ASCE Manuals and Reports on Engineering Practice No. 101

Underwater Investigations

Standard Practice Manual

ASCE

American Society of Civil Engineers

ASCE Manuals and Reports on Engineering Practice No. 101

Underwater Investigations

Standard Practice Manual

Edited by
Kenneth M. Childs Jr., Chair

Sponsored by the
Coasts, Oceans, Ports, and Rivers Institute
of the American Society of Civil Engineers

Published by
ASCE American Society of Civil Engineers
1801 Alexander Bell Drive
Reston, Virginia 20191-4400

Abstract: This manual provides guidance to the requestor and provider of underwater structural inspection services. Guidelines representing the standard of practice in the industry are presented for various inspection types, with the inspection types tailored to specific inspection objectives. The scope of work is defined for each inspection type, and guidelines are provided for the inspection of unique underwater structure types. References are provided for obtaining in-depth information on the structure types and defect types commonly found underwater.

Library of Congress Cataloging-in-Publication Data

Underwater investigations standard practice manual / edited by Kenneth M. Childs, Jr.; sponsored by Ports and Harbors Task Committee on Underwater Investigation Coasts, Oceans, Ports and Rivers Institute.

p. cm.—(ASCE manuals and reports on engineering practice ; no. 101)

Includes bibliographical references and index.

ISBN 0-7844-0545-X

1. Offshore structures—Inspection—Handbooks, manuals, etc. I. Childs, Kenneth M. II. American Society of Civil Engineers. Ports and Harbors Task Committee on Underwater Investigation. III. Coasts, Oceans, Ports and Rivers Institute (American Society of Civil Engineers). IV. Series.

TC1665.U53 2001

627'.98'0287—dc21 00-054309

The material presented in this publication has been prepared in accordance with generally recognized engineering principles and practices, and is for general information only. This information should not be used without first securing competent advice with respect to its suitability for any general or specific application.

The contents of this publication are not intended to be and should not be construed to be a standard of the American Society of Civil Engineers (ASCE) and are not intended for use as a reference in purchase of specifications, contracts, regulations, statutes, or any other legal document.

No reference made in this publication to any specific method, product, process, or service constitutes or implies an endorsement, recommendation, or warranty thereof by ASCE.

ASCE makes no representation or warranty of any kind, whether express or implied, concerning the accuracy, completeness, suitability, or utility of any information, apparatus, product, or process discussed in this publication, and assumes no liability therefore.

Anyone utilizing this information assumes all liability arising from such use, including but not limited to infringement of any patent or patents.

Library of Congress Catalog Card No: 00-054309
ISBN 0-7844-0545-X
Manufactured in the United States of America

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 everyday work, rather than the 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, in order that its merit may be definitely understood.

In February 1962 (and revised in April 1982) the Board of Direction voted to establish:

> A series entitled "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 reports of joint committees, bypassing of Journal publications may be authorized.

MANUALS AND REPORTS OF ENGINEERING PRACTICE

No.	Title
13	Filtering Materials for Sewage Treatment Plants
14	Accommodation of Utility Plant Within the Rights-of-Way of Urban Streets and Highways
35	A List of Translations of Foreign Literature on Hydraulics
40	Ground Water Management
41	Plastic Design in Steel: A Guide and Commentary
45	Consulting Engineering: A Guide for the Engagement of Engineering Services
46	Pipeline Route Selection for Rural and Cross-Country Pipelines
47	Selected Abstracts on Structural Applications of Plastics
49	Urban Planning Guide
50	Planning and Design Guidelines for Small Craft Harbors
51	Survey of Current Structural Research
52	Guide for the Design of Steel Transmission Towers
53	Criteria for Maintenance of Multilane Highways
55	Guide to Employment Conditions for Civil Engineers
57	Management, Operation and Maintenance of Irrigation and Drainage Systems
59	Computer Pricing Practices
60	Gravity Sanitary Sewer Design and Construction
62	Existing Sewer Evaluation and Rehabilitation
63	Structural Plastics Design Manual
64	Manual on Engineering Surveying
65	Construction Cost Control
66	Structural Plastics Selection Manual
67	Wind Tunnel Studies of Buildings and Structures
68	Aeration: A Wastewater Treatment Process
69	Sulfide in Wastewater Collection and Treatment Systems
70	Evapotranspiration and Irrigation Water Requirements
71	Agricultural Salinity Assessment and Management
72	Design of Steel Transmission Pole Structures
73	Quality in the Constructed Project: A Guide for Owners, Designers, and Constructors
74	Guidelines for Electrical Transmission Line Structural Loading
76	Design of Municipal Wastewater Treatment Plants
77	Design and Construction of Urban Stormwater Management Systems
78	Structural Fire Protection
79	Steel Penstocks
80	Ship Channel Design
81	Guidelines for Cloud Seeding to Augment Precipitation
82	Odor Control in Wastewater Treatment Plants
83	Environmental Site Investigation
84	Mechanical Connections in Wood Structures
85	Quality of Ground Water
86	Operation and Maintenance of Ground Water Facilities
87	Urban Runoff Quality Manual
88	Management of Water Treatment Plant Residuals
89	Pipeline Crossings
90	Guide to Structural Optimization
91	Design of Guyed Electrical Transmission Structures
92	Manhole Inspection and Rehabilitation
93	Crane Safety on Construction Sites
94	Inland Navigation: Locks, Dams, and Channels
95	Urban Subsurface Drainage
96	Guide to Improved Earthquake Performance of Electric Power Systems
97	Hydraulic Modeling: Concepts and Practice
98	Conveyance of Residuals from Water and Wastewater Treatment
99	Environmental Site Characterization and Remediation Design Guidance
100	Groundwater Contamination by Organic Pollutants: Analysis and Remediation

