise the protective coating and expose untreated wood to attack by wood-destroying organisms.

Abrasion. Abrasion of the surface of timber members can be caused by floating debris, marine traffic, floating docks, anchoring systems, and water-borne materials such as ice and sand. Areas of wood damaged by abrasion appear worn and smooth. The effects of abrasion damage are twofold:

1. Gradual reduction in the diameter of the member, and
2. Damage to the protective coating that exposes untreated wood to attack by wood-destroying organisms.

B.4.1.2.2 Construction Damage Timber members can be damaged during construction. Splits or cracks in members caused by improper handling,

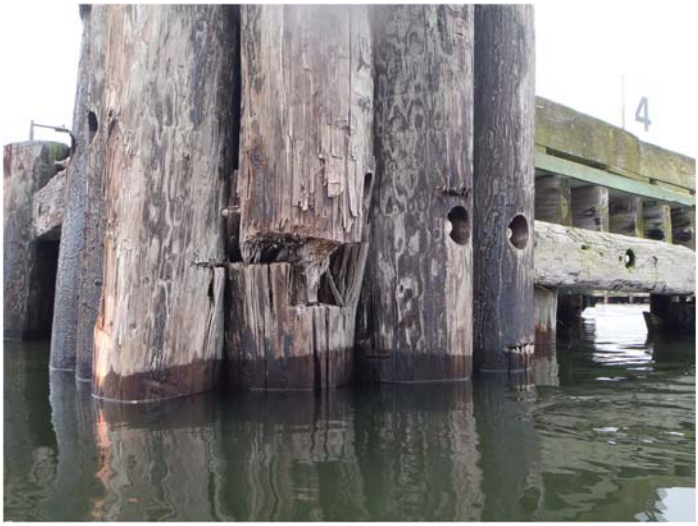

Fig. B-23. Impact damage on a timber fender pile
Source: Courtesy of Marine Solutions, Inc., reproduced with permission.

pile damage as a result of overdriving, scarring caused by machines used to place members, and any drilling or field cutting that does not receive field treatment to restore the integrity of the protective coating may leave the member vulnerable to attack by wood-destroying organisms. Depending on the specific nature of the damage, the load capacity of the member may be reduced.

B.4.1.2.3 Chemical Damage Chemicals commonly encountered in a marine environment, such as chlorides and sulfates, typically do not cause degradation of wood. However, animal waste can initiate damage to wood. The presence of bird droppings increases the amount of nitrogen in wood, which normally contains very little nitrogen. The added nitrogen can stimulate fungal decay. Additionally, the buildup of droppings can act to retain moisture and thereby also promote fungal decay.

B.5 MASONRY STRUCTURES

Stone masonry, although used today more for ornamentation or historical restoration, is often found as the primary structural building material at many older facilities, typically as mass-gravity retaining elements such as quay walls, abutments, and other similar structures (Fig. B-24). Granite, limestone, and sandstone are the most common types of stone found in masonry construction. Traditionally, stone masonry was used in the marine environment due to its increased durability in the tidal zone, particularly when subjected to freeze-thaw cycles or abrasion.

Cyclopean structures typically consist of graded rock ranging from 100 lbs to 7 tons (45 kgs to 6.35 mtons) or more, stacked below water. After placement of the rock in lifts, the voids between rocks are infused with concrete to create a solid conglomerate. Like their more modern counterparts, masonry structures in aquatic or marine environments are susceptible to various destructive processes. These can affect either the rock or the mortar and can lead to significant damage or destruction of the structure.

B.5.1 Erosion and Movement

By nature, stone walls rely on the geometry of individual stones for stability of the structure. Movement of individual stones due to erosion of fill or mortar can affect the overall global stability of the structure (Fig. B-25). In granite quay walls and other dry-laid structures, sinkholes are common as fines wash out from behind the wall. Over time, unless laid directly on bedrock or a pile foundation, the wall may settle or move, differentially affecting the overall batter.

Fig. B-24. Typical masonry structure under construction
Source: Courtesy of Appledore Marine Engineering, Inc., reproduced with permission.

Fig. B-25. Erosion and movement of a masonry block structure
Source: Courtesy of Appledore Marine Engineering, Inc., reproduced with permission.

B.5.2 Spalling

Spalling occurs when small pieces of the stone break away from the surface leaving a depression in the stone. A common cause of spalling is repeated freeze-thaw cycles where expansive forces generated by water freezing in the fissures and pores in the rock break the rock apart. Spalling of stone structures can also occur due to high temperatures caused by fire or other sources.

B.5.3 Splitting

Splitting of the rock used in masonry occurs when cracks open up in the rocks, eventually breaking the rock into small pieces (see Fig. B-26). This can be caused by volume changes such as seasonal expansion and contractions of the rock and freeze-thaw cycles. Plant growth can also generate and increase the size of cracks in the rock. Roots and stems in the crevices of rock can exert a wedging force, which can break up the rock.

B.5.4 Abrasion

Abrasion and weathering cause the hard surface of the rock to degenerate into small granules, giving the rock a smooth, rounded appearance. It is

Fig. B-26. Splitting of masonry blocks
Source: Courtesy of Marine Solutions, Inc., reproduced with permission.

caused by waterborne materials such as sand, debris, and ice. This type of deterioration can also be caused by chemicals (gases and solids) dissolved in the water. Oxidation and hydration of some compounds found in the rocks can also cause damage. Additionally, lichens and ivy can chemically attack the surface of stone, resulting in degradation of the rock surface.

B.5.5 Degradation of Mortar

The mortar used in masonry construction is also subject to deterioration (see Fig. B-27 and Fig. B-28). Frequently, this deterioration occurs more rapidly than that of the rocks themselves. The mechanisms of mortar deterioration are similar to that of concrete. Mortar is particularly susceptible to degradation at the waterline caused by freeze-thaw cycles. Finding the mortar essentially gone from this area is not uncommon. Abrasion and chemical damage are also agents of mortar deterioration.

B.5.6 Marine Borers

Marine borers can attack stone. Rock-burrowing clams, called Pholads, use chemical secretions to bore into the rock. They make pear-shaped burrows that enlarge as they grow, up to 2.5 in. in length and 1 in. in depth. This results in loss of cross section in the rock under attack.

Fig. B-27. Mortar degradation in the tidal zone
Source: Courtesy of Appledore Marine Engineering, Inc., reproduced with permission.

Fig. B-28. Close up view of loss of mortar between masonry blocks
Source: Courtesy of Appledore Marine Engineering, Inc., reproduced with permission.

B.6 COMPOSITE STRUCTURAL COMPONENTS

The use of composite materials for marine and waterfront construction is a somewhat new development when compared with conventional materials. Consequently, few composite structures can provide long-term information about performance and durability of the various materials and member types.

Fiber-reinforced polymer (FRP) composites or recycled plastics are typically less prone to deterioration than traditional materials. Composite materials are typically composed of glass, aramid fibers, or carbon. Glass fibers are economical but have limited structural value due to their low strength. The use of aramid fibers is usually limited to specialty applications of high stress and vibration due to their high cost and low modulus of elasticity. Carbon fibers offer significant advantages for marine applications that require high tensile strength, high modulus of elasticity, and low susceptibility to deterioration. Although the cost of carbon fiber is somewhat high, the material has proven to be versatile and cost effective in many applications when used in combination with other materials and when life-cycle costs are considered.

Common applications of composite materials in marine construction include piling, decking, and strengthening of members using carbon fiber laminates or wraps. Composite pilings are currently available in many proprietary configurations, including

- Recycled plastic with steel reinforcing,
- Recycled plastic with FRP reinforcing,
- Hollow steel core with a recycled plastic shell (the core may be filled with concrete or sand), and
- Hollow FRP core with a recycled shell (the core may be filled with concrete or sand).

B.6.1 Ultraviolet Deterioration

Early applications of composite piling exhibited deterioration such as cracking and splitting as a result of ultraviolet (UV) degradation, thermal stresses, and quality problems with constituent materials. UV resistance has improved dramatically in recent years (see Fig. B-29).

B.6.2 Material Incompatibility

Many problems have also been associated with the quality of the recycled materials used. Deterioration can be caused by differential thermal responses of the composite materials that can cause distress of the component if not accounted for in design. Similarly, adhesives used in the composite members may deteriorate over time when exposed to the marine environment.

Fig. B-29. Degraded fiberglass-reinforced pile casing showing abraded fibers
Source: Courtesy of Marine Solutions, Inc., reproduced with permission.

B.6.3 Corrosion Damage

Carbon fiber materials are susceptible to galvanic corrosion when used adjacent to metal. A barrier material, such as epoxy resin, must be used to separate the materials. Corrosion may also be a concern for composite components that rely on steel reinforcing or a steel core for strength. Cracks in the outer protective covering may leave the steel susceptible to corrosive deterioration.

B.6.4 Swelling

Some of the fibers used in the manufacturing of composite elements are susceptible to swelling in the presence of water. The fibers must be encased in a protective layer, typically a resin.

B.6.5 Overstress Damage

Composite materials often undergo significant deflection as a result of heavy loads. Large deflections can result in cracking of the outer shell, potentially compromising the member's structural integrity. Such deflections may also result in separation of the composite materials, as in the case of composite piles with a concrete filled core. Such overstress damage is often encountered in fender piling (see Fig. B-30). Permanent deflections can also result from the hysteresis effect of repeated large deflections. These

Fig. B-30. Cracked FRP pile from vessel impact
Source: Courtesy of Marine Solutions, Inc., reproduced with permission.

deflections can render the component ineffective and may lead to damage of adjacent members. Long-term deflection due to creep can also be a concern with composite materials.

B.7 COATING AND WRAP SYSTEMS

Several different types of coatings and wrap materials are used to provide protection of steel against the effects of seawater and corrosion. Asphalt enamels, coal-tar enamels, coal-tar epoxies, polyurethane materials, inorganic zincs, and other coatings are available. Additionally, various types of wraps including polyvinyl chloride (PVC) or fiberglass jackets and heat-shrink-applied barriers are common to protect marine pilings. Concrete and other materials are also commonly used to encase structural members in the marine environment. The basis of these systems is generally to isolate the structural member from the corrosive and abrasive marine environment.

B.7.1 Coatings

Coatings can fail for several reasons. However, disbonding and breakdown of coatings can often be traced back to poor surface preparation (see Fig. B-31). Shop-applied coatings provide greater control over conditions such as cleaning and moisture. However, damage to the coating can occur

Fig. B-31. Coating failure on steel bracing
Source: Courtesy of Marine Solutions, Inc., reproduced with permission.

during transport or installation. Structural steel shapes are prone to coating problems due to sharp corners and angles. When coatings are applied to these areas, internal forces in the coating draw it away from the edge, leaving the steel member either exposed or only partially covered.

Operational causes of coating deterioration include impact damage or a buildup of marine fouling, which can cause breaches of the coating and allow corrosion of the steel (see Fig. B-32). Isolated areas of coating loss or "holidays" in the coating can cause accelerated corrosion at the uncoated location where an electrochemical differential occurs between the coated and uncoated areas. A poorly adjusted cathodic protection system can result in blistering of the coating caused by electro-osmosis or hydrogen gas evolution.

B.7.2 Wraps

Several wrap materials are also available for either shop application or field installation. These products are generally composed of plastic, PVC sheet material, or mastic-coated tapes that are installed over structural members. As with coatings, these products are used as a preventative maintenance technique to provide protection against corrosion, marine organisms, floating debris, and moored vessels.

Various factors cause deterioration of wrap material, including impact damage, UV radiation, punctures or tears from floating debris and vessels, or heavy accumulation of marine growth. A disbanded, damaged, or incomplete wrap system can cause accelerated corrosion or concentrated

Fig. B-32. Deteriorated coal-tar epoxy polyamide coating resulting in corrosion of a steel fender pile
Source: Courtesy of Marine Solutions, Inc., reproduced with permission.

areas of marine organism attack (see Fig. B-33). Further, if not providing sufficient protection, wraps may hide ongoing deterioration. Dissolved oxygen testing may be performed to indicate the conditions beneath the wraps to evaluate corrosion potentials or conditions supporting marine organisms. Alternatively, selective removal and reinstallation of wrap systems is often necessary to correctly evaluate the effectiveness of the system and detect hidden deterioration.

B.8 LOAD ISOLATORS AND BEARINGS

Base isolation devices are being introduced for use with waterfront facilities. This is typically done as a means of retrofit for improved performance of a structure undergoing lateral forces, usually from earthquakes. These devices generally consist of a combination lead-rubber bearing assembly introduced between the supporting piling and the pile cap. This retrofit approach has been used for several decades with the foundations of buildings as a means of improving the structural performance of the building response to earthquakes. Slide bearings are commonly used to improve performance at the interface between bridges and supporting elements like abutments.

Fig. B-33. Torn PVC wrap exposing a timber fender pile
Source: Courtesy of Marine Solutions, Inc., reproduced with permission.

The typical lead-rubber base isolation unit consists of a cylindrical lead core surrounded by layers of rubber and steel laminated in such a fashion so as to make a larger cylindrically shaped element that is sandwiched between a top and bottom steel mounting plate. Diameters of the isolators can arrange from 12 in. to 60 in. (0.3 m to 1.5 m). The anchor bolts and steel retention brackets mate with the top and bottom mounting plates of the isolator and provide a means of connection to the substructure and superstructure (see Fig. B-34).

The rubber in the isolator unit acts as a soft spring that deforms laterally but is very stiff in the vertical direction. The lead core provides a damping mechanism by deforming under lateral loads. Slide bearings are of similar construction but typically incorporate a low-friction disk substituted for the flange plate.

Bearings are often located in close proximity to the splash zone (the intertidal area) beneath a marine structure. Placement of these units in locations of severe exposure promotes corrosion of the exposed steel elements. Typically, the steel fabrications of these assemblies are made from galvanized steel or stainless steel or they are covered with an epoxy coating. Inspection of these elements should address the following:

- **Corrosion.** The steel mounting plate and associated connection hardware should be inspected for corrosion. Excessive corrosion could be deleterious to the service life and performance of the bearings.

Fig. B-34. View of a lead-rubber base isolation unit installed below pier deck
Source: Courtesy of Moffatt & Nichol, Inc., reproduced with permission.

- **Debris.** Because the bearings are usually placed within a narrow space, finding birds' nests or other bio-fouling or the accumulation of trash or other deleterious material is not uncommon.
- **Damage to concrete.** Because of the possibility of entrapped moisture, the surrounding concrete element should be carefully inspected for obvious signs of cracks and/or spalls that are related to the corrosion of embedded reinforcing steel. Refer to Section B.2 "Concrete Structures" for discussion on the corrosion-related concrete damage mechanism.
- **Alignment.** Because the bearings are designed to facilitate movement of the superstructure in relation to the substructure, the possibility of permanent deformation after significant lateral loading exists. The bearings should be inspected relative to the alignment of the top- and bottom-mounting plates to preclude permanent distortion.

B.9 UNDERMINING OR SCOUR

Scour is the movement of riverbed or seabed material below its natural elevation by the action of moving water resulting from accelerated currents, wave energy focusing, and increased turbulence or propeller wash. This movement may result in degradation, or erosion, and aggradation (accumulation) of material. The loss of bottom material due to scour exposes a structure to undermining of the substructure components, including piles and abutments, posing an immediate and often unseen threat to safety. Even weathered rock can be eroded if the currents are able to move gravel or larger stones during floods. Three forms of scour can affect the safety of waterfront structures.

General scour. General scour is the general degradation or loss of the bed material along a considerable length of a river or marine area. It can be the result of natural erosion, mining activities, construction, or other events.

Contraction scour. Contraction scour involves an increase in velocity and shear stress on the bed at a structure. The contraction can be caused by a bridge or a natural narrowing of the stream channel. Contraction scour, in a natural channel or at a bridge crossing, involves the removal of material from the bed and banks across all or most of the channel width. Contraction scour occurs when the flow area of a stream at flood stage is reduced, either by a natural contraction or by obstructions within the channel. For continuity, a decrease in flow area results in an increase in average velocity and bed shear stress through the contraction. Hence, erosive forces increase in the contracted area, and more bed material is removed from the contracted waterway than is transported into the waterway. This increase in transport of bed material from the waterway lowers the natural bed elevation.

Local scour. Local scour is the removal of material from an area and is restricted to a minor proportion of the width of the channel or sea bed. The main mechanism of local scour is the formation of vortices due to increased current flow or propeller wash at the base of obstructions such as piers, piles, abutments, pipelines, gravity anchor blocks, anchor chains, or debris. With the somewhat recent incorporation of bow thrusters to deep draft container ships, scour is common along quays and quay walls, and, in some cases, has leached sand through open joints.

Another uncommon type of scour, which can occur during the early summer months, is strudel scour. When rivers thaw and the snow in the mountains melts, freshwater floods down over the shore-fast ice. Flooded areas may be many miles in extent. Eventually the water thaws a hole in the ice sheet and large quantities of water pours through, eroding a cone in the sea floor.

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APPENDIX C
OVERVIEW OF SPECIALIZED TECHNIQUES

C.1 INTRODUCTION

Waterfront structures of all types are susceptible to many defects and deterioration mechanisms. Some defects are unknowingly built into a structure, whereas others develop with time due to natural or manmade events. Although some of these defects may be detected by visual or tactile means, others may be hidden within the structure's members or components. In some cases, an indication of a defect may be readily observed, but the true extent or cause of the defect is not evident. For these cases, the use of specialized inspection techniques often involving various nondestructive testing (NDT) and partially destructive testing (PDT) can be used to more thoroughly investigate a structure's condition. NDT methods permit the inspection of an element without inflicting damage, whereas PDT typically causes minor localized, repairable damage. Specifically, NDT and PDT are used to investigate the material integrity of the test component and not the function of the component beyond material failure. In addition to NDT and PDT devices, several specialized techniques may benefit waterfront facility owners when data or images are not easily obtainable due to certain conditions.

This appendix presents an overview of various specialized inspection techniques as they apply to waterfront structures and miscellaneous support systems. Although many of these techniques are often performed by specialists, all waterfront facility owners and structure inspectors should be familiar with available advanced techniques so they can recommend appropriate testing procedures and recognize the limitations of the data.

Many specialized techniques have been developed and are commonly employed in the inspection of waterfront facilities. Several of these techniques are described herein, and the inspector should be aware that many other methods are also currently available, and new techniques are constantly being developed.