TABLE OF CONTENTS

CONTRIBUTING AUTHORS vii
Reviewers vii

1 INTRODUCTION 1
1.1 Intent of the Manual 1
1.2 Importance of Inspections 2
1.3 Limits of Inspections 3
1.4 Organization 4

2 STANDARDS OF PRACTICE 5
2.1 Type and Frequency of Inspections 5
2.2 Choosing the Proper Inspection Type 15
2.3 Minimum Qualifications of Inspection Personnel 15
2.4 Rating and Prioritization 19
2.5 Recommended Action Guidelines 22

3 SCOPE OF INSPECTION WORK 25
3.1 General 25
3.2 New Construction Inspections 27
3.3 Baseline Inspections 30
3.4 Routine Inspections 31
3.5 Repair Design Inspections 38
3.6 Special Inspections 40
3.7 Repair Construction Inspections 41
3.8 Post-Event Inspections 42

4 DOCUMENTATION AND REPORTING 45
4.1 General 45
4.2 Routine Inspection Report 45
4.3 Documentation 47

5 ADMINISTRATIVE CONSIDERATIONS 49
5.1 Agreements 49
5.2 Insurance 50

APPENDIX A SPECIAL CONSIDERATIONS FOR SPECIFIC STRUCTURE TYPES AND SYSTEMS ... 53
A.1 Bridges ... 53
A.2 Open-Piled Structures ... 58
A.3 Gravity and Retaining Structures ... 60
A.4 Marinas ... 65
A.5 Hydraulic Structures ... 69
A.6 Pipelines and Conduits ... 72
A.7 Dry Docks ... 74
A.8 Locks and Gates ... 78
A.9 Floating Structures ... 80
A.10 Breakwaters ... 83
A.11 Tower Bases ... 86
A.12 Moorings and Anchors ... 87
A.13 Tanks and Storage Facilities ... 91
A.14 Cathodic Protection Systems ... 93

APPENDIX B TYPES AND CAUSES OF DEFECTS AND DETERIORATION ... 99
B.1 Concrete Structures ... 99
B.2 Steel Structures ... 106
B.3 Wooden Structures ... 111
B.4 Masonry Structures ... 115
B.5 Composite Structural Components ... 116
B.6 Undermining and Scour ... 117

APPENDIX C BIBLIOGRAPHY ... 119

APPENDIX D GLOSSARY ... 123

INDEX ... 135

CONTRIBUTING AUTHORS

William J. Castle, P.E.
Thomas J. Collins, P.E., F. ASCE*
Christopher Crilley, P.E.
Martin L. Eskijian, P.E.
Chuck Garrison, P.E.
Ronald E. Heffron, P.E.*
Mathew Martinez, P.E.
Terri Regin, P.E.
Benny Skalmstad, P.Eng.*
Shelley D. Sommerfeld, P.E.*
Thomas E. Spencer, P.E.*
Erling B. Vegsund, AFF*
Patrick D. Veteto, P.E.
Stanley M. White, P.E.*

REVIEWERS

G.T. Barford, P.Eng.
Al Blaylock, P.E.
Angus Borland
Valery Buslov, Ph.D., P.E.
R. David Curfman, P.E.
John C. Daley, P.E.
Tyler C. Dunn, P.E.
Frank Kudrna, P.E.
David Robinson, P.E.
Dan Stromberg, P.E.
Alexander Viana
Philip Vitale, Ph.D., P.E.
Harold Weinberg, P.E.

*Member of the Editorial Committee

In memory of Chris Crilley
April 30, 1959–September 30, 2000

Chapter 1
INTRODUCTION

1.1 INTENT OF THE MANUAL

The intent of this manual is to provide guidelines and methods for conducting underwater engineering assessments of underwater components of existing waterfront facilities constructed of materials such as concrete, masonry, metals, composites, and wood and located in near-shore, waterfront, and inland locations exposed to freshwater or saltwater. It includes, but is not limited to, bridges, dams, discharge and intake structures, locks, port and harbor structures, waterfront and waterway structures, pipelines and tunnels, and other structures that are located in, store, or transport water. For convenience, in this manual, the term *waterfront structures* is used to refer to any of the types of structures listed here, where it is appropriate and not specifically limited. Offshore structures and nuclear facilities are beyond the scope of this manual.

A structural inspection and condition assessment of a waterfront facility can be undertaken for one or more purposes. They can include determining the existing or baseline condition, recommending and prioritizing maintenance and repair actions, determining the suitability and serviceability for specific uses and loads, ensuring life safety, improving durability, enabling historic preservation, establishing a baseline condition for change of ownership or legal purposes, or many other special purposes on the basis of the specific structure and its current or proposed function.

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 it is presumed that inspection personnel will possess the requisite knowledge based on their qualifications. Because any condition assessment will require "engineering judgment" and contain factors that cannot be readily defined and standardized, this manual is intended as a guide to be used by the professional engineer as part of an underwater structural condition assessment of an existing facility. The adoption or use of some or all of the 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 underwater facility assessments. Diving and related safety issues may be significant factors in conducting the assessments, but they are not covered 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 and lock-out procedures; penetration diving; contaminated water diving; and diving-related sicknesses and injuries such as embolisms, the bends, nitrogen narcosis, and physical exhaustion. It is therefore imperative that applicable safety and training requirements be adhered to in conducting such work.

1.2 IMPORTANCE OF INSPECTIONS

Underwater inspections are a necessary part of effective structure maintenance and management programs. They play an important part in protecting the public, providing reliable service, 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, and sometimes passing motorists. 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 underwater causes have led to requirements for periodic underwater inspections of bridges in the United States. Other public and private organizations have also adopted similar policies.