C.1.1 Qualifications for Specialized Techniques

Earlier in this manual, inspector qualifications were discussed. However, some specialized inspection techniques require additional qualifications and credentials. NDT and PDT methods range from simple timber coring to complex methods such as ultrasonic testing. The person conducting the test and the personnel interpreting the test data must be properly trained in the applied method. Additional qualifications should include both an understanding of the theory behind the test and practical experience. All inspection methods should be conducted in accordance with an acceptable standard of practice. The American Society for Non-destructive Testing (ASNT) and ASTM have many well-defined procedures and standards. In addition, other organizations [e.g., American Concrete Institute (ACI), American Welding Society (AWS), etc.] provide guidelines for some specialized techniques. Appropriate training credentials are warranted to ensure accurate data and to ensure that the data are defensible if questioned by other parties such as during legal disputes.

C.1.2 Data Collection and Interpretation

Upon embarking on a NDT or PDT program, a plan should be developed that details the type(s) of testing to be performed, amount of data needed, test locations, criteria for data interpretation, and follow-up procedures for handling unanticipated test results. Many testing methods produce considerable test data. Data should be collected on the applicable forms, which include the location and test results. When possible, copies of all field data should be retained as part of the structure's official file.

Interpretation of NDT/PDT data should be performed by persons knowledgeable both in the test theory and in the analysis or evaluation of the structure being tested. For some tests, such as ultrasonic weld inspection, recognized criteria exist for evaluating the effects of any detected anomalies. However, for many other test methods, the NDT/PDT data must be evaluated based on each individual structure's behavior.

Most nondestructive programs detect and assist in evaluating flaws and discontinuities and determining the strength or serviceability by indirect methods. The tests typically indicate the existence, extent, and location of discontinuities or abnormalities. However, the influence of the discontinuity or abnormality on the strength or serviceability of the structural component is often more difficult to determine. The validity of a NDT test depends on good engineering judgment based on experience or fully destructive testing validation results. The information collected by NDT/PDT is typically raw data and must be interpreted to correlate it to a usable parameter. Also, certain techniques may provide false data under certain conditions; therefore, it is important to be familiar with the technique and be able to recognize the false readings. Likewise, the inspector should not recommend testing, or accept testing results, without being familiar with the technique.

C.2 INFRARED THERMOGRAPHY

One type of deterioration encountered in waterfront structure decks is delamination within the concrete deck. Delamination is defined as a horizontal fracture plane at or above the top layer of the reinforcing. Overlay surfaces can hide delaminations until they are well advanced, and distinguishing between deterioration in the concrete deck slab and debonding of the overlay can be difficult.

Traditional inspection methods involve chain dragging and hammer sounding. These audible methods require inspector judgment and a great deal of effort, traffic control, and possible operational disruptions because of area closures. The presence of an asphalt or concrete overlay reduces the effectiveness of these traditional audible methods.

Infrared thermography is an alternative tool for locating and mapping delaminations in structure decks and pavements. A technique using an infrared scanner and control video camera, infrared thermography senses temperature differences between delaminated and nondelaminated areas. A delamination in a concrete deck creates a thermal discontinuity that acts as an insulator. Thermography operates on the principal that when the sun warms the deck, the delaminated area heats up at a faster rate and reaches a higher temperature than the solid areas.

A temperature difference between delaminated and solid areas is normally established only on sunny or partially sunny days. The deck must be dry and winds must be less than 25 mph. Temperature difference is primarily related to the amount of sun, not the ambient air temperature, so inspections can be undertaken under various temperatures.

The procedure involves scanning the concrete deck with an infrared camera and recording the video signal on videotape for detailed analysis in the office. A single pass, with a vehicle speed of approximately 5 mph, is typically made for each strip of the concrete deck. At the same time, a real-life control image of the deck surface is recorded. Distance footage is superimposed onto both videotape signals to locate defects.

Field confirmation of the infrared data consists of sounding several suspect deteriorated areas and measuring surface temperatures of both suspect and solid areas. Furthermore, select deck cores are typically taken for confirmation. These proposed core locations are typically marked at the time of the inspection.

Analysis of the infrared data is completed with the aid of a computer digitization program. During the analysis, the recorded temperature variations are interpreted to identify specific delaminated areas. Each delamination is identified and plotted onto plan view drawings of the deck. Square footage and percentage of delaminated deck are calculated. The real-life control data are examined to make sure that temperature variations were not caused by concrete spalls, discoloration, patches, tar, or debris. In addition, the real-life control data are used to plot existing repair patches, spalls, etc.

The use of infrared thermography for structure decks is covered in ASTM D4788-2013 (ASTM 2013). In addition, hand-held infrared thermography cameras are available, which are more portable than vehicle-mounted devices. These portable infrared thermography cameras may be used in other areas at a waterfront facility. However, manufacturer recommendations should be followed as the surface location or environment may affect the data obtained.

Infrared thermography is most commonly used on concrete decks with or without overlays; however, it can also be used on other concrete components. This method is proven to be accurate and easily repeatable.

Infrared thermography also provides for quicker data collection, because the equipment can be vehicle mounted and driven over the waterfront structure deck. By mounting the equipment to a vehicle, the process typically results in minimal disruption. Infrared thermography can be used in busy areas or where noise levels are high, unlike an audible inspection by a person with a hammer or chain-drag device.

Vehicle-mounted data collection for infrared thermography is completed with the aid of computer-logging software, and the image can be digitally processed for an overall assessment of the deck. Hand-held infrared thermography cameras may be useful in other concrete material areas at a waterfront facility. However, environmental conditions (e.g., material moisture content, ambient humidity, temperature, and other factors) may dictate applicable locations at a particular facility. Refer to Figs. C-1 and C-2.

Frequently, infrared thermography requires a temperature differential of approximately 0.5°C between the delaminated or debonded areas and solid regions of a concrete surface. This fact typically requires that inspections be done on days with approximately 50% sunshine. Wet areas, shadows, and debris on a concrete surface do not allow a temperature difference to be established, and, therefore, these areas cannot be inspected.

Infrared thermography locates the delaminated areas in the horizontal plane and does not provide any information on the depth layer where the defect occurs. If confirmation on depth is desired, cores can be taken.

If an inspector plans to use this technology at only a few structures or is considering setting up and operating a data collection vehicle, cost may be a prohibitive factor, because the scanning equipment and data processing software are expensive. Also, the vehicle must typically be operated by at

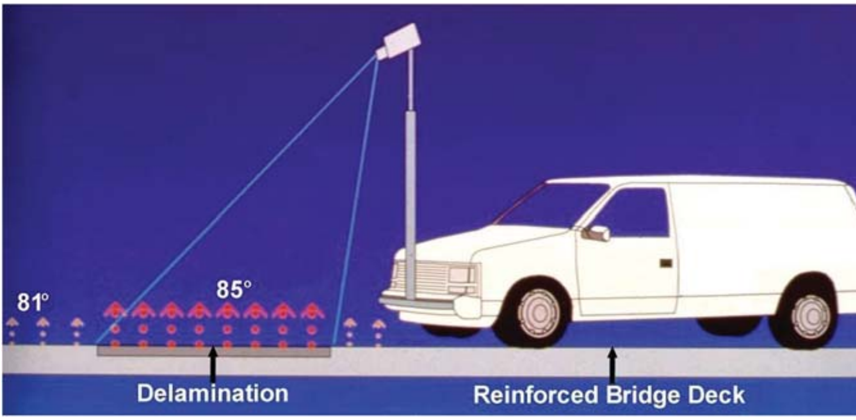

Fig. C-1. Infrared thermography equipment illustration
Source: Courtesy of Collins Engineers, Inc., reproduced with permission.

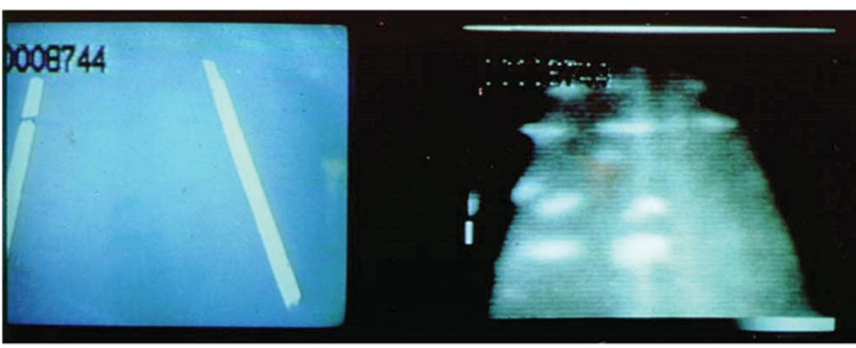

Fig. C-2. Infrared thermography images
Source: Courtesy of Collins Engineers, Inc., reproduced with permission.

least two inspectors. However, when compared with manually sounding a large deck or several smaller decks, infrared thermography may be cost effective. Furthermore, it may require less area disruption or coordination with port operations personnel.

C.3 GROUND-PENETRATING RADAR

Ground-penetrating radar (GPR) is a recognized NDT technique with many applications to structures, including sinkhole detection behind bulkheads, structure deck condition evaluation, overlay thickness determination, location of voiding under structure approach slabs, reinforcing steel location, foundation investigation, and underwater profiling. This section will mainly discuss the use of GPR on decks, structural elements, and approaches, although GPR can also be used over the water for channel bottom evaluations and over ground for subsurface utility location.

Over a body of freshwater, GPR systems radiate short pulses of electromagnetic energy from a broad-bandwidth antenna. These systems typically use a signal of 80, 100, or 300 MHz. Depending on the GPR system used, penetration of up to 40 ft (12 m) into resistive granular material can be attained, and layers as thin as 2 ft (0.6 m) can be detected. However, GPR systems will not work in soils or waters that are highly conductive due to chlorides or pollution. GPR over seawater does not work. Scour depression geometry, scour depression infill thickness, and riverbed deposition can often be detected using this technique.

A radar system typically consists of a control unit, radar antenna, and display unit. The control unit generates a radar pulse and sends it through a cable to the antenna. The antenna transmits the pulse into the surface. When this energy encounters an interface between two materials of differing dielectric properties, such as reinforcing steel, air, moisture, or the base-course material, a portion of the energy is reflected back to the radar antenna. The received pulse is sent back to the control unit for processing and storage. The display unit (video or chart recorder) presents the data.

The reflected energy is received by the transducer, amplified, and recorded. The electromagnetic pulse is repeated at a rapid rate, and the resultant stream of radar data produces a continuous record of the subsurface. The radar system creates a linear profile of the materials beneath the antenna pass.

For GPR over land, two different types of transducers (contact or horn type) can be mounted on a data-collection vehicle or hand towed. The location of the transducers can be varied across the width of the pavement, and, if additional information is required, several passes with the antenna in different locations can be made.

For most surveys, the antennae are mounted over the wheel tracks. The data are normally collected at a vehicle speed of 5 mph (8 km/hr) or less. Faster speeds are attainable, but the longitudinal and vertical resolution of the system is reduced. Horizontal data positioning is accomplished by using a GPS or a distance transducer connected to the drive train of the data-collection vehicle. Refer to Fig. C-3.

An event mark is automatically placed on the data at user-defined intervals, allowing defects to be located accurately. Once the survey is completed, a computer processes the data, and the results of the survey can then be presented in various formats.

GPR is most commonly used on ground to detect utilities, behind bulkheads to detect sinkholes, on concrete decks of a structure, or over the water to evaluate channel bottom characteristics. GPR also allows for an inspection

(a) (b)

Fig. C-3. GPR vehicle equipment
Source: (a) Courtesy of Fugro, Inc., reproduced with permission; (b) Courtesy of Collins Engineers, Inc., reproduced with permission.

of the concrete deck surface, which might be hidden by an overlay surface. If the concrete deck is not covered, GPR is not often used, because it is not as accurate or rapid as thermography.

On land or on top of a deck, the GPR system provides a means of determining the following items:

- Deck, pavement, and/or overlay thickness;
- Depth or location of reinforcing steel, bulkhead tie-back rods, or utilities; and
- Presence and size of voids beneath a pavement.

Over the water, GPR is typically only useful in shallow [less than 20 ft (6 m)] freshwater with granular bottom and sub-bottom sediments.

Over water or ground, GPR is limited by depth, conductive soils, and chlorides in the water (i.e., seawater or brackish water). With regard to concrete surfaces, GPR identifies areas of the concrete surface with different dielectric properties or conductivities. Some concretes, such as dry low permeability concrete, affect the ability of GPR to detect areas of delamination. GPR is also sensitive to the presence of water and chlorides on the deck and between overlays and the base concrete and the presence of debris on the deck surface. These conditions can significantly influence the accuracy of the data.

GPR must also be scanned perpendicular to the top layer of reinforcing steel. Therefore, inspection of some structures will require the survey to be conducted perpendicular to the flow of traffic. This will require traffic to be restricted or stopped altogether while the survey is being conducted. Frequently, several passes must be made on the deck area, and the cost may be prohibitive. Refer to Fig. C-4.

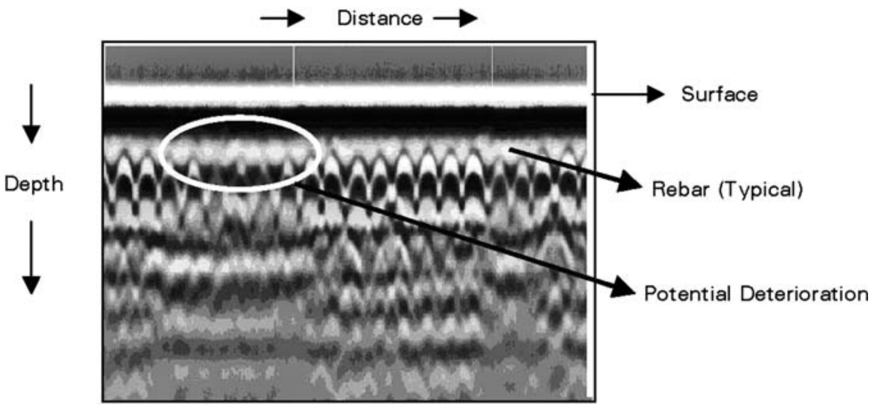

Fig. C-4. GPR image of concrete deck delamination
Source: Courtesy of Collins Engineers, Inc., reproduced with permission.

C.4 ACOUSTIC EMISSION

Noises occurring in nature are accompanied by and are the result of an energy release of some kind. Fatigue cracks, weld discontinuities, and many other failure-causing mechanisms also produce sound energy. Although a portion of the sound produced by materials under stress may exist as audible sound, most is low energy and inaudible. This depends on deformation magnitude and type and on flaw growth or failure.

For the purposes of this discussion, an acoustic emission (AE) is defined as inaudible sound energy released within a material undergoing deformation or flaw growth. An AE test is described as a method used to detect this sound energy. To detect AE, one or more "listening" transducers are attached to the test object. Positioning of AE transducers in the path of anticipated sound propagation enables detection. The detected signals are then electronically processed to derive information on the location and severity of growing flaws. Note that "guard" transducers are also used in conjunction with the "listening" transducers to differentiate the flaws from normal structure noises.

AE testing differs significantly from the other NDT methods discussed in this appendix. Perhaps the most notable differences are the following: (1) The detected signal is produced by the test material itself, not by an external source. The AE transducers need only act as receivers. (2) AE tests detect movement, whereas most other methods typically only detect existing geometrical discontinuities. (3) An applied stress is required to cause flaw growth, and, hence, the acoustic emission. The applied stress can be the result of the component's service and dead loads or an induced load used specifically for the AE test. In many tests, a combination of the two is necessary.

AE testing is used to detect cracks, corrosion, weld defects, and material embrittlement. This method can be used on various materials, such as metal, timber, concrete, fiberglass, composites, and ceramics. An entire structure can be monitored with AE testing from a few locations, reducing the amount of access required. AE testing can also be conducted while the structure is in service.

AE testing is a real-time NDT method. In other words, it monitors the actual condition of the component during the test. The AE test method can also be used to record an accumulation of damage occurring within a structure. The data obtained can be used as history for a structure and possibly to predict failure.

A primary limitation of AE testing on structures is the requirement to differentiate the sound energy released by a growing flaw from background noise. Many background noise generators, such as bolts, joint friction, traffic, port operations, and so forth, can mimic or mask the sound energy released from growing cracks. Some AE test methods avoid this problem by isolating areas known to contain possible background noise generators.

When a global AE inspection is conducted to determine areas where structural problems exist, additional NDT or PDT methods may be required to identify the exact nature of the emission source defect.

C.5 STEEL REINFORCEMENT TESTING

Covermeters or pachometers are electromagnetic devices that detect the reinforcing steel in concrete and measure its size and depth of cover. The device produces a magnetic field and locates the reinforcing steel by measuring the distortion of the magnetic field created by the presence of the steel. The received signal increases with increasing bar size and decreases with increasing cover thickness. Making certain assumptions, the pachometer can be calibrated to convert the signal into a distance, which indicates the depth of cover.

The importance of measuring depth of concrete surface cover is highlighted by the relationship between cover depth and deterioration mechanisms. Inadequate cover can undermine the protection that the concrete provides to the steel reinforcement from corrosion. Carbonation begins as soon as concrete is exposed to air, where carbon dioxide and moisture mix with products in the concrete to cause chemical changes. The process of carbonation neutralizes the protective alkaline nature of the concrete. If the cover is too shallow, the carbonation will reach the level of the reinforcing steel and the alkaline protection will be lost, allowing corrosion to begin on the steel. The exposure of the concrete and reinforcing steel to chlorides and moisture will further accelerate the corrosion process once the cover has been breached by cracks or spalls. If the cover is too deep, the possibility exists of increased crack widths and decreased effective depth, which both affect design parameters on a concrete member.

Accurately locating the reinforcing steel in concrete allows the inspector to determine if the steel is placed outside of the zone of carbonation. Covermeters, in general, can accurately measure the cover depth within 0.25 in. in the range of 0 to 3 in. in lightly reinforced structural members. Covermeters can also be used to locate reinforcing steel for the purpose of "tying in" a new structural member to an existing structure. This process typically occurs during rehabilitation and involves drilling into the existing structure and added reinforcing steel, which spans from the old to the new components.

Several factors may limit the effectiveness of a covermeter as an NDT method. Traditional covermeters only locate the reinforcing steel and may not provide any actual information about defects or the material's state of deterioration. Furthermore, it may not distinguish if one or more bars are present at a certain location, and, therefore, the intensity of the signal may be misinterpreted, and the cover depth can be incorrectly noted as shallower than the true depth. This problem is most pronounced in heavily reinforced structures or when large steel objects, such as scaffolds, are near the test area. Also, some reports indicate that the epoxy coatings on reinforcing steel can distort the readings of certain devices. Likewise, the relative material properties of the concrete often must be assumed to utilize conversion charts for the readings. Refer to Fig. C-5.