Underwater inspections can play an important part in structure maintenance programs. All structures deteriorate and are subject to environmental and external physical forces. Although individual materials have differing mechanisms of deterioration, the environment at the waterline, with moderate temperatures, moisture, oxygen, and chlorides or other chemicals, is conducive to most forms of deterioration. This distress may not be recognizable from above water, nor can the extent and severity be determined in most cases. An engineer cannot fully define the extent of distress or design an appropriate repair without the benefit of an underwater inspection. Designers sometimes attempt to overcome shortcomings in knowledge of the distress by requiring contractors to "repair the structure to its original configuration and dimensions." Because contractors try to avoid risk to themselves, they pass on the cost of this risk to the owner through higher bids and ultimately higher costs. Well-defined construction and repair requirements, based on competent underwater inspections, reduce these costs.

Construction of new facilities and repairs to existing facilities are routinely inspected above water and often include comprehensive quality control and quality assurance programs. The same type of monitoring is warranted for underwater work. In fact, greater inspection is necessary because it is impossible to casually observe the quality of underwater work. Engineers, with responsibilities to their clients and to the public, must take whatever means are available to ensure that their clients receive the highest quality and to ensure the safety of the structure for the public. This obligation often requires competent underwater inspection.

1.3 LIMITS OF INSPECTIONS

Underwater inspections should include all portions of structures that cannot be inspected from above water. In very shallow waters, often an underwater inspection 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, waters with slippery or unstable bottoms, and very turbid water, even a few feet of water may be too deep to permit a safe or satisfactory inspection from above water. The responsible authority must determine whether 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 above, the underwater inspection should extend from the channel bottom or mudline to at least the high-water level.

In some special circumstances, some limited excavation may be necessary at the interface between the structure and the mudline. Such excavation should be clarified in the scope of work and may require special environmental permits. For structures on which it is difficult to inspect some above-water portions, such as the underside of a deck system, it may be appropriate to include above-water portions with the underwater inspection. In many cases, inspections of the above-water and below-water portions of the structure should 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. Conduct of the inspection of the above-water and below-water portions of the structure by the same inspection team generally will also be more cost-effective.

1.4 ORGANIZATION

This manual has been organized in sections to provide both general and specific guidance. Chapter 2 provides an overview of the general requirements for conducting underwater inspections. It also includes descriptions of the common types of inspections and guidelines for inspection frequency. 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.

Chapter 3 provides guidance for developing scopes of work for various types of assessments and inspections.

Chapter 4 provides guidelines for preparing a report of the underwater structural condition assessment. It outlines the contents of a typical report, which include background information; descriptions of the inspection, the testing methods, and the facilities inspected; reporting and documentation of inspection results; topics to be discussed in the assessment; and conclusions and recommendations.

Chapter 5 provides general guidelines for developing agreements between consultants and facility owners. It also presents an overview of the special requirements for insurance related to underwater engineering assessments.

Appendices A through D 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, 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 underwater inspection of structures, representing recommended practices designed to ensure that structures are adequately maintained for the protection of life, the environment, property, and equipment as well as to maximize the longevity of the structure. These requirements include

- type and frequency of inspections
- minimum qualifications of the inspection team
- rating and prioritization
- recommended action guidelines

2.1 TYPE AND FREQUENCY OF INSPECTIONS

2.1.1 General

Seven inspection types are covered by this manual:

- new construction inspection
- baseline inspection
- routine inspection
- repair design inspection
- special inspection
- repair construction inspection
- post-event inspection

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

Routine inspections, repair design inspections, special inspections, and repair construction inspections define routine maintenance activities. The routine inspection should be used as a screening mechanism to determine whether and when other inspections should be conducted. Finally, post-event inspections are conducted only in response to a significant loading or environmental event.

The typical flow and context of inspection activities associated with the seven inspection types is shown in Figure 2-1. Figure 2-1 indicates a typical model of how inspection activities may flow but should not be construed as the only method. In many cases, it may be necessary or advantageous to combine inspection types or deviate from the typical flow of activities to tailor the inspection scope of work to the global project requirements.

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

After a structure has been built, recommended practice is to conduct an underwater *baseline inspection* before accepting the structure. However, if not performed at the time of original construction, the baseline inspection should be performed coincident with the first routine inspection.

Routine inspections are intended to be conducted to the level of detail required to evaluate the overall condition of the structure, determine whether additional maintenance attention to the structure is necessary, and determine the priority of such attention. Documentation of inspection results therefore should be limited to the collection of data necessary to support these objectives to minimize the expenditure of maintenance resources. *Repair design inspections,* by contrast, are conducted only when repairs must be performed, as determined from the routine inspection. Repair design inspections may take considerably longer to execute than routine inspections because they require the detailed documentation of all defects to be repaired. By using this two-tiered approach to the inspection process, inspection resources are used in a very efficient manner.

A routine inspection is not always required before a repair design inspection. In situations where the need for repairs is known or is obvious, or for small facilities, it may be advantageous to conduct the routine inspection and the repair design inspection simultaneously.