Fig. C-5. Pachometer unit
Source: Courtesy of Collins Engineers, Inc., reproduced with permission.

C.6 SCHMIDT HAMMER

A rebound hammer, commonly referred to as a Schmidt hammer, is a mechanical device used to measure the compressive strength of in-place concrete. The device consists of a plunger and a spring-loaded hammer. When triggered, the hammer strikes the free end of the plunger that is in contact with the concrete, which in turn causes the plunger to rebound. The extent of the rebound is measured on a linear scale attached to the device. This test is covered in *ASTM C805-13a* (ASTM 2013a).

The rebound hammer is used to assess the uniformity of in situ concrete and to delineate zones of poor quality or deteriorated concrete. It is also useful for detecting changes in concrete characteristics over time, such as hydration of cement, for the purpose of removing forms or shoring.

Advantages of the rebound hammer are that it is portable, easy to use, and low cost and can be used to evaluate large areas quickly.

The rebound hammer is valuable purely as a qualitative tool. It only measures the hardness of the concrete at the surface by comparing the amount of hammer rebound on a scale of 1 to 100 with an estimated compressive strength of the concrete. Other tests, such as a compression test, must be used to determine the actual strength of the concrete. Several factors govern the rebound measurement, including the size, age, and finish of the concrete and the aggregate type and moisture content. The Schmidt hammer test should not be used over exposed aggregate in the concrete, because a false reading will be displayed. Refer to Fig. C-6.

Fig. C-6. Standard rebound hammer
Source: Courtesy of Collins Engineers, Inc., reproduced with permission.

C.7 IMPACT-ECHO TESTING

The impact-echo method is a NDT technique used for detecting internal flaws in concrete. It has been used on various members, particularly slab, beam, and wall type members. The impact-echo test method produces a transient stress pulse in a member by means of a point impact. This pulse produces a surface wave and waves that travel into the element. These waves are reflected by internal defects and the boundaries of the element.

The testing apparatus consists of a hand-held unit that generates an impact that produces a wave and a receiving transducer that receives the reflected waves. A computer-based system is then used to process the data and display the echo waveform data. The operator interprets the data to determine the presence and extent of defects found. Impact-echo testing is covered in ASTM C1383-04(2010) (ASTM 2010).

The impact-echo technique utilizes easily transportable equipment and can be performed by a single individual. Testing is fairly rapid, and only minimal surface preparation is needed to ensure proper transfer of the impact energy to the structure. Tests are often done in a grid pattern, with the size of the grid determined by the suspected damage. Experience has shown that the technique can be used to locate subsurface delamination, honeycomb, cracks, voids, etc. In the hands of a skilled technician, it may also locate voids around reinforcing steel and within grouted prestressing strand and posttensioned tendon conduits. Refer to Fig. C-7.

Fig. C-7. Impact-echo testing to detect flaws in concrete
Source: Courtesy of Collins Engineers, Inc., reproduced with permission.

The impact-echo method requires interpretation of the waveform output for each test by the field technician. The testing technician must be trained and experienced to properly interpret the output data. Prior to testing, design plans should be carefully reviewed for embedded items or other details that may affect wave behavior and test results. The presence of steel reinforcement bars must also be properly accounted for. The maximum element thickness for this test is approximately 6.5 ft (2 m).

C.8 WINDSOR PROBE

The penetration method, typically utilizing the Windsor probe test system, consists of a device that drives a probe into the concrete using a constant amount of energy. The probe is made of a hardened steel alloy specifically designed to crack the aggregate particles and to compress the concrete being tested. Once fired, the length of the probe projecting from the concrete is measured. A test typically consists of firing three probes and averaging the projecting lengths. This test is covered in ASTM C803/C803M-03(2010) (ASTM 2010).

Penetration tests are used to assess the uniformity of in situ concrete and to delineate zones of poor quality or deteriorated concrete. They are also well suited for estimating compressive strength of concrete and the relative strength of concrete across the same structure. Penetration tests are commonly used to estimate early age strength of concrete for the purpose of stripping forms.

The penetration test method is basically a qualitative tool, and like the rebound hammer, requires that other tests be conducted to determine the actual strength of the concrete being tested. The penetration method also damages the concrete at the test location. The probes must be removed and the holes patched. Refer to Fig. C-8.

C.9 HALF-CELL TESTING CORROSION SURVEY

Half-cell testing can be conducted on coated steel members or embedded steel reinforcement in concrete to determine if corrosion is occurring. It can be conducted on elements located above or below the water. Steel reinforcement is typically protected from corrosion by the alkaline nature of concrete. If the alkalinity of the concrete is compromised, corrosion on the steel will commence, provided moisture and oxygen are present. The corrosion reaction will promote anodic and cathodic activity along the reinforcing steel. The corrosion of the reinforcement produces a corrosion cell caused by these differences in electrical potential.

The half-cell testing method uses this process to detect whether the reinforcing steel is under active corrosion. This method utilizes a multimeter

Fig. C-8. Winsor probe kit
Source: Courtesy of Collins Engineers, Inc., reproduced with permission.

to measure the potential difference between the steel and a half-cell apparatus. The analysis of the potential difference can indicate if active corrosion is taking place on the reinforcing steel. Likewise, this method can be used on a coated steel pile to detect if corrosion may be occurring below the coating. Lastly, half-cell testing can be used to obtain voltage readings to ensure that a cathodic protection system is working properly.

Although commonly used on steel piles or concrete decks, the half-cell test can be performed on any reinforced concrete component, provided a direct electrical connection can be made to the reinforcing steel. Because the test can only detect corrosion directly under the device, a systematic grid of test points should be created to map the potential readings throughout the concrete component. This map can then be analyzed to determine the probable areas of active corrosion.

Half-cell testing requires specialized equipment, including a half-cell reference apparatus and a multimeter. For topside applications, such as investigating the condition of steel reinforcement in a concrete deck, a copper-copper sulfate (Cu-CUSO4) half-cell reference apparatus is typically used. For underwater seawater applications, a silver-silver chloride (Ag-AgCl) reference half-cell would be more appropriate.

The potential measurements for Cu-CUSO4 half-cell reference apparatus can be interpreted as follows, but it depends on the type of half-cell:

- To −0.20 volts indicates greater than 90% probability of no corrosion;
- −0.20 to −0.35 volts indicates that corrosion is uncertain;

- < −0.35 volts indicates greater than 90% probability that corrosion is occurring; and
- A positive number indicates that the moisture content of the concrete is insufficient, and therefore the test is not valid.

The potential measurements for an Ag-AgCl half-cell reference apparatus can be interpreted as follows, but it depends on the type of half-cell:

- To −0.15 volts indicates greater than 90% probability of no corrosion;
- −0.15 to −0.30 volts indicates that corrosion is uncertain;
- < −0.30 volts indicates greater than 90% probability that corrosion is occurring; and
- A positive number indicates that the moisture content of the concrete is insufficient, and therefore the test is not valid.

Note that a connection with the reinforcing steel is required; therefore, holes may need to be drilled in the concrete to locate and connect to the steel. This test method only indicates the probability of corrosion present at the time of testing and does not indicate the extent or rate of corrosion. Refer to Fig. C-9.

Where structure elements are fully submerged and locating a topside multimeter voltage device nearby is impractical, proprietary devices, such

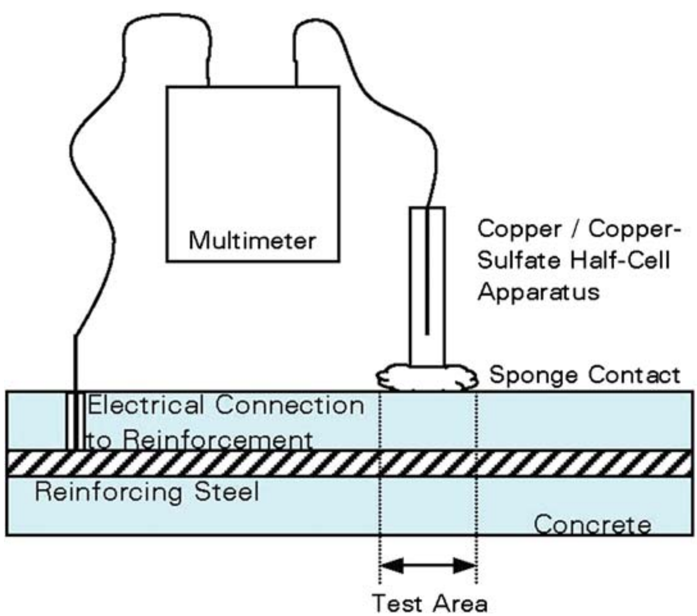

Fig. C-9. Half-cell testing illustration
Source: Courtesy of Collins Engineers, Inc., reproduced with permission.

as the Buckley bathycorrometer and Polatrak CP gun, can operate underwater in a self-contained waterproof containment unit.

Using this half-cell testing methodology, information can be obtained about members protected by cathodic protection. For example, elements are generally considered adequately protected by cathodic protection if a reading is < -0.80 volts with a silver-silver chloride (Ag-AgCl) reference half-cell. Furthermore, hydrogen embrittlement of welded members underwater may be a concern if readings of < -1.3 volts are obtained due to an overactive impressed current cathodic protection system.

C.10 CHLORIDE ION TESTING

Chloride ions (CI) are the major cause of reinforcing steel corrosion in concrete. Chloride ions are most often provided from seawater, although they may also be available as contaminants in the original concrete mix. Although present, these chloride ions are not likely to cause problems unless they exist in unusually high concentrations. Because corrosion of steel reinforcing is generally considered to begin at a chloride ion content of between 0.025 and 0.033% by weight of concrete, knowledge of chloride content can aid in determining the likelihood of the onset or presence of corrosion and aid in estimating the remaining life of a facility. Note that chloride content can be expressed in several ways. Primarily, these include the percentage of chloride ion in the bulk solid or the chloride content in parts per million (ppm) of a solution containing dissolved material. Both results, percent Cl^- in bulk and ppm Cl^- in solution, have been shown in the past to be accurate. If discussing ppm Cl^-, the threshold is considered typically 500 ppm, although empirically each site may be unique.

In evaluating chloride content, a chloride profile (chloride concentration percentage versus depth measurement below the concrete surface) should be developed. This profile is important for assessing the future corrosion susceptibility of steel reinforcing and for determining the primary source of chlorides.

The chloride content in concrete is typically determined through laboratory analysis of powdered concrete samples. The powdered samples can be obtained on site or in the laboratory. Field-collected powdered samples are typically taken by drilling at different depths down to and beyond the level of the reinforcing steel. Extreme care should be exercised to avoid inadvertent contamination of the samples. Alternatively, cores can be collected and powdered samples can be obtained at different depths by grinding the core sample in the laboratory. The collection of these samples, in essence, actually destroys a portion of the component, making this test procedure similar to material sampling as described later in this appendix. However, because this test can be performed in the field and results obtained quickly, it has been separated from the material sampling section discussions in this appendix.

The chloride ion content of concrete is usually measured in the laboratory using wet chemical analysis. Although laboratory testing is the most accurate, it is time consuming and often takes several weeks before results are available. As a result, field test kits have been developed. The use of field test kits allows rapid determination of chloride levels to be made on site. Although the field kits are not as accurate as the laboratory method, they do provide good correlation with laboratory tests when a correction factor is used.

There are various detailed procedures for chloride testing published by ASTM International. However, the ASTM International standards typical apply to testing in the laboratory, not in the field. However, AASHTO T260-97R2009 (*Sampling and Testing for Chloride Ion in Concrete and Concrete Raw Materials)* is a useful reference by the American Association of State Highway and Transportation Officials in Washington, DC.

Chloride ion testing can be performed on any concrete component. Field kits allow inspectors to perform the test on site and determine chloride levels immediately.

Collecting samples to perform this test requires damaging a portion of the concrete member and potentially compromising the tested area, thus requiring repair. Therefore, several samples cannot be taken from a single location to validate results. This method is also time consuming and requires access to the member. After conducting this test in an area, the area should be repaired or patched to prevent future deterioration.

C.11 MATERIAL SAMPLING

To fully determine the condition of a structure, extracting material samples from the structure may sometimes be necessary so that laboratory tests can be conducted to better determine the condition of the structure's materials or the states of deterioration or damage. Typical laboratory tests may include compressive tests and petrographic examination of concrete; tension tests, charpy tests, or crack surface investigations of steel; or even simple integrity examination of timber.

Prior to obtaining any samples, the extent and purpose of the sampling must be determined. The sample size is often stipulated in the specific test methods to be used. In most cases, particularly where deterioration is present, taking samples from both good and poor areas is advisable so that a comparison can be made. Once the number and location of samples are determined, they should be plotted on a drawing of the structure to both aid in fieldwork and serve as a record for the evaluation of the test results.

All materials can be sampled and tested either in the field or in a laboratory to provide useful information as to the strength, extent of deterioration, and material characteristics. Specimens should come from representative areas of the structure using a statistically representative sampling number with a minimum of three samples.

All material samples should be collected and tests conducted in accordance with ASTM and methods for the respective materials.

The removal of material from the structure should only be conducted when a specific piece of information is required and the information attained provides useful information in the evaluation of the structure.

Extracting samples will leave holes or voids in the tested component, and, therefore, repairs will be required. Concrete and timber repairs are somewhat easy, but steel repairs may be more complex. Welding requires the use of experienced personnel, and care should be taken to minimize any residual stresses or fatigue-prone details associated with the repair.

C.11.1 Concrete Sampling

Concrete material sampling most often consists of drilled cores, though sections may also be obtained by sawing or breaking off a portion of the component. The core size should be determined by the tests to be run; however, in most cases, a 4-in. diameter core is extracted. Core holes are normally filled with grout; other sample areas should also be repaired with a suitable mortar material. When feasible, steel reinforcement should typically be avoided unless sampling specifically requires it to be part of the core. Refer to Fig. C-10.

Samples should be marked for location and orientation and packed to prevent damage during transport. As part of the sampling operation, reinforcing steel is typically located and marked to avoid cutting it during the sample extraction. In some instances, including reinforcing steel as part of the sample may be desirable. In these cases, confirming that the cut reinforcing steel will not jeopardize the structure's integrity is necessary.

Some concrete tests that require samples include

- Carbonation,
- Permeability,
- Cement content,
- Percent air content,
- Moisture content,
- Steel reinforcing yield strength,
- Concrete compression strength,
- Modulus of elasticity (static and dynamic), and
- Concrete splitting tensile strength.

Fig. C-10. Concrete deck core photographs
Source: Courtesy of Collins Engineers, Inc., reproduced with permission.

C.11.2 Steel and Timber Testing

Material coupons for steel members are usually obtained by sawing, coring, or collecting drill shavings. Coupons may be flame cut; however, the heat induced by the cutting operation alters the material's properties in the vicinity of the cut both in the sample and in the remaining base material. These heat-affected areas must then be removed by grinding prior to testing. Repair to the base material is also often required. For these reasons, flame cutting should typically be avoided. In selecting coupon locations to test material properties, such as yield strength or toughness, the investigator must remember that the properties of steel members vary over the cross section as a result of differing rates of heat loss due to fabrication techniques and rolling or production practices. The orientation of the steel samples should be recorded prior to removal. Refer to Fig. C-11.

Some of the steel tests that require samples are

- Brinell hardness test,
- Charpy impact test,
- Chemical analysis, and
- Tensile strength test.

Timber sampling often consists of the use of incremental borer (up to 1/4-in. diameter for void verification or preservative penetration

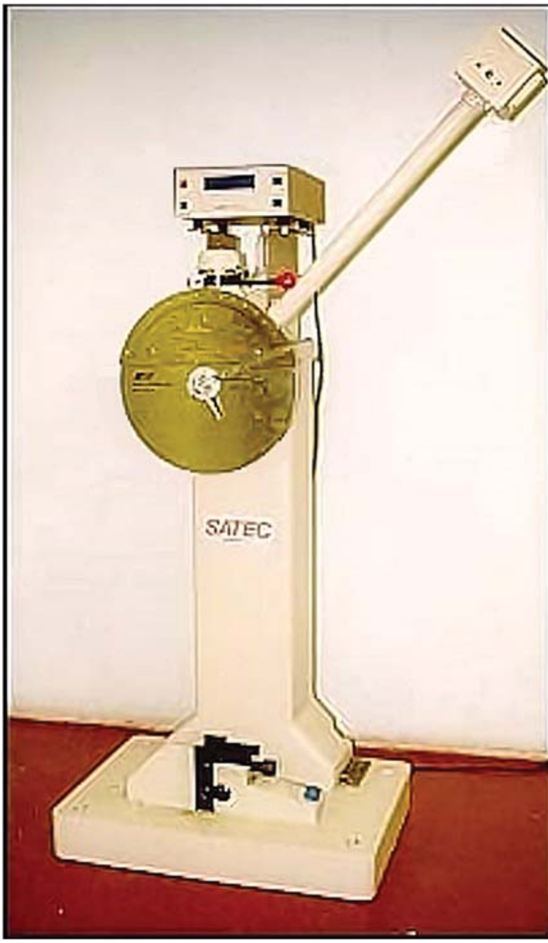

Fig. C-11. Charpy impact metal testing machine
Source: Courtesy of Collins Engineers, Inc., reproduced with permission.

examination) or extraction cores (typically 2-in. diameter or greater for marine borer investigations and strength testing), though sections may also be obtained by sawing off a portion of the component. Bore holes should be plugged with a treated hardwood dowel. Larger-diameter core holes are more challenging to plug and should be handled based on the required life span of the repair. Drilling, boring, and probing are most often used to assess the presence of marine borers or voids, the extent of rot, and the depth of preservative penetration. Refer to Fig. C-12.

Timber sample cores are assessed to determine if bacterial or fungal decay is present and the extent of interior rot and to determine the species of

Fig. C-12. Timber cores placed in tray
Source: Courtesy of Collins Engineers, Inc., reproduced with permission.

timber, if required. These methods typically do not produce a global sample specimen; however, several local specimens from random locations can be effective. Any holes should be plugged with a treated hardwood dowel.

Moisture content and rot can also be assessed on specimens using electrical devices, such as the Shigometer. These devices require electrodes to be driven into the timber or that small holes be drilled to insert probes into the timber. These detect the presence of timber rot; however, drilling or coring should be conducted to determine the extent of the rot.

C.12 ULTRASONIC TESTING

Ultrasonic testing (UT) is used to evaluate various materials and examine the internal (volumetric) condition of materials. Specifically, it is used to confirm suspected discontinuities or cracks and check questionable material thicknesses or lengths in steel, concrete, or timber. Typical discontinuities, which are detectable by use of UT, include laminations, surface cracks, and many surface and subsurface weld-related discontinuities (lack of fusion, porosity, etc.). Although ultrasonics may be used in timber, there are mixed opinions within the industry as to the effectiveness of the nonhomogeneous material in a marine environment. Therefore, the user should be familiar with the applications and limitations of UT on timber in the marine environment.

A transducer is a device that is capable of converting energy from one form to another. In the case of UT, electrical energy is changed to mechanical energy and vice versa. UT transducers convert electrical energy into mechanical vibrations, which in turn produce high-frequency sound waves. They also convert high-frequency sound back into electrical energy upon receiving the return echoes.

The most common ultrasonic technique currently in use in the United States is called pulse echo. The pulse-echo method employs short bursts, or pulses, of waves, which are transmitted into the specimen by the transducer, which must be in integral contact with the specimen. Any returning unexpected echo from these pulses is evaluated to determine reflector location and size.

The signal height, or amplitude, relates to the amount of reflected sound energy. Large reflectors, causing total reflection of sound, produce signal responses of higher amplitude than smaller reflectors, which only reflect a portion of sound energy. Larger return echo amplitudes suggest larger-sized flaws. Echo indications are normally retested from another position to confirm flaw size and position. Basic ultrasonic pulse-echo systems utilize a power supply, pulser, receiver/amplifier, oscilloscope (cathode ray tube or CRT), timer (clock), and a transducer. Refer to Figs. C-13, C-14, and C-15.

Power for the testing equipment is supplied by portable battery packs or by an external AC source. The pulser, also called the pulse generator, produces the short duration voltage burst, which is applied to the transducer. The rate of these voltage bursts is controlled by a clock or timer. Sound echoes returning to the transducer are relayed to the receiver, amplified, filtered, and sent to the CRT for display on the screen. Pulse-echo methods include compression, shear, and surface wave modes.

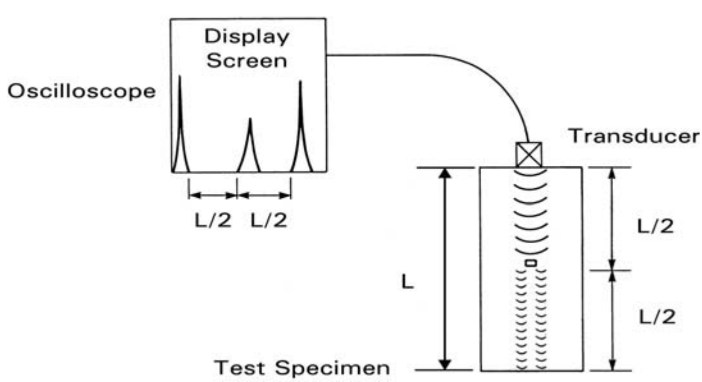

Fig. C-13. Pulse-echo UT illustration
Source: Courtesy of Collins Engineers, Inc., reproduced with permission.

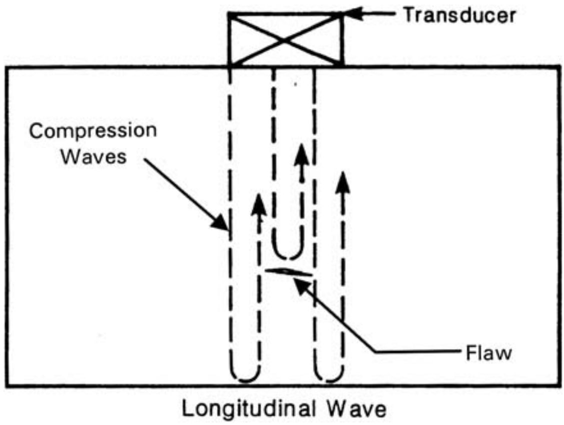

Fig. C-14. Pulse-echo UT compression wave schematic
Source: Courtesy of Collins Engineers, Inc., reproduced with permission.

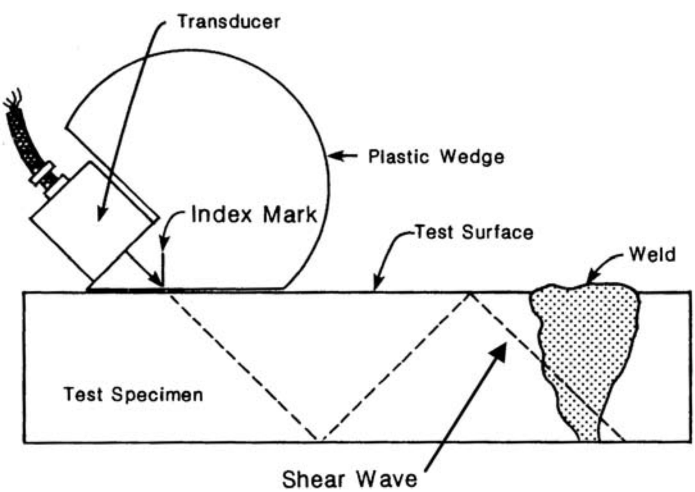

Fig. C-15. Pulse-echo UT shear wave schematic
Source: Courtesy of Collins Engineers, Inc., reproduced with permission.

Phased array is a unique type of UT and has several advantages over traditional UT devices. However, phased array units are more complex and require additional training.

UT should not be performed on rough surfaces, on parts with complicated geometries, on highly attenuative materials, or where the discontinuity size is expected to be smaller than one-half of the wavelength. Rough surfaces may require grinding in surface preparation. Other factors that limit the successful application of UT are lack of properly trained personnel, over estimation of the accuracy of flaw locating and sizing, and poorly written testing procedures. Typically, a certified Level II ASNT specialist should conduct all testing, and a Level III ASNT specialist should develop written testing procedures for uncommon applications.

C.13 LIQUID PENETRANT

Liquid-penetrant testing is used to confirm the presence of a crack or flaw. Liquid-penetrant tests can be conducted on many nonporous materials, including metallic and nonmetallic, magnetic and nonmagnetic, and conductive and nonconductive materials. This method is highly sensitive to small surface discontinuities and produces indications directly on the surface of the component, providing a visual representation of the flaw.

Liquid-penetrant testing relies on the capacity of a liquid to enter into a discontinuity; therefore, it can only find discontinuities that are open to the surface of the material. It can be used with any material provided the material is nonporous and is not adversely affected by the penetrant material.

The basic procedure requires that the material be prepared by removing all surface contaminants and applying a liquid (penetrating oil) to the surface being tested. The penetrant will seek out and enter small surface openings. Penetrant is then removed from the test surface by wiping or water rinsing. A drying developer is next applied. The penetrant remaining in the discontinuity bleeds out forming a highly visible, contrasting indication on the test surface. See Figs. C-16 and C-17.

A good penetrant is defined by the ability of the fluid to be drawn into small openings, even against gravity. Many variables affect this penetrating ability, including surface tension of the liquid, wetting ability, surface condition, surface contamination, and temperature.

Two major types of penetrants are used: (1) visible dye penetrants and (2) fluorescent penetrants. Visible dye penetrants are normally red, providing contrast with the applied white developer under visible light. Fluorescent penetrants contain dyes that fluoresce brilliantly when viewed under a black light in a darkened area. The ability to see penetrant indications on the test surface relates to the contrast provided between the penetrant and the test surface. Fluorescent penetrants provide better contrast than visible dye penetrants. For this reason, fluorescent penetrants are more accurate than visible dye penetrants.

Interpretation of the liquid penetrant indication involves determining what condition is present to have caused the indication, evaluating the

Fig. C-16. Liquid penetrant and developer applied to a casting
Source: Courtesy of Collins Engineers, Inc., reproduced with permission.

Fig. C-17. Gusset plate with applied dye penetrant
Source: Courtesy of Collins Engineers, Inc., reproduced with permission.

condition as to its effect and seriousness from the standpoint of usability of the part, and reporting inspection results accurately and clearly.

Proper interpretation and evaluation of liquid penetrant indications requires knowledge of the types, causes, appearance of indications, knowledge of the test method and material fabrication process, adequate illumination, good eyesight, and experience.

The penetrant materials typically come in aerosol form, making them very portable and well adapted to field use. This also allows large areas of a component to be tested rapidly even if the component has a complex geometric shape. Powder penetrant materials are also available but are typically cumbersome in the field.

Finally, penetrant materials and the associated equipment are somewhat inexpensive, especially when compared with most other NDT methods.

Liquid-penetrant testing does have several limitations, including the fact that this method only works on nonporous materials, surface finish and roughness can affect the sensitivity of the test, and it can only detect discontinuities that are open to the surface. Discontinuities filled with contaminants, paint, rust, oxidation, or corrosion products may not be detected. Therefore, surface preparation is critical. The process also requires multiple time-consuming steps, including preparing the surface, applying the dye or fluorescent, cleaning off the dye or fluorescent, applying the developer, and cleaning off the developer after the test is completed. This effort requires the safe handling of chemicals and the proper disposal of saturated cleaning rags and empty aerosol cans.

Finally, the test sensitivity is lowered at reduced temperatures, because crack widths are typically reduced, and the test medium is less fluid.

C.14 MAGNETIC PARTICLE

The magnetic-particle test (MT) is used for testing ferromagnetic materials (steel, wrought iron, cast iron, etc.). MT is used to confirm suspected cracks or test suspect details. The primary advantage of MT is high sensitivity in the detection of tight surface cracks and other small discontinuities. Typical detectable discontinuities include cracks, lack of fusion, and other weld-related surface discontinuities. Base metal discontinuities such as seams, laps, and “stringers” are also easily detected. Refer to Figs. C-18 and C-19.

As defined by the American National Standards Institute (ANSI), the MT method utilizes the principle that magnetic lines of force, when present in a ferromagnetic material, will be distorted by a change in material continuity such as a sharp dimensional change or a discontinuity. If the discontinuity is open to or close to the surface of a magnetized material, flux lines will be distorted at the surface; a condition termed flux leakage. When fine magnetic particles are distributed over the area of the discontinuity while the flux leakage exists, they will be held in place, and the accumulation of particles will be visible.

Fig. C-18. Magnetic particle testing kit
Source: Courtesy of Collins Engineers, Inc., reproduced with permission.

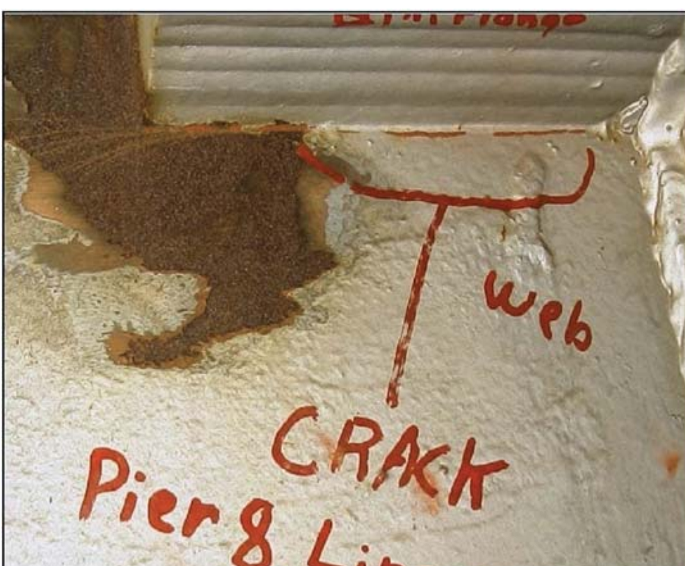

Fig. C-19. Crack identified by magnetic particle
Source: Courtesy of Collins Engineers, Inc., reproduced with permission.

The objective of MT is to cause a magnetic field of sufficient strength and predetermined direction to leak if discontinuities are present. The inspector detects these leaks by sprinkling the test area with iron filings, blowing away the excess, and then looking for areas where the filings have accumulated. These areas of accumulation indicate a surface or possibly a subsurface discontinuity.

MT methods and implementation procedures are fully described by the following terms:

- Dry method: The dry method describes the type of indicating medium, the iron filing powder, as dry. Commercial powders are available in various colors including red, black, grey, or yellow. The color selection should be based on the maximum color contrast with the material to be tested. Dry fluorescent particles are also available for use with a black light. Dry particles are finely divided ferromagnetic material with high permeability and low retentivity. The powder consists of a mixture of particle sizes, smaller ones being attracted by weak leakage fields and larger ones for detecting larger discontinuities.
- Wet method: If powders or particles are suspended in oil or water, the method is considered wet. Wet suspensions are also available in various colors and fluorescent. They can be sprayed onto the part, or the part can be bathed in a suspension. Wet fluorescent particles provide maximum sensitivity (superior visibility) if used with the proper current, lighting, and surface preparation. Wet particles are mixed with the suspension in predetermined concentrations and particle sizes. The concentration will affect the test sensitivity. Light concentrations will produce faint indications, and heavy concentrations may provide too much coverage. Wet particles are generally smaller in size and lower in permeability than dry particles.
- Continuous procedure: This term is used if magnetizing force is applied prior to the application of the particles and terminated after excess powder has been blown away.
- Residual procedure: The term residual is used where the particles are applied after the part has been magnetized and the magnetizing current has been terminated.

Field-testing of structures and related structures use portable units, which include the small portable prod or yoke units with alternating current/half-wave direct current (AC/HWDC) capability. Portable prod equipment is commonly available in amperages up to 1,500. However, 115-volt single-phase AC can also power the equipment. Some magnetic units do not require electricity, but they are less common.

Yokes are lightweight portable units easily carried to the job site. On some yokes, the legs are fixed at a set distance; on others, the legs are adjustable for various pole spacings. Yokes operate with 115-volt AC.

MT is a sensitive means of locating small and shallow surface cracks and has the ability to locate near-surface discontinuities with direct current. Unlike liquid penetrant, cracks filled with foreign material can be detected and no elaborate surface preparation is necessary. This test is also effective on painted surfaces.

This method is reasonably fast and inexpensive, especially compared with some other NDT methods, and the equipment is very portable. The method also presents few limitations on size or shape of the part being inspected.

MT does have some limitations, however. This test will work only on ferromagnetic material, and the magnetic field must be in a direction perpendicular to the principal plane of the discontinuity for best detection. MT will not disclose fine porosity. The deeper the discontinuity lies below the test surface, the larger the discontinuity must be to provide a readable indication.

C.15 STRUCTURE-MONITORING SYSTEMS

In contrast with other NDT testing methods where the inspector conducts an inspection over a finite time interval, monitoring systems provide continuous data over an indefinite time interval. Monitoring devices are typically mounted to the structure, connected to a data collection device, and left by the inspector to monitor the structure. These systems can be set to monitor a specific component or section of the structure, or be designed to encompass the entire structure. The scope of monitoring depends on the desired data, the potential problem areas, and/or the potential areas of structure movement. Refer to Fig. C-20.

A monitoring system can comprise various sensors; a data collection device (computer); and, in the case of a remote system, a communication device, which transmits the data to the monitoring station for analysis. Sensor types include strain gauges, clinometers (tilt meters), accelerometers, thermocouples, and various other devices.

- Strain gauges: The term "strain gauge" typically covers a wide range of devices that are used, as their name implies, to measure the strains of structural members under load.
- Clinometers: Measures the inclination or tilt of a structure or structural component.
- Accelerometers: Measures structure dynamics under conditions such as high winds, seismic activity, and/or vehicular traffic.
- Thermocouple: Measures the temperature of a structure or its environment.

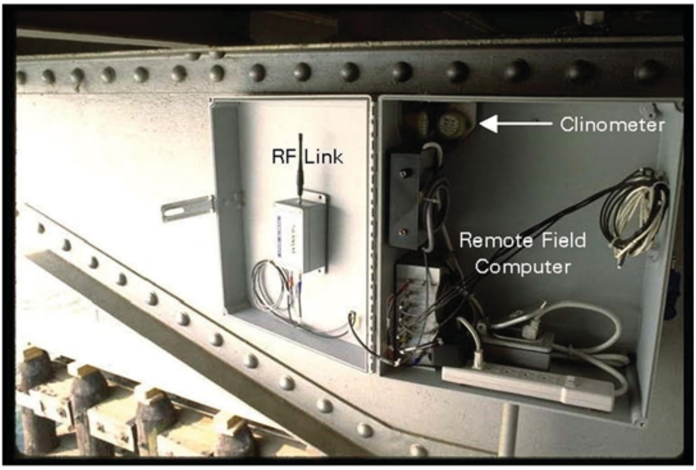

Fig. C-20. Remote field computer, clinometers, and radio frequency (RF) link mounted in protective enclosure
Source: Courtesy of Collins Engineers, Inc., reproduced with permission.

Strain gauges are the predominant sensors in use today. Several strain gauges are available, and selection should be made based on the location of their use and the specific data type and quantity to be collected. A strain gauge will have an established initial set length that is used as a datum, and the gauge will electronically measure an elongation. The resulting elongation divided by the gauge length yields the strain at that point. This calculation is typically performed automatically by the data acquisition system. Strain gauges can also be used to measure rotational strain. Strain gauges can be placed either external to or, in certain circumstances, within the object being examined. Groups of gauges are usually installed in patterns determined by the type of data desired. Strain gauges are typically small and flat and do not interfere with the use of the structure. The strain gauges are then connected to a data acquisition system that records the strain data. Under real-time loading situations, the acquisition system can automatically collect data at a given time interval, perhaps every 10 minutes, to record a strain-time history.

In the area of waterfront structures, strain gauges may be installed at carefully selected locations on a structure to measure strains under live load conditions. These strains may be due to daily crane loads, vessel impact forces, wind, temperature, or specifically applied test loads. This strain data is then evaluated directly, or more often, converted to stresses that can be compared with calculated design stresses. Thus, strain data allow the real performance of a structure to be compared with the theoretical design and enable development of an analytical model to more accurately predict actual performance.

Strain gauges are also often employed to study the performance of a local area or detail for which theoretical analysis may be difficult. In field situations, strain gauges may also be used as monitoring systems at locations of great concern to detect either movement or changes in stresses. This work may be required to verify safety in areas of uncertain stability or strength. In a sufficiently sophisticated system, movement beyond a certain range may cause alarms to sound at the structure or at an off-site monitoring station.