In some cases, a more in-depth investigation, involving various types of in situ or laboratory testing, may be required. This type of inspection is called a *special inspection.*

During the course of implementing repairs, underwater inspections should be conducted to ensure that proper quality control and documentation are followed and that the requirements of the repair contract documents are adhered to. This type of inspection is called a *repair construction inspection.*

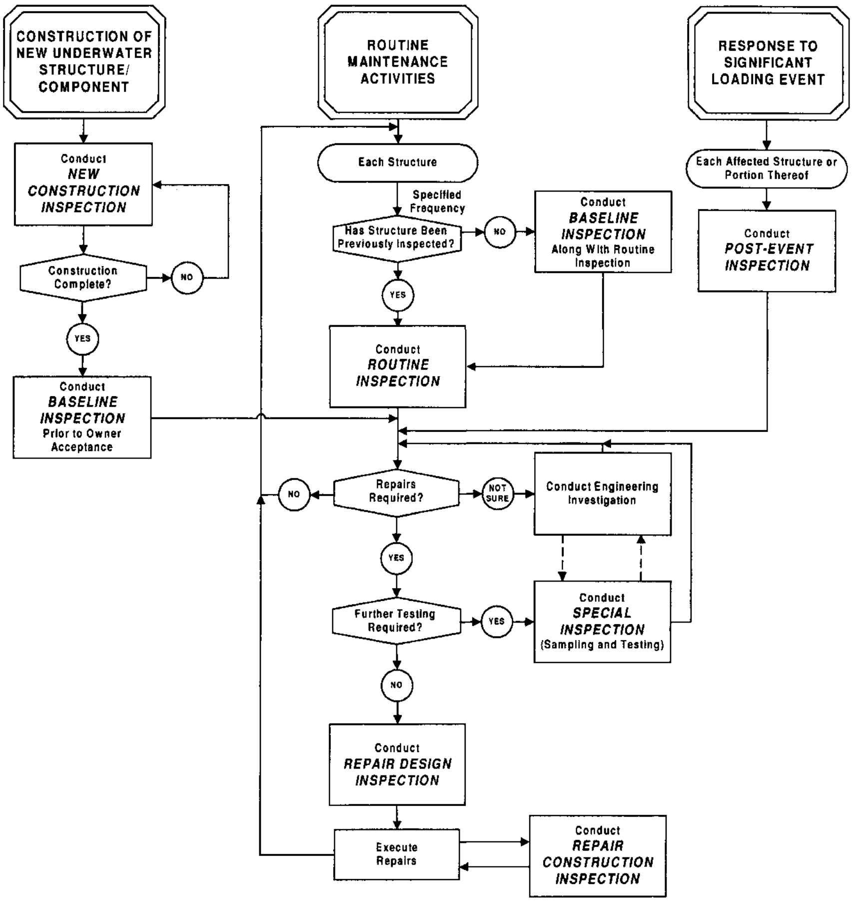

FIGURE 2-1. Flow and context of inspection activities.

Finally, in the event of an earthquake, vessel impact, tsunami, fire, flood, or similar circumstance, a very rapid *post-event inspection* may need to be conducted to determine whether there is significant damage and to ensure the safety of personnel and equipment.

Table 2-1 summarizes the purpose and frequency of each inspection type. A discussion of the purpose and frequency of each inspection type follows, along with an overview of the scope. Chapter 3 presents details of the scope of work for each inspection type.

2.1.2 New Construction Inspections

2.1.2.1 Purpose and Frequency. New construction inspections should be performed during the construction of new underwater structures or dur-

TABLE 2-1. Summary of Underwater Inspection Types

Inspection Type	Purpose	Frequency
New Construction Inspection	To ensure proper ongoing quality of new construction in accordance with plans and specifications	During construction of new underwater 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 before owner acceptance For existing structures, to verify dimensions and construction configuration details	Before owner acceptance of newly constructed structure or at the time of the first routine inspection on existing structures
Routine Inspection	To assess the general overall condition of the structure, assign a condition assessment rating, and assign recommended actions for future maintenance activities	As indicated in Table 2-2
Repair Design Inspection	To record relevant attributes of each defect to be repaired such that repair bid documents may be generated	Only when decision has been made to proceed with repairs on a structure
Special Inspection	To perform detailed testing or investigation of a structure required to understand the nature and extent of the deterioration before determining the need for and type of repairs required	Only when deemed necessary as a result of a routine or repair design inspection
Repair Construction Inspection	To ensure proper quality of repairs, resolve field problems, and ensure proper documentation of payment quantities	During repair projects involving underwater structures or components
Post-event Inspection	To perform a rapid underwater evaluation of a structure after an earthquake, storm, vessel impact, fire, tsunami, or similar event to determine whether further attention to the structure is necessary as a result of the event	After a significant potentially damage-causing event

ing the construction of structures that have components that extend below the waterline, to ensure proper construction quality in accordance with the design plans and specifications.

2.1.2.2 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 as well as resolution of field problems. Details of the scope of new construction inspections are presented in Chapter 3.

2.1.3 Baseline Inspections

2.1.3.1 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 before owner acceptance. Baseline inspections are typically conducted on newly constructed facilities before owner acceptance or final payment to the contractor. If the baseline inspection was 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.

2.1.3.2 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 and 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.

2.1.4 Routine Inspections

2.1.4.1 Purpose and Frequency. The primary purpose of a routine inspection is to assess the general overall condition of underwater portions of the structure, assign a condition assessment rating to the underwater portions of the structure, and recommend what future course of action should be taken for the structure, if any. Routine inspections should be performed on a routine, cyclical basis and therefore represent a proactive, rather than reactive, approach to maintenance.

The frequency with which routine inspections should be conducted is a function of several variables. The most important of these variables include the material type, age of the structure, and the service environment. The recommended frequency between underwater inspections varies from 2 to 6 years and is presented in Table 2-2. These 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, the importance of the structure, and other factors.