Therefore, strain gauges may be used at locations where replacing an existing structure of uncertain strength is difficult or prohibitively expensive, while still allowing safe use of the facility. See Figs. C-21, C-22, and C-23.

Monitoring systems have many applications in the inspection of structure components. The sensors are very versatile and can be applied to many materials. They are typically small and can be attached in tight-fitting areas. Furthermore, many of the sensors have a high level of accuracy and can be applied in both static and dynamic situations. Once installed, the sensors can provide data for an indefinite period of time.

The ability to continuously monitor structures or specific components allows the owner to record and clearly observe performance and detect deterioration. These systems work well from a preventative maintenance stance.

Monitoring systems, however, do have some limitations. The sensors, although typically inexpensive, are often one-time use devices. Once

Fig. C-21. Strain gauges attached to steel member
Source: Courtesy of Collins Engineers, Inc., reproduced with permission.

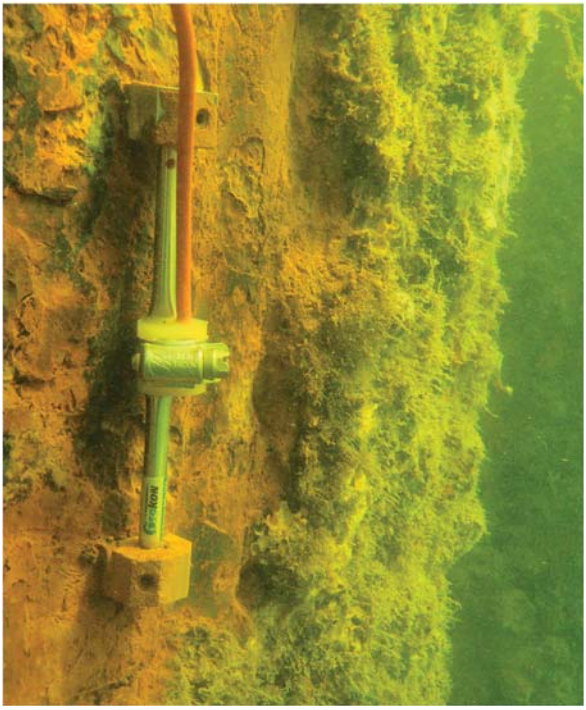

Fig. C-22. Submerged strain gauges attached to sheet pile bulkhead
Source: Courtesy of Collins Engineers, Inc., reproduced with permission.

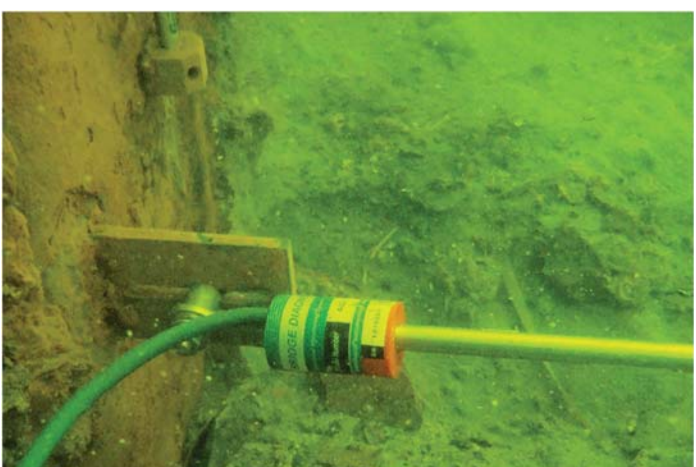

Fig. C-23. Submerged seafloor displacement gauge attached to sheet pile bulkhead
Source: Courtesy of Collins Engineers, Inc., reproduced with permission.

mounted to a particular structure they cannot be removed and reused for another application. The sensors also typically require a high level of expertise to install.

Although the sensors are inexpensive, the data collection and transmission devices can be expensive and require specialized individuals to maintain and process the data. The gathered data must also be analyzed and manipulated to provide usable information.

C.16 UNKNOWN FOUNDATION INVESTIGATION

Many older waterfront structures do not have any design or as-built plans on file to document the type, depth, geometry, or materials incorporated into their foundations. Structures with unknown foundations pose a potential problem from a scour safety perspective. In addition to scour concerns, unknown foundations also pose a concern when a structure is considered for operational changes such as increased vertical or lateral loading or berth-area dredging for deeper draft vessels.

The evaluation of unknown foundations can be conducted either by conventional methods, such as physically disruptive excavation, coring, or boring methods, as well as less invasive NDT methods. Conventional methods can be more disruptive and expensive. Therefore, research emphasis has recently been placed on NDT methods that can reliably determine the foundation property parameters with less cost and disruption to the site.

The important parameters in the evaluation of unknown foundations are

- Foundation depth: the bottom elevation of the footing, piles, etc.;
- Foundation type: shallow (footings), deep (piles or shafts), etc.;
- Foundation geometry: buried substructure dimensions, pile locations, etc.;
- Foundation materials: steel, timber, concrete, masonry, etc.; and
- Foundation integrity: condition of foundation materials.

The foundation depth and type, if unknown, are considered to be the most critical pieces of information in a scour evaluation. The foundation geometry, materials, and integrity are frequently desired when improvements are being considered near to a structure. Refer to Fig. C-24.

In determining which NDT methods might be useful, the method's capacity to detect and delineate the foundation components from the surrounding environment is often the deciding factor. The subsurface environment typically consists of a mixture of air, water, riprap materials, soil, and/or rock. Thus, the method must be chosen considering the wide range of substructure, geological, and hydrological conditions at a particular facility site.

Fig. C-24. Excavation of tie rod to measure remaining tie rod area
Source: Courtesy of Collins Engineers, Inc., reproduced with permission.

The NDT methods used for unknown foundation investigation can be categorized as surface methods or borehole methods. Surface methods are generally less invasive, because they do not require soil disruption like borehole methods. Although the following list provides a brief sample of applicable methods, the inspector should be aware that other methods are also currently being researched and implemented. Currently used surface methods include

- Sonic echo/impulse response (SE/IR) test. The source and receiver are placed on the top and/or sides of the exposed pile or columnar-shaped

substructure. The depth of the reflector is calculated using the identified echo time(s) for SE tests, or resonant peaks for IR tests.
- Bending wave test. Two horizontal receivers are mounted a few feet apart on one side of an exposed pile, and then the pile is impacted horizontally on the opposite side a few feet above the topmost receiver. This method is based on the dispersion characteristics and echoes of bending waves traveling along very slender members like piles.
- Ultraseismic test (UST). An exposed substructure is impacted with an impulse hammer to generate and record the travel of compression or flexural waves down and up the substructure at multiple receiver locations.
- Spectral analysis of surface waves (SASW) test. This involves determining the variation of surface wave velocity versus depth in layered systems. The bottom depths of exposed substructures or footings are indicated by slower velocities of surface wave travel in underlying soils.
- Ground-penetrating radar (GPR). This method uses a radio frequency signal that is transmitted into the subsurface and records the reflection echoes from the concrete/soil interface to determine the unknown depth.

Currently used borehole methods include

- Parallel seismic test. An exposed foundation substructure is impacted either vertically or horizontally with an impulse hammer to generate compression or flexural waves that travel down the foundation and are reflected by the surrounding soil. The reflected compression wave arrival is tracked at regular intervals by either a hydrophone receiver or geophone receiver.
- Borehole radar test. A transmitter/receiver radar antenna is used to measure the reflection of radar echoes from the side of the substructure foundation.
- Induction field. A magnetic field is induced around the steel of the pile or reinforced concrete foundation. The field strength will decrease significantly below the bottoms of the foundation.

C.17 UNDERWATER ACOUSTIC IMAGING AND CHANNEL BOTTOM SOUNDINGS

Waterfront inspections require understanding the surrounding channel bottom and condition of submerged structural elements. Sonar is a useful tool to determine and document underwater conditions. However, numerous different types of sonar technologies are available depending on the inspector's objectives. The structure inspector may wish to use sonar technology to evaluate and document the adjacent channel bottom, scour depressions, submerged debris, and submerged portions of the structure.

Although this section introduces the use of sonar for underwater acoustic imaging and channel bottom sounding survey, it does not prescribe dredge quality hydrographic surveys, nor is it an exhaustive resource of underwater technologies. The channel bottom depth soundings conducted by a typical waterfront structure inspector are usually neither as detailed, nor as extensive as those of a certified hydrographic surveyor completing a bathymetric map for navigation or dredging operations.

Basic channel bottom soundings are often known as water depth soundings. This process is used to obtain underwater surface elevation data for evaluating the channel bottom surrounding a structure and the waterway in general. Water depth soundings, as part of a waterfront structure inspection, can utilize simplified methods or more specialized equipment depending on the required level of sophistication.

C.17.1 Channel Bottom Sonar Data

Channel bottom depth soundings may be conducted by simple single-beam sonar (fathometers) or even with lead lines (or sounding poles). These techniques result in profiles under the vessel or spot elevations at each lead line observation point. Other situations may require more detailed multibeam (swath) bathymetric surveys. This can be more common when assessing slopes, revetments, breakwaters, and other long linear features. Locations that are subject to sediment movement, especially sand waves, frequently require multibeam surveys, because spot elevations and profiles do not represent volumes and sand waves appropriately. Multibeam bathymetry is also far more reliable in identifying pits, mounds, and localized scouring and accretion around foundation or fender features.

Many sites require side-scan sonar for acoustic imaging of the seafloor, foreign objects, and the submerged portion of the structure, especially in poor visibility where sonar sensors generally perform adequately. Another method of employing sonar techniques is in sub-bottom profiling of the seafloor to investigate the subsurface geology. Sub-bottom profiling is a geophysical technique that requires calibration against physical inspection data, such as boring cores. Sub-bottom profiling data can be a valuable asset for identifying the limits of mobile sediment (erosion potential), investigating soil heterogeneity between borings, and considering soil rippability/pile drivability during dredging or construction.

The level of accuracy in hydrographic surveying varies greatly based on the equipment and methods used. The surveys must be properly referenced to the appropriate geodetic or local control and referenced to the correct datum—both horizontal and vertical. Mistaking NAVD88 vertical control for local MLLW can be a critical but easily made error. In addition, data (GPS-derived vertical data in particular) are subject to revision over time. Thus, for all methods of marine survey, the inspector needs to consider when the best interests of the project are served by having a certified hydrographer complete and validate the survey—especially as the conditions observed could identify deficiencies requiring remediation.

Hydrographic surveys may involve using a small survey boat equipped with single-beam, multibeam, or side-scan sonar systems. These systems can be used independently or together. They can also be coupled with above water laser scanners to develop a three-dimensional image or model. These systems rely heavily on accurate GPS coordinates and are only as accurate as the horizontal and vertical controls. For a more in-depth discussion of these systems, see USACE (2004) and IHO (2008).

The results of all marine surveys should be compared with any previous survey data available and retained for future comparisons to monitor changes in sea-floor conditions affecting the structure.

Applications for sonar surveys primarily include vessel operations and maintenance dredging activities. However, the structure inspector may use sonar technology to evaluate and document the adjacent channel bottom, scour depressions, submerged debris, and submerged portions of the structure. Besides sonar surveys, other methods of recording water depth soundings include a lead line or a sounding pole.

A lead line is a simple device typically consisting of standard surveyor's tape with a weight attached to the end. The inspector simply lowers the lead line until the weight comes to rest on the channel bottom. The inspector then pulls the line taut and records the reading from the channel bottom to the waterline or top of deck. An inspector working from the top of the deck most often obtains lead line readings along the fascia of a structure at predetermined intervals (e.g., measurements obtained at a certain bent numbering or stationing along a bulkhead).

A sounding pole is another simple device that typically consists of an extendable, graduated rod. An inspector on the deck or in a boat typically places the pole vertically on the channel bottom and records the measurement at the waterline. The inspector then records the distance from the waterline elevation to a known elevation on the structure.

The most commonly used electronic sounding device is a single-beam sonar fathometer. This device uses a transducer just below the waterline and repeatedly transmits sound energy through the water column. The time interval between the transmission of the sound pulse and the returning echo from the channel bottom is used to automatically calculate a depth measurement that is recorded onto the device. Determining water sound velocity with adjustment and the use of a bar check provides quality control measures for sonar soundings.

Fig. C-25. Sector scanning sonar image of steel bulkhead with typical defects circled
Source: Courtesy of Collins Engineers, Inc., reproduced with permission.

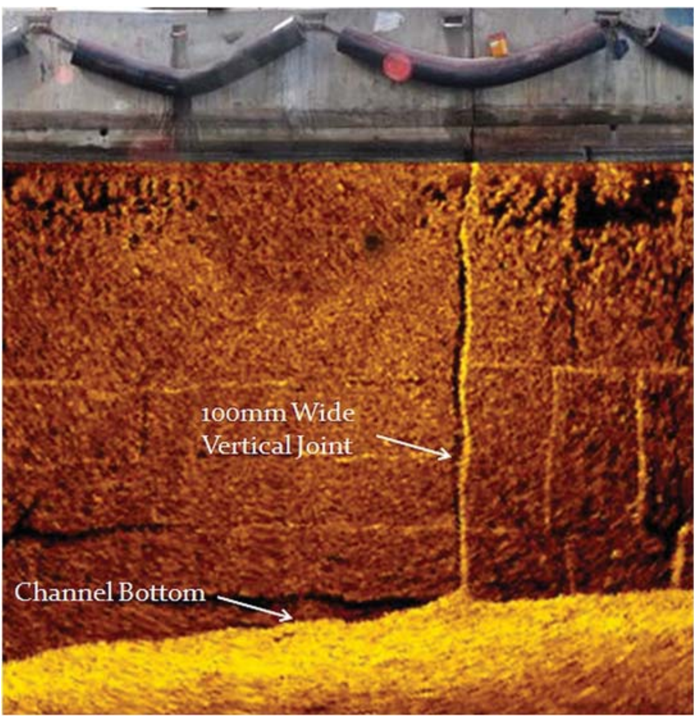

Fig. C-26. Sector scanning sonar image of quay wall with offset blocks and noted vertical joint
Source: Courtesy of Collins Engineers, Inc., reproduced with permission.

Depending on the complexity of the sonar device, single-beam technology is limited by its inability to detect refilled scour holes, false readings from heavy drift or heavy turbulence, distorted scale on the readout due to varying boat speed, and inability to provide information about the geophysical sub-bottom. Furthermore, the technology must compensate for any water surface elevation changes during tidal swings while taking channel bottom to waterline measurements.

All these methods are limited by the softness of the channel bottom. The swiftness of the current also can affect lead line and sounding pole measurements because the water velocity can introduce horizontal drift into the line or cause a lightly weighted tape to drift downstream. This method also may be more prone to inaccuracies resulting from the experience of the inspector.

C.17.2 Underwater Acoustic Imaging Data

Some sonar devices produce high-resolution images to enable documentation and evaluation of underwater conditions such as structure material surface condition, channel bottom elevation location, and presence of debris or underwater objects that represent a security concern. These sonar devices can obtain photograph-like quality images of bulkheads, piles, and armored slopes under wharves. See Figs. C-25 and C-26.

Underwater acoustic imaging provides photograph-like documentation of a structure element surface, but it is limited in its ability to penetrate beyond line of sight. Also, the images may not accurately represent the structural element material if heavy marine growth is present. Sonar imaging can also be used for diver tracking in real time, which can be a valuable safety consideration. Depending on the type of sonar device used, acoustic images may be displayed in two-dimensional (2D) exhibits or three-dimensional (3D) point-cloud data sets or models.

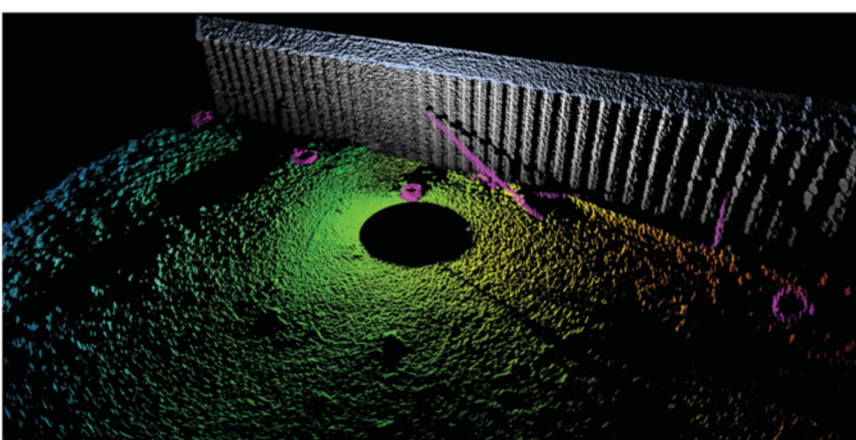

Fig. C-27. Multibeam sonar image of steel sheeting bulkhead with debris on channel bottom
Source: Courtesy of Collins Engineers, Inc., reproduced with permission.

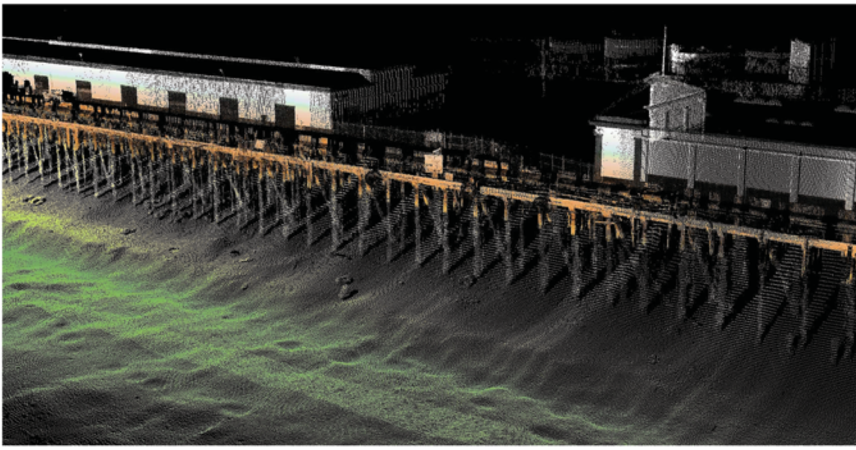

Fig. C-28. Multibeam sonar data integrated with topside mobile laser scanner data Source: Courtesy of Fugro, Inc., reproduced with permission.

Fig. C-29. Side-scan sonar image of sunken vessel on channel bottom Source: Courtesy of Fugro, Inc., reproduced with permission.

Underwater acoustic images vary in quality, resolution, and dimensional perspective (2D or 3D), depending on the particular sonar device. Sonar technologies can be classified into two broad categories based on the type of data—2D or 3D—that they produce. Two-dimensional sonar systems can be modeled into a 3D space or just plotted in a 2D view. For

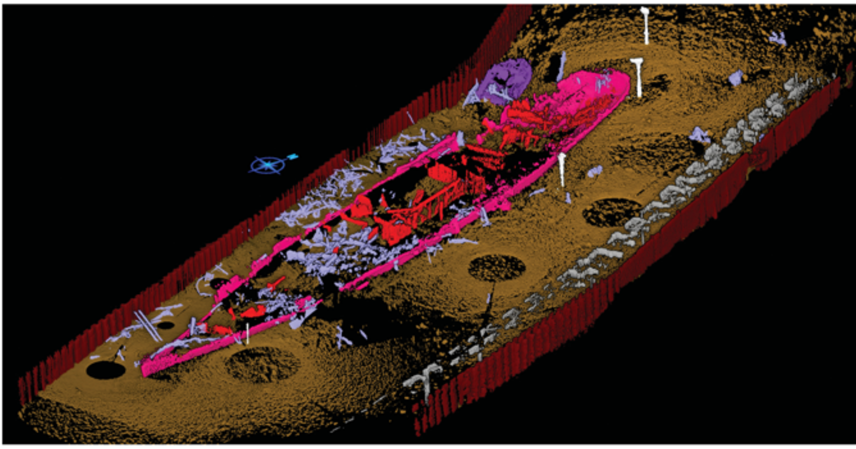

Fig. C-30. Multibeam image of a sunken vessel in navigational channel between steel sheet pile bulkheads
Source: Courtesy of Collins Engineers, Inc., reproduced with permission.

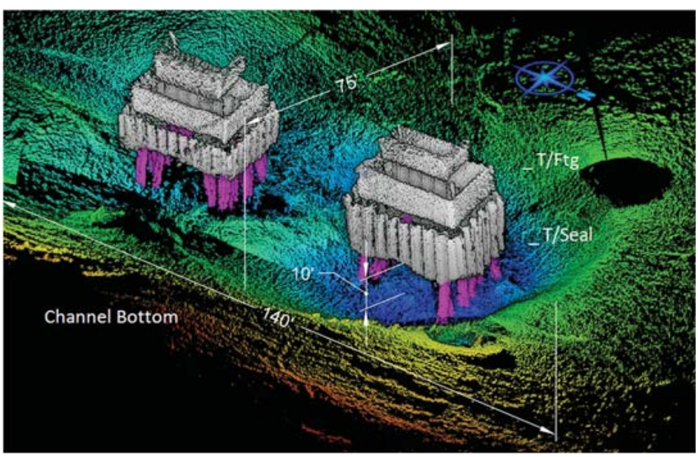

Fig. C-31. Multibeam sonar image of undermined foundation
Source: Courtesy of Collins Engineers, Inc., reproduced with permission.

3D sonar data collection, multibeam sonar systems, also referred to as swath echosounders, can collect channel bottom data and submerged vertical surfaces. Another form of multibeam sonar is 3D mechanical scanning sonar, which is essentially a multibeam sonar unit fitted with a mechanical stepping motor set on a tripod resting on the channel bottom. Refer to Figs. C-27 through C-33.

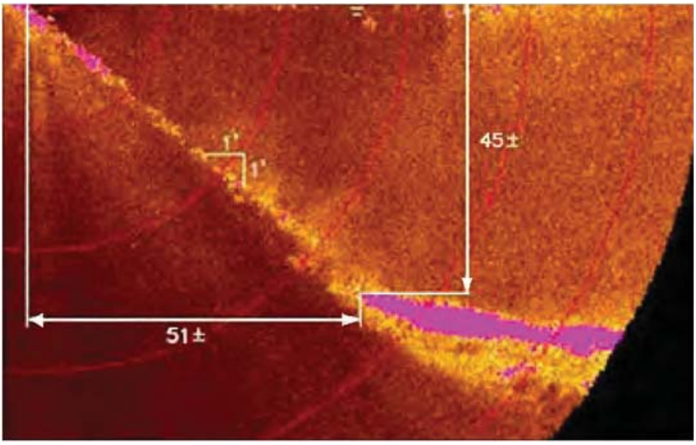

Fig. C-32. Sector-scanning sonar image of embankment slope erosion
Source: Courtesy of Collins Engineers, Inc., reproduced with permission.

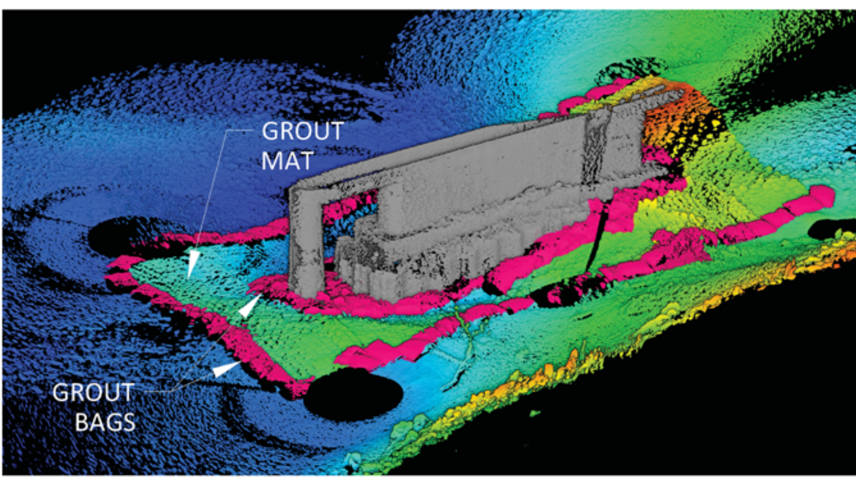

Fig. C-33. Multibeam sonar image of repaired undermining with grout bags
Source: Courtesy of Collins Engineers, Inc., reproduced with permission.

C.18 MICROBIAL-INDUCED CORROSION

Often deterioration may be present but the cause of the defect is unknown without further investigation. In the case where accelerated corrosion due to bacteria colonies is suspected, performing bacteria testing may be warranted at the site. Bacteria have been known to deteriorate timber, steel, and concrete structures.

Fig. C-34. Bacteria testing of samples obtained at a steel sheeting bulkhead with MIC
Source: Courtesy of Collins Engineers, Inc., reproduced with permission.

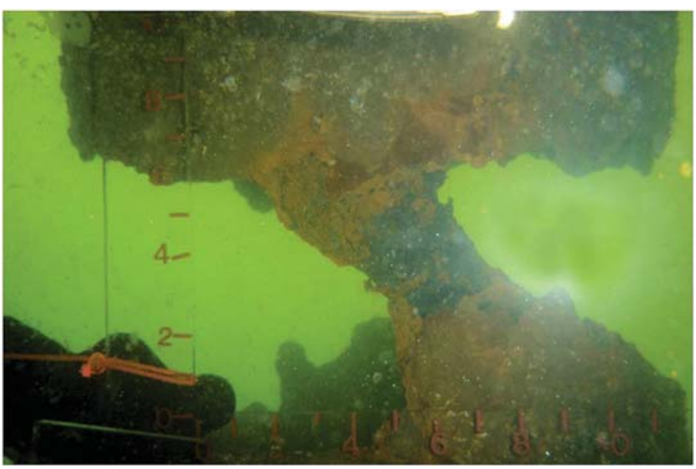

Fig. C-35. Underwater image of deteriorated pipe pile with MIC
Source: Courtesy of Collins Engineers, Inc., reproduced with permission.

The most common type of bacterial deterioration is related to steel substructure elements. Bacteria testing for microbial-induced corrosion (MIC) investigations may be conducted in the field or at a laboratory. However, the sample collection of the water and any bacteria film is

Fig. C-36. Steel sheeting bulkhead with living MIC colonies near low water level
Source: Courtesy of Collins Engineers, Inc., reproduced with permission.

generally the same. Bacteria testing can often determine the bacteria type(s) working in an active colony to cause corrosion. To determine the section loss associated with the corrosion, an ultrasonic thickness meter is often used. Refer to Figs. C-34 through C-36.

APPENDIX D
INSPECTION NOMENCLATURE

Helping to ensure the consistency of waterfront inspection and assessment information between in-field data collection and reporting efforts is a standard system of shorthand and references/orientations to capture defect and configuration information. The exemplary nomenclature included herein is not exhaustive and is intended as a guide, whereas the actual nomenclature will be determined by the client or engineer in charge of the inspection and assessment effort.

D.1 DATA COLLECTION NOMENCLATURE

The following includes exemplary defect and configuration recording nomenclature that is frequently used (see Fig. D-1 for pile orientation key and Table D-1 for defect types):

- Pile sides: face (F), corner (C), quadrant (Q), and position (P) from top of pile to top of defect;
- Pile caps or girders: horizontal (H), vertical (V), and area (A);
- Deck: parallel dimension (X) and perpendicular dimension (Y) to outboard end in ft;
- Record H and V to the nearest 2 or 3 in.; L, X, and Y to the nearest 0.5 ft; and A in square feet or percent;
- Record above water crack widths (W) to nearest 1/16 in. minimum;
- Record underwater crack widths (W) to nearest 1/100 in. minimum with crack gauge; and
- Calculate repair depth (D) to the nearest 1 in., or define a default value; all dimensions should be rounded up; items labeled TBD are to be determined.

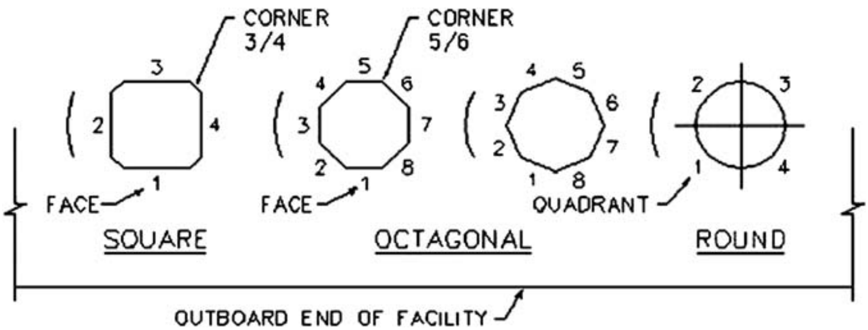

Fig. D-1. Pile orientation key
Source: Courtesy of Port of Los Angeles, reproduced with permission.

- Gridlines:
  - "0" defines the edge of concrete deck adjacent to gridline 1 (or lowest number).
  - The next higher number defines the edge of concrete deck adjacent to last gridline number.
  - "0A" defines the edge of concrete deck adjacent to gridline A (or lowest letter).
  - The next higher letter defines the edge of concrete deck adjacent to last gridline letter.
  - Structural elements beyond the edge of deck will be defined by the gridline at edge of deck, plus the distance in feet (or meters for metric drawings) in between.

D.2 REPORTING NOMENCLATURE

Figure D-2 includes typical symbols used to graphically depict and communicate both inspected elements and observed defects.

Table D-1. Defect Types

Defect	Abbreviation	Description
General defects		
Abrasion	ABS	Sea debris, material, etc. contacting the structure/chain
Broken	BRK	When a structure is present but no longer has any capacity
General crack	CRK	Use this if nothing else fits for cracks
Through crack	CKT	Crack through entire element

Table D-1. Defect Types *(Continued)*

Defect	Abbreviation	Description
General deterioration	DET	Generally deteriorated element
Displaced element	DIS	Displaced element
Loose element	LS	Loose element with broken or missing fasteners
Missing	MIA	If the element is missing and would need to be replaced
Concrete defects		
Horizontal crack	CKH	Horizontal cracking
Vertical crack on multiple faces	CKM	Vertical cracking on multiple faces of concrete pile; found in tidal and splash zones
Vertical crack	CKV	Vertical cracking on single face of concrete pile; found in tidal and splash zones.
Closed corrosion spall	DEL	Delaminated concrete generally due to rebar expansion
Chemical disintegration	DSC	Found in tidal zone leads to soft concrete exterior
Erosion	ERS	Found in tidal zone with aggregate exposed
Exposed top of pile	EXP	Top of driven pile is exposed and not properly contained in cap or extension
Open corrosion spall	OCS	When DEL deteriorates further, with rebar exposed
Undermining	UNM	Scour at toe caused by currents or waves
Voids	VOD	Voids/hallows in concrete due to poor vibration of concrete
Timber defects		
Marine borers	MBR	Often appears 1/4 in.-deep scrapes down the timber
Fungal decay	FDY	Rot caused by the wetting and drying of the timber
Nonbearing	NBR	The pile is no longer supporting the cap
Split	SPL	The drift pin from the PC can often split the pile

(Continued)

Table D-1. Defect Types *(Continued)*

Defect	Abbreviation	Description
Crushed	CSH	The P or PC may crush if overloaded, deformed grain
Steel defects		
Coating loss	CTL	Section exhibiting no coating from initial COR or scratches
Pitting	PIT	Deep narrow penetrations, often leads to holes
Corrosion	COR	Area generally covered in orange-black by-product
Knife edge	KNE	Typically H-piles with edges that have corroded to a point
Corrosion hole	HOL	Advanced COR or PIT
Weld crack	CRW	Often narrow cracks along the edge of a weld
Anode loss	ANL	Percent of an anode that has been depleted
Buckling	BUC	Generally overloading related
Impact damage	IMP	Deformation due to an impact may become COH
Chain wear	CHW	The wear caused from chain-to-chain contact
Masonry defects		
Mortar degradation	MDE	Deteriorated, loose, or missing mortar between blocks
Settlement	SET	Settling of the wall or structure
Sinkholes	SNK	Typically topside holes caused by loss of fill
Voids	VOD	Section wall where the fill material has been washed out
Separation	SEP	Gaps between blocks
Undermining	UNM	Scour at toe caused by currents or waves
Corrosion	COR	Area generally covered in orange-black by-product
Other		
Overgrown vegetation	OVG	Overgrown vegetation in area
Disconnected conduit	DJ	Disconnected conduit at expansion joint coupler
Train rail end gap	GAP	Gap in train rail ends
Potential safety hazard	HAZ	Potential safety hazard such as missing vault cover

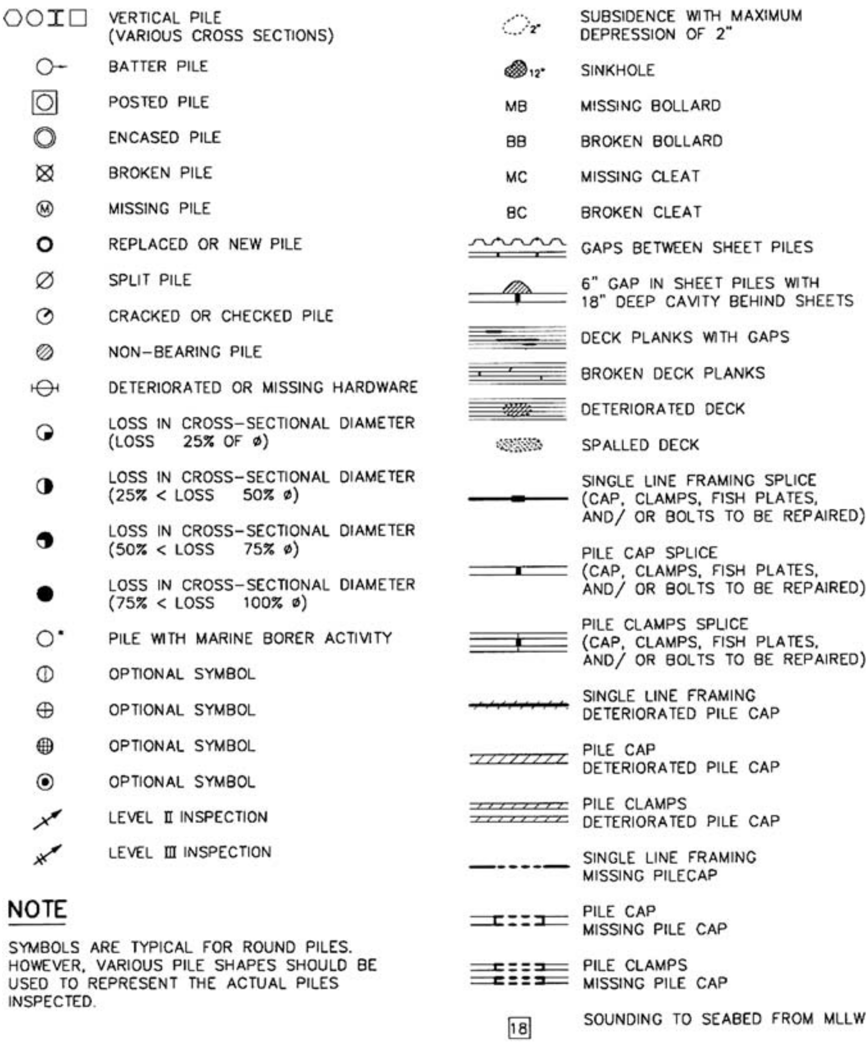

Fig. D-2. Typical symbols used to graphically depict and communicate both inspected elements and observed defects
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APPENDIX E
GLOSSARY

American Association of State Highway and Transportation Officials (AASHTO)—a standards setting body that publishes specifications, test protocols, and guidelines that are used in highway design and construction throughout the United States. Despite its name, the association represents not only highways but air, rail, water, and public transportation as well.

Abrasion—a wearing away of surfaces by friction

Abutment—the foundation/retaining structure at the approach and departure ends of a bridge

Acid copper chromate (ACC)—wood preservative used for timber treatment

Alkali-aggregate reaction (AAR)—two most common forms are alkali-silica reaction (ASR) and alkali-carbonate reaction (ACR). Both are caused by a reaction between chemical ions in the alkaline cement solution in concrete and reactive forms of aggregate.

Alkali-carbonate reaction (ACR)—a reaction that occurs between some of the dolomitic limestone aggregates and alkalis in the cement; the reaction forms a gel, which swells when sufficient moisture is present, causing cracking around the reacting aggregates

Alkali-silica reaction (ASR)—a potentially expansive chemical reaction between siliceous aggregate and the hydroxide ions associated with the ions of sodium and potassium in solution in the paste. The siliceous rocks involved in this reaction are those with an imperfect crystal structure or those that are not crystalline, which can be very deleterious if the forces generated by the expanding silica gels exceed the cohesive forces of the placement.