By conducting routine assessments on a cyclical basis, deteriorated elements will be detected and remediated before the deterioration progresses

TABLE 2-2. Recommended Maximum Interval between Underwater Routine Inspections (Years)[1]

	Construction Material					
	Unwrapped Wood or Unprotected Steel (No Coating or Cathodic Protection)[4]		Concrete, Wrapped Wood, Protected Steel, or Composite Materials (FRP, Plastic, etc.)[4]		Channel Bottom or Mudline – Scour[4,5] (Soundings[6] / Direct Observation)	
Condition Rating from Previous Inspection	Benign[2] Environment	Aggressive[3] Environment	Benign[2] Environment	Aggressive[3] Environment	Benign[2] Environment	Aggressive[3] 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

FRP, fiber-reinforced polymer.

1. The recommended maximum interval between routine inspections should be reduced as appropriate based on the extent of deterioration observed on a structure, the rate of further anticipated deterioration, the importance of the structure, or other factors. The intervals may likewise be increased as appropriate for atypical cases such as alternative deterioration-resistant construction materials (i.e., special hardwoods) or other factors. Regulatory jurisdictions also may dictate the maximum inspection interval.

2. Benign environments include freshwater with low to moderate currents (maximum current always < .75 kts).

3. Aggressive environments include brackish water or saltwater, polluted water, and water with moderate to swift currents (maximum current ≥ .75 kts).

4. The intervals indicate requirements for soundings and direct observation, respectively.

5. For most structures, two maximum intervals will be shown in this table: one for the assessment of construction material (wood, concrete, steel, etc.) and one for scour (last two columns). The shorter interval of the two should dictate the maximum interval used.

6. Soundings may be performed at the time of the above-water inspection.

to a level that could threaten structural integrity. In addition, significant damage or breakage caused by impact from vessels, floating debris, or other sources will be detected during routine inspections.

2.1.4.2 Scope of Work Overview. Because underwater visibility is limited and underwater portions of components are often covered with marine growth, a comprehensive visual inspection of all component surfaces during a routine inspection is impractical. For this reason, routine inspections focus on three levels of effort (the three levels are defined in more detail in Chapter 3):

- Level I Visual or tactile inspection of underwater components without the removal of marine growth.
- Level II Partial marine growth removal of a statistically representative sample—typically 10% of all components.
- Level III Nondestructive testing (NDT) or partially destructive testing (PDT) of a statistically representative sample—typically 5% of all components. May consist of PDT of wood and remaining thickness measurement of steel components.

On completion of the inspection, a condition assessment rating should be assigned, 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 new condition and does not consider the actual or anticipated loading (structural demand) because such information typically is 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.

2.1.5 Repair Design Inspections

2.1.5.1 Purpose and Frequency. The purpose of the repair design inspection is to record defects to be repaired, including all relevant defect attributes, such that repair bid documents may be generated. Repair design inspections should be conducted only when repairs are to be performed and with as little interval as practicable between the time of the repair design inspection and the execution of repairs, because long delays between the inspection and the repair construction may result in additional deterioration, rendering the repair quantity estimates inaccurate. Typically, repair design inspections will result from a recommendation made after a routine inspection. However, when the need for repairs is obvious and the priority is clear, a repair design inspection may be conducted without being preceded by a routine inspection or may be combined with a routine inspection.

2.1.5.2 Scope of Work Overview. Before beginning a repair design inspection, the criteria for what defects should be repaired should be established. In addition, it may be beneficial to determine the method(s) of repair for all typical situations on the structure. The repair 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.

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

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

2.1.6 Special Inspections

2.1.6.1 Purpose and Frequency. Special inspections are conducted for the purpose of collecting more detailed information than normally collected during a routine or repair design inspection. Such information may be necessary to understand the nature or extent of deterioration before determining the need for and type of repairs. Special inspections may also be performed to estimate the remaining useful life of the structure. One example of the need for a special inspection would be a concrete structure that has piles that are soft below the waterline. In such a case, the special inspection would include coring and testing as well as analysis to determine whether the cause of the softness is related to sulfate attack, alkali–silica reaction (ASR), or delayed ettringite formation (DEF).

Special inspections are typically performed on an exceptional basis as a result of a recommendation made after a routine inspection. However, a special inspection also may be performed concurrently with a routine inspection or repair design inspection where appropriate.

2.1.6.2 Scope of Work Overview. The scope of a special inspection may vary widely depending on the objectives of the inspection and the nature of the deterioration. Examples of common special inspection techniques are listed below. Some of these techniques also may be used in conducting routine or repair design inspections under some circumstances.

- concrete coring for physical testing 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, and so forth)
- 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
- subbottom profiling
- side-scan or multibeam sonar investigations
- wood preservative retention testing
- wooden component removal and dissection
- dissolved oxygen (DO) testing
- marine borer investigation
- fluorometer dye and leak detection testing
- scour analysis or soil particle size analysis
- magnetic particle inspection
- coating thickness and continuity inspection
- postmarine growth removal inspection

The type of inspection or testing technique must be specified by the requester of the services and may typically be based on a recommendation made after a routine inspection. Details on the scope of a special inspection are presented in Chapter 3.

2.1.7 Repair Construction Inspections

2.1.7.1 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 on-site inspector, while evaluating work against the contract specifications, also may evaluate contractor claims for progress payments or additional work. Because repair quantities and specified repair methods are only estimates based on the best judgment of the inspection engineer during the repair design inspection and because widespread removal of unsound materials occasionally reveals conditions that differ from anticipated 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.

2.1.7.2 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 assurance that repair quantities are properly recorded where necessary. Details of the scope of repair construction inspections are presented in Chapter 3.

2.1.8 Post-Event Inspections

2.1.8.1 Purpose and Frequency. Post-event inspections should be conducted after 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 assess rapidly the structural stability of the structure and determine whether further attention to the structure is necessary as a result of the event.

2.1.8.2 Scope of Work Overview. Post-event inspections are intended to be relatively rapid, visual or tactile inspections conducted to determine whether 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 often is used to indicate whether 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 CHOOSING THE PROPER INSPECTION TYPE

Each of the seven inspection types defined herein has a distinct purpose. It should be emphasized that these inspection types are not necessarily exclusive; they 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 MINIMUM QUALIFICATIONS OF INSPECTION PERSONNEL

2.3.1 General

The nature of underwater inspection work necessitates that judgment be applied to decisions made throughout the inspection process. A properly executed underwater inspection goes well beyond the mere logging of observed defects. For this reason, the underwater inspection team should always be led by a registered, licensed professional engineer who is also a qualified diver. The requirement for a professional engineer–diver ensures that an individual with the necessary training and experience is available on site to observe, assess, and exercise sound judgment. Situations in which such judgment plays a crucial role in the inspection process include the following.

- 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 wooden pile requires an understanding of structural redundancies and alternate load paths as well as 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 firsthand 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 that corrosion

TABLE 2-3. Matching Inspection Objectives with the Seven Inspection Types

Objective	Inspection Type	Included in Standard Scope of Work	Addition to Standard Scope of Work
To ensure quality control during new construction	New construction inspection	✓	
To verify installed quantities for contractor payment	New construction inspection	✓	
To respond to field questions and problems during new construction	New construction inspection	✓	
To verify that structure is built in general compliance with the design drawings, if available	Baseline inspection	✓	
To ensure that new structure has no significant defects before owner acceptance	Baseline inspection	✓	
To generate design drawings where no drawings exist	Baseline inspection		✓
To assess and rate the overall condition of an existing structure	Routine inspection	✓	
To determine what future maintenance activities are necessary on a structure	Routine inspection	✓	
To quantitatively evaluate the local loss of structural capacity of typical components as a result of damage or deterioration	Routine inspection	✓	
To quantitatively evaluate the global structural integrity relative to actual loads on the structure, considering observed damage or deterioration	Routine inspection		✓[1]
To estimate the remaining useful life of the structure	Routine inspection		✓[2]
To develop order-of-magnitude estimates of probable costs for rehabilitation work	Routine inspection		✓
To document details of defects and components to be repaired	Repair design inspection	✓	
To develop detailed quantity estimates for rehabilitation work	Repair design inspection	✓	

continued on next page

TABLE 2-3. *Continued*

Objective	Inspection Type	Included in Standard Scope of Work	Addition to Standard Scope of Work
To develop detailed repair plans (bid documents) including drawings and specifications	Repair design inspection		✓
Determine the cause of observed deterioration to fix it or prevent it in the future, where such cause is not readily apparent	Special inspection[3]		✓
To quantify the extent of observed deterioration	Special inspection[3]		✓
To determine the structural significance of observed damage	Special inspection[3]		✓
To determine the significance of observed damage on future durability	Special inspection[3]		✓
To ensure quality control of repairs during construction	Repair construction inspection	✓	
To respond to field questions and problems during construction of repairs	Repair construction inspection	✓	
To ensure impartial documentation of repair quantities during construction of repairs	Repair construction inspection	✓	
To assess and rate structural integrity after a significant loading or environmental event	Post-event inspection	✓	
To determine whether additional remedial attention is necessary on a structure as a result of a significant loading or environmental event	Post-event inspection	✓	

1. Engineering evaluation.

2. May require special inspection.

3. Special inspections have no "standard" scope of work. Each special inspection should be conducted for a predefined purpose, and such purposes may vary considerably.

profiling of representative members be conducted to evaluate section loss against 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 to the corrosion threshold to estimate the remaining useful life of the structure.
- Determining the most appropriate method of conducting a repair design inspection requires a detailed understanding of which repair methods will be cost-effective and economical. For example, piles that are to 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, it is important to distinguish an overstressing crack from a corrosion crack; 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 minimum qualifications of the team leader and team members. In addition, the number of members of the inspection team and the qualifications and expertise of the individual members should be determined in consideration of the diving environment and site conditions, the engineering requirements of the task, and client and regulatory requirements.

All diving operations shall be conducted in accordance with and all personnel shall meet the minimum requirements of applicable regulations. In the United States, diving generally is performed in accordance with the requirements of the federal Commercial Diving Standards of the Occupational Safety and Health Administration (OSHA), as well as state OSHA requirements, as applicable.

2.3.2 Team Leader

The underwater inspection team shall be led by and be under the direct on-site supervision of a team leader who shall be a registered, licensed professional civil or structural (or related) engineer.

In addition, the team leader shall be a trained diver and shall participate actively in the inspection by personally diving to conduct a significant portion (minimum of 25%) of the diving inspection work. The team leader shall have a minimum of 5 years experience conducting underwater structural inspections and a minimum of 5 years engineering experience specifically related to the type of facility under investigation.

For new construction inspections and repair construction inspection only, in lieu of the requirements for a registered, licensed professional or structural engineer, the team leader shall be a graduate of a 4-year civil engineering curriculum and have a minimum of 2 years of construction inspection experience or a certified inspector with a minimum of 10 years of construction inspection experience. The certification shall be from a nationally recognized building authority or a result of successful completion of a course of study in structural inspections as described below.