Aluminum—a structural lightweight metal used in ships and docks and a metal used in sheathing; may be used as a sacrificial anode in cathodic protection against corrosion

American Society for Testing and Materials (ASTM)—a globally recognized leader in the development and delivery of international voluntary consensus standards

American Wood Preservers Association (AWPA)—a nonprofit organization that is responsible for promulgating voluntary wood preservation standards

Ammoniacal copper arsenate (ACA)—a wood preservative used for timber treatment

Ammoniacal copper zinc arsenate (ACZA)—a wood preservative used for timber treatment

Amphipod—a smaller division (order) of the larger group (class) of invertebrates known as Crustacea. Chelura is an example.

Amphoteric—a metal that is susceptible to corrosion in both acid and alkaline environments. Aluminum is an example of an amphoteric metal.

Anode—the positive electrode of an electrolytic cell

Atmospheric pressure—normal pressure of air at sea level, 14.7 pounds per square in. (101.4 kPA)

Bankia—a genus of molluscan marine borers

Bark—the outside layer of a tree, composed of living, inner bark called phloem and an outer bark of dead tissue

Barnacle—an encrusting fouling organism belonging to the large general group (class) Crustacea

Batter pile—a pile driven at an angle such that the pile can develop both axial and lateral load resistance

Beams and stringers—lumber of rectangular cross section, 5 in. (127 mm) or more thick and 8 in. (203 mm) or more wide, graded with respect to its strength when loaded on the narrow face

Bearing piles—those piles in a structure that support the load

Bench capping—a method of replacing damaged piles at higher elevations when more than one pile in line is to be repaired

Bent—transverse row of piles fastened together by a pile cap

Biological deterioration—deterioration or damage caused by living organisms

Biofouling or **biological fouling**—the accumulation of microorganisms, plants, algae, or animals on wetted surfaces

Bitt—a vertical post, usually one of a pair, used to secure ropes or cables

Bitumastic—a coating made from higher boiling point materials found in tar

Bleeding—the exudation of liquid preservative from treated wood, the exudate may evaporate, remain liquid, or harden into a semisolid or solid state

Bollard—cast steel cylindrical capped head extending up from a base plate for fastening ships to piers

Borers, marine—marine organisms that attack wood in the submerged portions of structures placed in salt or brackish waters. Two general groups of borers are recognized, the Crustacea and the Mollusca.

Boring—a sample taken from wood for detection of deterioration or preservative penetration; the movement of certain organisms through wood

Bracing—wood or supports supplying additional strength to a structure

Brackish water—water that is partly salt and partly fresh

Branding—permanent marking on a treated wood product to identify the supplier and date of treatment; other information may be included in a brand when so specified

Breakwater—a structure used to eliminate or reduce the magnitude of wave impinging on the shoreline or vessels behind it

Breasting dolphin—a free-standing independent structure that a vessel will bear against when current, wind, or berthing motion moves the ship into the pier or wharf; breasting dolphins are typically equipped with energy-absorbing fender systems and are pile supported or solid filled structures.

Brinell hardness test—the oldest of the hardness test methods in common use today, the Brinell test is frequently used to determine the hardness of forgings and castings that have a grain structure too course for Rockwell or Vickers testing. Therefore, Brinell tests are frequently done on large parts. By varying the test force and ball size, nearly all metals can be tested using a Brinell test. Brinell values are considered test-force independent as long as the ball size/test force relationship is the same.

Brown rot—deterioration caused by a group of fungi producing a brown residue or powder

Bulkhead—a structure used in waterfront construction to retain earth fill

Bullrail—a wide low curb along the outboard edge of the pier or wharf, it may be cast-in-place concrete, steel or timber; fixed or removable; mooring hardware is often mounted on top of the bullrail.

Burrow—tunnel or excavation made by marine borers

Caliper—a compass or divider with curved legs for measuring diameter of pipes, rods, or piles

Camel—a floating device acting as a fender and used to separate a moored vessel from a pier, wharf, quay, or other vessel, camels are used with ships that have hull configurations that do not match well with typical pier or wharf fender systems, such as submarines or where vessels require an offset from the pier or wharf due to deck or superstructure overhangs, such as an aircraft carrier.

Cap log—a timber member connecting and protecting the heads of piles; generally not a structural member

Capstan—vertical axled rotating machine used to apply force to ropes, cables, and hawsers. The principle is similar to that of the windlass, which has a horizontal axle.

Carbonation—occurs when the calcium in concrete is attacked by carbon dioxide of the air and converted to calcium carbonate

Catenary—the curve that an idealized hanging chain or cable assumes under its own weight when supported only at its ends

Cathode—the negative electrode of an electrolytic cell

Cathodic protection (CP)—using anodes or direct current systems to minimize or stop the corrosion process by establishing the steel as a cathode of an electrochemical cell

Chafing—abrasion caused by material rubbing against a structure

Charpy impact test—also known as the Charpy V-notch test, a standardized high strain-rate test that determines the amount of energy absorbed by a material during fracture. This absorbed energy is a measure of a given material's notch toughness and acts as a tool to study temperature-dependent ductile-brittle transition.

Check—a separation along the grain of the wood, the separation occurring across the annual rings

Chelura—a genus of Crustacea borers

Chemical damage—deterioration of structural members due to the effect of chemical reactions

Chock—a piece of wood fitted between two piles to prevent the piles from rolling upon impact

Chromated copper arsenate (CCA)—a wood preservative used for timber treatment since the mid 1930s

Clamped—a method of fastening, where one member is sandwiched between two other members

Clear water box—A transparent container filled with clean water to provide a transparent path for viewing or photographing objects submerged in dark or dirty water

Cleat—a wood or metal fitting usually with two projecting horns around which a rope may be made fast; a piece fastened to or projecting from something and serving as a support or check

Coal tar derivative—preservative obtained from the distillation of coal tar

Coastal waters—seawaters bordering the continents subject to tidal flow

Coatings—protective covers to prevent corrosion

Cofferdam—a temporary enclosure built within, or in pairs across, a body of water and constructed to allow the enclosed area to be pumped out, creating a dry work environment for the major work to proceed

Cold iron—describes the condition of a ship when all shipboard boilers, engines, and generators are inoperative during repairs or due to intentional shutdown and can furnish none of the ship’s required services

Composite—a structural member or members made up of disparate materials

Concrete forms—generally temporary wood or steel structures constructed to retain wet concrete until the concrete sets

Conditioning—the heating or removal of moisture from unseasoned or partially seasoned wood as a preliminary to preservative treatment and as a means of improving the penetrability and absorptive properties of the wood

Connectors, timber—devices, such as metal rings and plate and wood discs that, when embedded in each member, increase the efficiency of a timber joint

Coping—a top course of stone or concrete to tie a structure together or to distribute the pressure from exterior loading

Copper-copper sulfate—Reference cell for electrolyte potential measurements in seawater

Copper naphthenate—a toxic chemical preservative particularly effective against insects and destructive fungi

Core—the cylinder of wood, removed by means of an increment borer, from which may be determined, by linear measurement, sapwood thickness and preservative penetration, and, by assay, preservative retention and distribution

Corrosion—destruction of a metal by a chemical or electrochemical reaction with its environment

Crack—a split or separation of material

Creosote, coal tar—a distillate derived from coal tar. As used in the wood-preserving industry, creosote denotes a distillate of coal tar produced by the high-temperature carbonization of bituminous coal. Creosote consists principally of liquid and solid aromatic hydrocarbons and contains some tar acids and tar bases; it is heavier than water and has a continuous boiling range beginning at about 200 °C.

Creosote-coal tar solution—solution of coal tar and creosote in selected proportions; usually contains 20 to 50% coal tar

Creosote, marine grade—a coal tar creosote meeting special requirements as specified for the treatment of materials for marine use

Crevice corrosion—corrosion of a metal at an area where contact is made with a nonmetallic material

Crib—cellular framework of timber, concrete, or steel filled with ballast

Crustacea—a large group (class) of invertebrate animals. Barnacles, Limnoria, Sphaeroma, and Chelura are examples.

Cyclopean masonry—a type of stonework built with huge boulders, roughly fitted together with minimal clearance between adjacent stones and no use of mortar

Deadman—a buried plate, wall, or block attached at some distance from and forming an anchorage for a retaining wall

Decay—disintegration of wood substance due to the action of wood-destroying fungi

Delayed ettringite formation (DEF)—a type of internal sulfate attack in concrete, which is common in many precast concrete elements that have been heat treated beyond a certain temperature and have suppressed the normal ettringite formation, or, in a concrete that is made using a high-sulfate portland cement. Instead of normal formation of ettringite by cement hydration in the plastic state, in these concretes ettringite forms after the hardening of the concrete. In the continued presence of moisture, components of ettringite (i.e., Ca, Al, S) slowly dissolve out and form ettringite in the confined spaces in hardened paste and thereby cause expansion, subsequent separations around the aggregate particles, stresses in the paste due to restrained expansion, and the resultant eventual cracking of concrete.

Depassivate—remove ability of steel to resist corrosion

Differential global positioning system (DGPS)—an enhancement to the global positioning system that provides improved location accuracy, from the 15-m nominal GPS accuracy to about 10 cm in the best case implementations

Differential thermal analysis (DTA)—a thermoanalytic technique, similar to differential scanning calorimetry. In DTA, the material under study and an inert reference are made to undergo identical thermal cycles, while recording any temperature difference between sample and reference. This differential temperature is then plotted against time or against temperature (DTA curve or thermogram). Changes in the sample, either exothermic or endothermic, can be detected relative to the inert reference.

Dimension stock—square of flat wood, usually in pieces smaller than the minimum sizes admitted by standard lumber grades, that is rough, dressed, green, or dry, and cut to the approximate dimension required for the various products of woodworking factories

Dip treatment—the total submergence of a structural member in the preservative

Disbonding—coating separating from the protected structure

Discharge structure—outfalls at the ends of pipes, where the material flowing in the pipes enters the ocean or lake. Usually concrete or masonry but can be steel or wood

Dolphin—a free-standing, pile-supported or solid-filled structure used for mooring and berthing vessels, protection of the end of piers or wharves, turning ships, or protection of bridge structure

Dote—"dote," "doze," and "rot" are synonymous with decay

Douglas fir, interior—Douglas fir growing east of the summit of the Cascade Mountains; sometimes referred to as "intermountain Douglas fir." Interior Douglas fir growing in Oregon, Washington, Idaho, Wyoming, and Montana is designated "Douglas fir interior north."

Douglas fir, Pacific coast—Douglas fir growing between the Pacific Ocean and the summit of the Cascade Mountains; sometimes referred to as "coastal Douglas fir"

Drydock—a specialized facility used for repair of ships, where the vessel is removed from the water or placed within a lock and the water is removed, leaving the ship in the dry to facilitate repairs

Dry rot—a term loosely applied to many types of decay but especially to that which permits the wood to be crushed easily to a dry powder when in an advanced stage. The term is actually a misnomer for any decay, because all fungi require considerable moisture for growth, and the wood must have been moist at the time the rot occurred.

Durability—as applied to wood, its lasting qualities or permanence in service with reference to its resistance to decay and other forms of deterioration. Decay resistance is a somewhat more specific term indicating resistance to attack by wood-destroying fungi under conditions favorable to their growth.

Ebb—to recede from the flood, falling tide

Efflorescence—a surface encrustation caused by the evaporation of solutions seeping out onto the surface of rock or concrete

Electrochemical—a phenomenon where chemical change occurs through the indirect exchange of electrons

Electrolyte—a chemical substance or mixture, usually liquid, containing ions that migrate in an electric field

Embed—to place or fix firmly in surrounding matter; also "imbed"

Embrittlement—causing a loss of ductility, such as hydrogen embrittlement, where the introduction of hydrogen into metal reduces its ductility

Empty cell process—a method of pressure treating wood without use of a preliminary vacuum

Estuary—an area connecting a harbor or open sea and a freshwater river

Eurocode—a set of harmonized technical rules developed by the European Committee for Standardisation for the structural design of construction works in the European Union

Evaluation—statement of value; a spoken or written statement of the value, quality, importance, extent, or condition of something

Fenders—energy-absorbing devices used on the face of a pier, wharf, or dolphin to protect the ship and shore facility from damage due to contact between the two during berthing and mooring

Fiber-reinforced polymer (FRP)—composite materials made of a polymer matrix reinforced with fibers. The fibers are usually fiberglass, carbon, or aramid, whereas the polymer is usually an epoxy, vinylester, or polyester thermosetting plastic. FRPs are commonly used in the aerospace, automotive, marine, and construction industries.

Fir—a species of wood used in waterfront structures. See Douglas fir.

Fishplate—timber or steel member used to stiffen and tie posts to caps and bench cap or pile

Fleet mooring—an offshore anchoring system placed in a fixed location

Flood—rising tide

Flow—direction of movement

Fluke—the barbed shaped part of an anchor that digs into the bottom

Fouling—organisms growing on the surfaces of submerged materials

Freeboard—the height of a structure or deck above the water level

Full cell process—a method of pressure treating wood using initial vacuum

Fungus—a primitive plant in the group that includes molds, mushrooms, and others.

Gabions—a wire container filled with stones used for retaining structures

Galvanic—pertaining to the electrochemical interaction between two metals such as in galvanic couple or galvanic series

Galvanic anode—a metal that, because of its relative position in the galvanic series, provides sacrificial protection to metal or metals that are more noble in the series, when coupled in an electrolyte. The anodes, such as zinc, magnesium, or aluminum, are the current source in one type of cathodic protection.

Galvanic corrosion—an electrochemical process in which one metal corrodes preferentially when in electrical contact with a different type of metal and both metals are immersed in an electrolyte

Girder—a large-sized beam used as a main structural member, normally for the support of other beams

Grade—any of the quality classes into which lumber products are segregated

Grade mark—identification of lumber with symbols or lettering to certify its quality of grade, which is based on the presence or absence of defects such as knots, checks, or decay.

Grain—the direction, size arrangement, appearance, or quality of the fibers in wood

Grain, close—wood with narrow and inconspicuous annual rings. The term is sometimes used to designate wood having small and closely spaced pores, but in this sense the term "fine texture" is more often used.

Grain, coarse—wood with wide and conspicuous annual rings in which there is considerable difference between springwood and summerwood. The term is also used to designate wood with large pores, but in this sense the term "coarse textured" is more often used.

Grain, cross—wood in which the cells or fibers do not run parallel with the axis or sides of a piece

Grain, diagonal—wood in which the annual rings are at an angle with the axis of a piece as a result of sawing at an angle to the axis of the tree

Grain, edge—wood in which the rings (so-called grain) form an angle of 45 degrees or more with the surface of the piece; also called "vertical grain" and "quarter sawn"

Grain, flat—wood in which the rings form an angle of less than 45 degrees with the surface of the piece; also "plain sawn"

Grain, interlocking—wood in which the fibers are inclined in one direction in a number of rings of annual growth, then gradually reverse and are inclined in an opposite direction in succeeding growth rings, then reverse again

Grain, open—common classification of painters for wood with large pores; also called "coarse textured"

Grain, plain-sawn—another term for flat grain, used generally in hardwoods

Grain, quarter-sawn—another term for edge grain, used generally in hardwoods

Grain, spiral—a type of growth in which the fibers take a spiral course about the bole of a tree instead of the normal vertical course. The spiral may extend right handed or left handed around the trunk.

Grain, vertical—another term for edge grain

Grain, wavy—wood in which the fibers collectively take the form of waves or undulations

Green—unseasoned, wet

Greenheart—a tropical wood used in marine construction, resistant to marine borer attack

Greensalt—chromated copper arsenate (CCA)

Gribble—the common name for the crustacean borer, Limnoria

Groin—a structure consisting of large rocks, precast concrete units, reinforced or prestressed concrete piles, steel sheet piles, or timber cribbing filled with rock, projecting outward perpendicular to the shoreline designed to control the rate of shifting sand

Ground-penetrating radar (GPR)—a geophysical method that uses radar pulses to image the subsurface. This nondestructive method uses electromagnetic radiation in the microwave band (UHF/VHF frequencies) of the radio spectrum and detects the reflected signals from subsurface structures. GPR can be used in several media, including rock, soil, ice, freshwater, pavements, and structures. It can detect objects, changes in material, and voids and cracks.

Grout—a cement-sand mortar of plastic consistency that can easily be poured

Hardwoods—the botanical group of trees that are broadleaved. The term has no reference to the actual hardness of the wood.

Heartwood—the inner core of a woody stem, extending from the center to sapwood and usually of darker color

Heavy timber construction—construction composed of planks or laminated floors supported by beams or girders

Helical anchors—screwed-in steel anchoring systems used for columns, tie backs, marina anchoring systems, and pipeline tie downs

Honeycombs—voids or hollows in the concrete

Hotel services—dockside utilities provided for a ship at a berth (also called "ship's services," "utility services," and "cold iron services")

Hydrology—the study of the movement, distribution, and quality of water throughout the Earth

Imbed—see "embed"

Impressed current—a cathodic protection system that uses an external electrical alternating current to provide corrosion protection to a steel structure

Increment borer—an auger-like instrument with a hollow bit used to extract cores of wood from piling

Inertial measurement unit (IMU)—an electronic device that measures and reports on a craft's velocity, orientation, and gravitational forces, using a combination of accelerometers and gyroscopes, sometimes also magnetometers

Infilling—the somewhat slow replacement of scoured-out material with softer, finer silt

Inland—that part of the land above the waterline (shore line)

Inspection (of construction materials)—the scrutiny and supervision of the purchasing, acquiring, manufacturing, treating, and handling of material for compliance with specification requirements

Inspection (of structures)—the method by which structures are examined for determination of the presence and extent of deterioration

Intake structure—at the opposite end of the conduit from the discharge end; can be of the same materials as the discharge

Interlock—the connection or joint between two adjacent steel sheet piles

Intertidal—the area between mean low water and mean high water

Investigation—to inspect carefully, systematically, and thoroughly a complex or hidden structure and to evaluate or set the value of the structure and/or repairs needed

Ion—an electrically charged atom or group of atoms

Isopod—a smaller division (order) of the larger group (class) of invertebrates known as Crustacea, which includes Limnoria and Sphaeroma

Jetty—a dock or breakwater that projects into the water to prevent formation of sandbars, normally located near harbor entrances and river estuaries

Jewelry—the hardware fittings on a buoy to which the mooring lines/chains are attached

Joists and planks—lumber of rectangular cross section, from 2 in. up to but not including 5 in. thick, and 4 in. or more wide, graded with respect to its strength in bending when loaded either on the narrow face (joist) or on the wide face (plank). If 5 in. or more thick, the lumber is known as beams and stringers.

Kenter joining link—constructed in three parts: two half links and a stud. The stud slides in place and locks the whole link. The stud is secured by hammering a tapered pin into the hole drilled diagonally through all three parts of the joining link.

Key—a wedge in rock used as an anchor

Kiln-dried—lumber or other materials that have been dried in drying kilns to a moisture content, usually below that obtained in air drying, by the application of artificially supplied controlled heat, humidity, and air circulation

Laitance—soft, punky weak layer of cement and aggregate fines on a concrete surface that is usually caused by an overwet mixture, overworking the mixture, improper excessive finishing, combination thereof, or on concrete during tremie pours. Often found in layers at the face of concrete piers/abutments.

Laminate—a single layer of wood or plastic in an assembly of layers

Leaching—the process of removing a soluble substance from a heterogeneous material by means of a solvent (usually water)

Lead wool—lead that is spun to form a wool-like material and pounded into masonry joints that are still found in older structures

Lighterage—small craft designed to transport cargo or personnel from ship to shore; includes amphibians, landing craft, discharge lighters, causeways, and barges

Limnoria—the common "gribble," a genus of Crustacea borers causing serious destruction to marine structures

Locks—an enclosed chamber in a canal, dam, etc. with gates at each end, for raising or lowering vessels from one level to another by admitting or releasing water

Magnesium—a metal that may be used as a sacrificial anode in cathodic protection against corrosion

Marine borers—see borers

Marine organisms—living entities normally found in natural waters containing measurable salinity

Masonry—a structure built with stones, bricks, and other materials, usually held together with mortar

Mean high water (MHW)—a tidal datum: the average of all the high water heights observed over the National Tidal Datum Epoch

Mean higher high water (MHHW)—a tidal datum: the average of the higher high water height of each tidal day observed over the National Tidal Datum Epoch

Mean low water (MLW)—the average of all the low water heights observed over the National Tidal Datum Epoch

Mean lower low water (MLLW)—a tidal datum: the average of the lower low water height of each tidal day observed over the National Tidal Datum Epoch

Mean sea level (MSL)—The arithmetic mean of hourly heights observed over the National Tidal Datum Epoch

Mediterranean mooring—a mooring in which a ship's bow is moored to buoys and the stern is tied to the pier

Microbial-induced corrosion (MIC)—caused by the presence of microbes whose metabolism produces acids and sulfides; microbes and their by-products in the presence of metals can produce a film conducive to accelerated local corrosion

Mill scale—the heavy oxide layer resulting from hot fabrication or heat treatment of metals

Moisture content—as related to wood, the weight of water contained in wood, usually expressed as a percentage of the oven-dry weight of the wood

Moisture, free—moisture that is held inside the cell cavities of wood in contrast to that within the cell walls

Mollusca—one of the 11 main divisions (phylla) used in animal classification that includes several of the destructive marine borers

Monopile dolphin—a single pile dolphin usually consisting of a large-diameter concrete or steel pipe pile filled with concrete, used as a mooring or breasting dolphin

Mooring dolphin—a freestanding pile-supported or solid-filled structure used for mooring vessels, usually placed at the bow or stern of a moored ship to provide mooring points to attach breasting lines, bow lines, and stern lines

Multibeam—a device typically used by hydrographic surveyors to determine the depth of water and the nature of the sea bed. Most modern systems work by transmitting a broad acoustic fan-shaped pulse from a specially designed transducer across the full swath acrosstrack with a narrow alongtrack then forming multiple receive beams (beamforming) that is much narrower in the acrosstrack (around 1 degree depending on the system). From this narrow beam a two-way travel time of the acoustic pulse is then established utilizing a bottom detection algorithm. If the speed of sound in water is known for the full water column profile, the depth and position of the return signal can be determined from the receive angle and the two-way travel time.

Mudline—the point of intersection of the seawater and the bottom soil

Mushroomed—the head of a pile that has been subjected to excessive axial load and/or deterioration such that the timber fibers have separated, causing the pile head to flatten, resulting in reduced load capacity

Mussels—molluscan fouling organisms

Nacerda—a beetle that can cause damage to the superstructure of wharves

Nail, dating—a nail with a date or symbol on its head that is driven into wood to indicate the year of treatment, or the date of installation

National Geodetic Vertical Datum (NGVD)—Reference mean sea level elevation measured in 1929

National Tidal Datum Epoch (NTDE)—The specific 19-year period adopted by the National Ocean Service as the official time segment over which tide observations are taken and reduced to obtain mean values (e.g., mean lower low water, etc.) for tidal data. It is necessary for standardization because of periodic and apparent secular trends in sea level. The present NTDE is 1983 through 2001 and is actively considered for revision every 20 to 25 years. Tidal data in certain regions with anomolous sea level changes (Alaska, Gulf of Mexico) are calculated on a Modified 5-Year Epoch.

Nearshore—area of the water next to the shoreline

Neat cement—cement mortar without added sand

Nominal dimension—the dimension of lumber corresponding approximately to the size before dressing to actual size and used for convenience in defining size and in computing quantities

Nonbearing pile—a pile that is not connected to a pile cap such that the pile is not carrying any axial load

Nondestructive testing (NDT)—testing such as ultrasonic thickness measurement of steel

Oak—a species of hardwood used in waterfront structures

Ogee washer—a special cast washer used in waterfront construction to distribute the load from a bolt and nut to a timber face to prevent the wood from being crushed as the nut is tightened

Oil borne—chemical capable of dissolving in an oil solvent

Opposite hand—mirror image

Pachometer—a device designed to specifically locate reinforcing steel in concrete and to assist in the determination of the size of the hidden reinforcing steel

Partially destructive testing (PDT)—tests carried out to the specimen's failure to understand a specimen's structural performance or material behavior under different loads. These tests are generally much easier to carry out, yield more information, and are easier to interpret than nondestructive testing. Examples of specimens may be concrete cores or steel coupons taken from existing structures.

Passivation—in physical chemistry and engineering, refers to a material becoming "passive," that is, being less affected by environmental factors such as air or water. It involves a shielding outer layer of corrosion that can be applied as a microcoating or found occurring spontaneously in nature.

Penetration—the depth to which preservative enters the wood

Penstock—enclosed pipe that delivers water to hydraulic turbines or sewerage systems

Penta preservative—a wood-preserving solution made of pentachlorophenol, C6CL5OH, dissolved in hydrocarbon solvent. Often an auxiliary solvent is added to increase the solubility of the "penta."

Pentachlorophenol—a toxic chemical preservative particularly effective against destructive fungi

Petrographic analysis—for concrete this analysis is used to determine the quality of the aggregate, concrete paste, bonding, etc.

Petroleum, oil, lubricant (POL)—a broad term used to describe all petroleum-containing products

Pfisteria—a skin and nervous system disease that may be passed to human beings by infected fish. Symptoms in fish are massive fish kills and ulcerated lesions in the fish.

Pholad—a molluscan marine borer

Photogrammetry—the science of making measurements from photographs

Pier—a structure that projects from the shore, oriented perpendicular, or at an angle to the shore

Pile adrift—an old or structurally inadequate pile that has been abandoned for load-carrying capacity and is generally not connected to other members in the structure

Pile bent—See "bent"

Pile cap—a beam member connecting pile heads and through which deck loads are transmitted to the piles

Pile, marine—a pile that is partly embedded in bottom soil and partly exposed to salt seawater

Pile top cap—any cover fastened over the cut surface of a pile to prevent exposure to the atmosphere

Pitting—a form of extremely localized corrosion that leads to the creation of small pits and/or holes in the metal

Plug, tie—a wood plug used for filling an old spike hole. The plug is usually treated with preservative.

Plumbness—the quality or state of being plumb or vertical

Pointing—filling joints or defects in the face of a masonry structure

Polychlorinated biphenyls (PCBs)—a carcinogenic chemical compound formerly used as insulating and cooling liquids in electrical equipment often found in sediments where waste products from industry have been released into the water. A PCB count is now required, prior to all dredging operations.

Polyethylene—a plastic material used for sheathing

Polyvinyl chloride (PVC)—a plastic material used for sheathing

Pop-outs—shallow, cone-shaped holes in the surface of the concrete

Posting—a method of replacing damaged sections of piles at higher elevations

Posts and timbers—lumber of square or approximately square cross-section, 5 × 5 and larger, graded primarily for use as posts or columns carrying axial load

Pounds per cubic foot (PCF)—a way of expressing a material's density, weight divided by volume

Pounds per square inch (PSI)—unit of pressure

Pounds per square inch absolute (PSIA)—pressure measured relative to a vacuum

Pounds per square inch gauge (PSIG)—a unit of pressure relative to the surrounding atmosphere

Preservative—a chemical compound that creates a protective mechanism against destructive organisms

Preservative, oil-borne—a wood preservative that is introduced into wood in the form of a solution in oil

Preservative, oil type—preservatives such as creosote, creosote-coal tar solutions, creosote-petroleum solutions, and oil-borne preservatives, or other preservatives strictly of an oily nature that are generally insoluble in water

Preservative, waterborne—a wood preservative that is introduced into wood in the form of a solution in water

Preservative, water repellent—a solution of one or more chemicals and water-repellent materials that preserves the wood and retards changes in moisture content and the accompanying changes in dimensions

Preservative, wood—the term "preservative" is intended to include such chemicals or combinations thereof that will protect wood against deterioration from any one or combination of the following: decay, insects, marine borers, fire, weathering, absorption of water, and chemical action

Pressure treatment—impregnation of wood with a preservative applied under pressure

Pretreatment seasoning—the removal of water from the wood before treatment to make the entrance and retention of the preservative possible

Probing—the penetrating through the surface with a probe to detect deterioration

Pulse velocity/pulse echo testing—use of ultrasonic signals for measuring distances/thickness

Punky—an area of decay in a timber member exhibiting a soft spongy appearance; structural integrity is lost in these areas.

Punt—a small flat bottomed boat with square ends

Quaywall—a retaining structure used to contain earth or stone behind a wharf

Rebar—reinforcing steel used in concrete such that the concrete and reinforcement act together in resisting forces

Rectifier—a component of an impressed current cathodic protection system that converts the external alternating current to direct current to minimize or stop the corrosion process

Relieved edges—the exposed edges of a timber plank cut on an angle to reduce edge splintering, i.e., chamfering

Repair—the restoring or replacing to a sound or good condition after damage

Resilient—capable of withstanding shock without permanent damage

Retaining wall—a wall for sustaining the pressure of earth or fill deposited behind it

Retention—per unit volume the quantity of preservative in the wood

Revetment—sloping structures placed on banks or cliffs in such a way as to absorb the energy of incoming water

Riprap—Rough stone of various sizes placed compactly or irregularly to prevent scour by water

Rubble—field stone or rough stone as it comes from the quarry. When it is of a large or massive size it is termed "block rubble."

Salinity—the amount of total salt content in proportion to a unit volume of water

Sapwood—the outer light-colored wood of the tree stem

Scab—wood member used in posting to provide a positive connection between the post and pile and/or pile cap

Scaling—gradual and constant loss of surface mortar and aggregates from an area of concrete

Schmidt hammer—a mechanical device utilizing a standard hammer for testing the condition of a concrete surface

Scour—a condition where bottom material has been washed away from a pile or structure that penetrates the bottom

Seasoned, air-dried, or **air-seasoned**—dried by exposure to the atmosphere, usually in a yard, without artificial heat

Seasoned, kiln-dried—dried in a kiln with the use of artificial heat

Seasoning—the evaporation or extraction of moisture from green or partially dried wood

Seawall—coastal structure built along the shoreline to protect coastal areas caused by waves and flooding by heavy waves

Shake—a separation along the grain of the wood; the separation usually occurring between the annual rings

Shank—The long, straight part of an anchor, to which the anchor line attaches at one end and the fluke(s) at the other end

Sheathing—the exposed face material used in bulkhead construction

Sheeting—a lining of planks or boards for supporting an embankment, usually placed vertically and supported by walers, braces, and piles

Shim—a small piece of wood placed between two members of a structure to bring them to a desired relative position

Shiplapped lumber—lumber that is edge dressed to make a lapped joint

Side-scan sonar—a category of sonar system that is used to efficiently create an image of large areas of the sea floor. It may be used to conduct surveys for maritime archaeology; in conjunction with seafloor samples it can provide an understanding of the differences in material and texture type of the sea bed. Side-scan sonar imagery is also a commonly used tool to detect debris items and other obstructions on the sea floor that may be hazardous to shipping or to sea floor installations by the oil and gas industry.

Silver-silver chloride—reference cell for electrolyte potential measurements in seawater

Skiff—a small boat

Slip—the space between two approximately parallel piers or the space formed by a cut into the land that provides two approximately parallel mooring faces

Soft rot—deterioration of wood components—often without visual distortion or apparent damage to the wood—by certain molds and other fungi that are outside of the common wood-destroying group. The affected wood is likely to be extremely brittle and break without splinters.

Softwoods—the botanical group of trees with needle-like or scale-like leaves often referred to as "conifers." The term softwood has no reference to the softness of the wood.

Soil resistivity—a measure of how much the soil resists the flow of electricity

Sonar, multibeam—sonar transmitted in a 180-degree pattern to record bottom topography, scour, or depth over a wide swath in a single pass

Sonar and side-scan sonar—an ultra-high frequency sound wave generating device for measuring distances by reference to time intervals between sending and receiving any pulse. Usual sonar transmits signals vertically, side-scan transmits signals at an angle less than 90 degrees.

Sounding—a method used to determine interior deterioration in wood and concrete; a method used to determine the depth of water

Spalling—the chipping or fragmentation of a concrete surface or surface coating

Specific gravity—as applied to preservatives, the ratio of weight of a given volume of a preservative to the weight of an equal volume of water

Splicing—the replacement of the damaged portion of a pile

Split—a lengthwise separation of the wood extending completely through the piece from one surface to another

Spud piles—piles driven at an angle to develop horizontal resistance to loading

Staining—the discoloration of wood indicating the presence of fungus activity

Steel sheet pile wall—a bulkhead composed of driven vertical or near vertical steel sheet sections interlocked to form a continuous wall, sometimes tied back to anchors

Stringer—a horizontal timber member spanning between pile caps used to support decking

Structural deterioration—the failure or damage to a structure due to biological, chemical, or mechanical means

Structural lumber—lumber that is 2 in. or more thick and 4 in. or more wide, intended for use where working stresses are required. The grading of structural lumber is based on both the strength of the piece and the use of the entire piece.

Sub-decking—area beneath the surface decking

Sulfate attack—exposure of concrete to sulfates; the most common sulfates are sodium, potassium, magnesium, and calcium sulfates, which react with various hydration products in the presence of moisture to form ettringite, which leads to softening of the concrete

Surface treatment—the applying of a preservative to the surface by means of a brush, swab, or spray gun

Synthetic resin—a chemical sometimes used for impregnating piles

Tar—a generic term applied to nonaqueous liquids obtained as residue in the destructive distillation of organic materials such as coal, lignite, petroleum, wood, and others.

Tar, coal—the nonaqueous portion of the liquid distillate obtained during the carbonization of bituminous coal

Tender—the individual responsible for the diver's welfare during an inspection; also a small boat

Teredo—a genus of molluscan marine borers, commonly called the "shipworm"

Teredo tube—a tubular residue left by teredo borers

Tidal—of, relating to, caused by, or having tides

Tidal datum—a vertical reference based on a specific stage of tide that serves as a baseline elevation to which sounding depths or topographic heights are referenced

Tide—the periodic rising and falling of the surface of the ocean and of water bodies

Tie back, tie rod—generally, a tension rod with anchorage used to restrain a wall from movement or displacement

Timber—a broad term including standing trees and certain products cut from them, including lumber 5 in. or larger in least nominal dimension

Topography—the configuration of the physical features of a place or region

Treatment, dual—treatment of wood to be used under severe conditions of exposure with two dissimilar synergistic preservatives in two separate treating cycles, e.g., treatment of marine piles and wood for areas of extreme borer hazard. Usually, the first treatment is with a waterborne salt preservative, the second with creosote or creosote-coal tar solution.

Treatment, empty-cell—a treatment in which air imprisoned in the wood is employed to force out part of the preservative when treating pressure is released and a final vacuum is applied

Treatment, fire-retardant—treatment of wood under pressure with chemical to reduce its flame spread, fuel contribution, and smoke development

Treatment, full-cell—a treatment involving a preliminary vacuum followed by pressure impregnation such that the cell cavities in the treated portion of the wood remain partially or completely filled with preservative

Tremie—method of placing concrete underwater by gravity or by pumping in which the concrete does not fall directly through the water but is placed below water level through a pipe, the lower end of which is kept immersed in fresh concrete so that the rising concrete from the bottom displaces the water without washing out the cement content

Tsunami—solitary wave caused by an underwater earthquake

Tunicate—Sea grape: a semitransparent organism the size of a grape that often exists in polluted waters. Some cause rashes on divers.

Ultrasonic thickness measurement—a measurement made from one side of a material using ultrasonic wave transmission and return to determine thickness

Unified Facilities Criteria (UFC)—documents that provide planning, design, construction, sustainment, restoration, and modernization criteria and apply to military departments, defense agencies, and Department of Defense field activities

United States Geological Survey (USGS)—a science organization that provides impartial information on the health of ecosystems and environment, natural hazards, natural resources, the impacts of climate and land-use change, and the core science systems that provide timely, relevant, and usable information

Wale or waler—a horizontal member, usually of wood, used for bracing the sheeting or trench, cofferdam, bulkhead, or similar structures

Wane—bark on the edge or corner of a piece, or the absence of wood in a piece from any cause

Waterborne—a preservative soluble in water

Wharf—a structure oriented approximately parallel to shore, where ships can be moored at the offshore face

Windsor probe—a device used to determine the strength of concrete by shooting a standardized probe into the concrete and measuring the depth of embedment

White rot—deterioration caused by a group of fungi that cause "bleaching" of the wood

Wolman Salts—Fluor Chrome Arsenate Phenol Type A

Wood—a broad term including standing trees and certain products cut from them, including lumber 5 in. or larger in least nominal dimension

Wood preservation—the art of protecting wood against the action of destructive agents; usually refers to the treatment of wood with chemical substances (preservatives), which reduce its susceptibility to deterioration by fungi, insects, or marine borers

Xylophaga—a genus of wood boring pholads

Zinc—a metal as a sacrificial anodes in cathodic protection against corrosion

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