2.3.3 Team Members

Team members involved in inspection, note-taking, and documentation work shall be trained divers who are graduates of a 4-year engineering curriculum and have been certified, in the United States, as an engineer-in-training (EIT; in other countries, comparable evidence of minimum competence may be substituted) or technician–divers who have completed a course of study in structural inspections. The minimum acceptable course in structural inspections shall include 80 hours of instruction specifically related to structural inspection and require the successful completion of a comprehensive examination. One acceptable course of such instruction is the US Department of Transportation's "Safety Inspection of In-Service Bridges." Certification as a Level IV Bridge Inspector by the National Institute for Certification in Engineering Technologies (NICET) will also be acceptable.

Other divers performing manual tasks (such as cleaning or supporting the diving operation but not conducting or reporting inspections) may have lesser qualifications. In addition, other divers and technicians with special knowledge, skills, or experience may be part of the team as required to support the objective.

2.4 RATING AND PRIORITIZATION

2.4.1 General

Ratings are assigned to the underwater portions of each structure on completion of routine inspections and post-event inspections. 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 because of 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 only event-induced damage, 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.

2.4.2 Condition Assessment Ratings

The condition assessment rating should be assigned on completion of the routine inspection and should remain associated with the structural unit (as defined in Chapter 3, Section 3.1.1) until the structure is rerated after a quantitative engineering evaluation or repairs, or on completion of the next scheduled routine inspection.

A scale of 1 to 6 is used for the rating system as shown in Table 2-4. 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.

It is important to understand that ratings are used to describe the existing in-place structure relative to its condition when newly built. 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. It is also important to recognize that the rating is applicable to the below-water portions of the structure only, although a similar inspection and rating may also be performed on the above-water portions of the structure.

It is equally important to understand that the correct assignment of ratings requires both experience and an understanding of the structural concept of the structure to be rated. Judgment must be applied considering

- scope of damage (total number of defects)
- severity of damage (type and size of defects)
- distribution of damage (local or general)
- types of components affected (their structural "sensitivity")
- location of defect on component (relative to point of maximum moment or shear)

Therefore, 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.

2.4.3 Post-Event Condition Ratings

The post-event condition rating should be assigned on completion of the underwater post-event inspection, preferably before leaving the site. The rating should be used to reflect whether additional attention is necessary and, if so, at what priority level. Table 2-5 shows the four post-event condition ratings. A rating of "A" indicates no further action is required, and a rating of "D" indicates major structural damage requiring urgent attention.

The following guiding principles should be followed when assigning post-event condition ratings.

TABLE 2-4. Routine Underwater Condition Assessment Ratings

Rating	Description
6 Good	No visible damage, or only minor damage is noted. Structural elements may show very minor deterioration, but no overstressing is observed. No repairs are required.
5 Satisfactory	Limited minor to moderate defects or deterioration are observed, but no overstressing is observed. No repairs are required.
4 Fair	All primary structural elements are sound, but minor to moderate defects or deterioration is 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 is 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.

- 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 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.

TABLE 2-5. Post-Event Condition 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 is 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.

- Assignment of ratings should reflect an overall characterization of the entire underwater portion of the 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.
- It should be recognized that the assignment of rating codes requires judgment. Use of standard rating guidelines is intended to make assignment of these ratings uniform among inspection personnel.

2.5 RECOMMENDED ACTION GUIDELINES

Whereas condition assessment and post-event condition 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 on 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.

Typical recommended action options for each inspection type are depicted in Figure 2-2. A description of each recommended action choice is provided in Table 2-6. Multiple recommended actions may be assigned on 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 emergency (because of broken piles), repair design inspection (because of deteriorated and broken piles), and special inspection (because the cause of deteriorated piles is not known and coring, testing, and analysis is required). In this example, guidance in the report should state that the emergency action should be taken first (erect barricades or close a portion of the structure), then the special inspection should be conducted to determine the cause of the deterioration, and the repair design inspection should follow.

TABLE 2-6. Description of Recommended Action Options

Recommended Action	Description
Emergency Action	Recommended whenever an unsafe condition is observed. If the situation is life threatening or if significant property damage or environmental damage may occur, appropriate owner representatives should be contacted immediately.
	May consist of barricading or closing all or portions of the structure, placing load restrictions, or unloading portions of a structure.
Engineering Evaluation	Recommended whenever significant damage or defects are encountered that require a structural investigation or evaluation to quantify the structural capacity, determine whether repairs are required, or determine which 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 or anticipated loads that are or will be imposed on the structure.
Repair Design Inspection	Recommended whenever repairs are required, typically as a result of a routine inspection, but also may result from a special inspection or post-event inspection.
Special Inspection	Typically recommended to determine the cause or significance of atypical deterioration, usually before designing repairs.
	Special testing, analysis, monitoring, or investigation using nonstandard equipment or techniques is typically required.
Develop Repair Plans	Recommended when the repair design inspection has been completed and any special inspections recommended have been completed.
	Indicates that the field data have been collected and that 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.

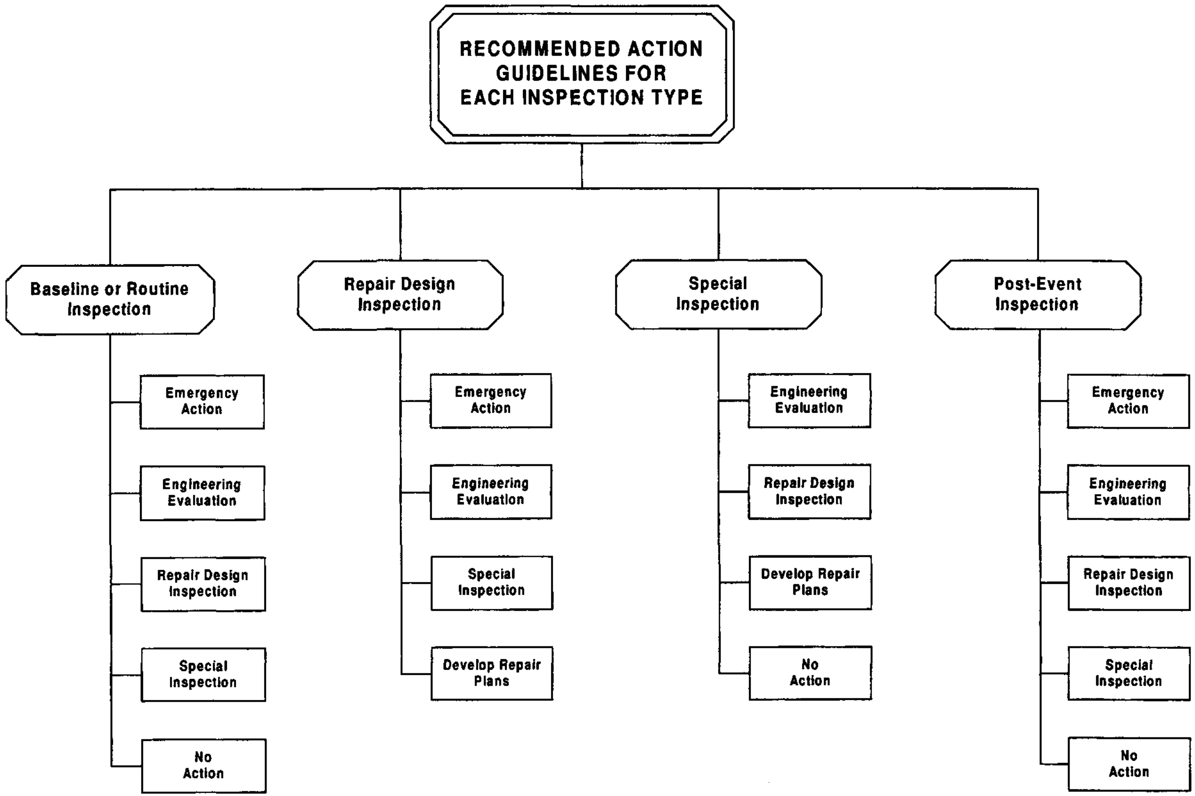

FIGURE 2-2. Recommended action guidelines.

Chapter 3
SCOPE OF INSPECTION WORK

3.1 GENERAL

The scope and methods for conducting each of the seven inspection types are presented in this section. These methods are general in nature and are applicable to all structure types and all construction materials. This manual does not present detailed "how-to" techniques; rather, it provides guidance regarding methodology. It is assumed that the provider of underwater inspection services possesses the required expertise to implement the methodologies described here competently and professionally.

Unique aspects of scopes of work for inspections that are applicable to specific structure types are presented in Appendix A. Definitions of defect types and deterioration mechanisms for each material type are presented in Appendix B.

It is imperative to confirm and document with the owner, at the outset of the work, the specific scope and limits of the work.

3.1.1 Structural Boundaries

Inspections should be conducted and ratings should be assigned against distinct structural units. For example, a wooden pier projecting from a steel-sheet pile bulkhead should be divided into at least two distinct structures for 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. For example, whereas a bridge or dam may each be defined as one structural unit, it may be advantageous to break other structures such as large piers, wharves, or tunnels into multiple structures. Common boundaries include expansion joints, configuration changes, changes in age of construction, changes in direction, and changes in bent numbering sequence.

3.1.2 Limits of Inspection

Inspections should be conducted on all accessible components below water that are routinely submerged or are within the splash zone. The upper limit may be defined as the elevation of mean high water in tidal waters. In nontidal areas, the limits of the inspection may vary depending on the structure type and time of the year. The lower limit is typically defined as the channel bottom, mudline, or sea floor. Such limits should be clarified in the scope of work for the specific project. Common practice is to include in the scope of the underwater inspection all portions of the structure that may not be accessible during the next routine above-water inspection.

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

Because of 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 efforts are defined, with the underwater inspection requirements defined as a percentage of these three levels of effort.

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

Level II A detailed inspection that requires marine growth to be removed from portions of the structure. Cleaning is time-consuming, 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; 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. This inspection also should focus on typical areas of weakness such as attachment points and welds. It is intended to detect and identify damaged and deteriorated areas that may be hidden by surface biofouling. The thoroughness of cleaning should be governed by the tasks necessary to discern the condition of the underlying material. Removal of all biofouling staining is generally not required.

Level III A detailed inspection 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 ultrasonics, coring or boring, physical material sampling, and in situ hardness testing. This inspection is generally limited to key structural areas, areas that are suspect, and areas that may be representative of the underwater structure.

Table 3-1 is a summary of the information typically collected for each of these inspection levels.

3.2 NEW CONSTRUCTION INSPECTIONS

3.2.1 Objectives

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

- perform quality control to verify compliance with design documents
- verify quantities installed for contractor payment
- respond to field questions and resolve field problems
- develop a list of deficiencies for the contractor to correct

TABLE 3-1. Summary of Inspection Levels

		Detectable Defects			
Level	Purpose	Steel	Concrete	Wood	Composite
I	To confirm as-built condition and detect severe damage	Extensive corrosion and holes Severe mechanical damage	Major spalling and cracking Severe reinforcement corrosion Broken piles	Major loss of section Broken piles and bracings Severe abrasion or marine borer attack	Permanent deformation Broken piles Major cracking or mechanical damage
II	To detect surface defects normally obscured by marine growth	Moderate mechanical damage Corrosion pitting and loss of section	Surface cracking, spalling, and erosion Rust staining Exposed reinforcing steel or pre-stressing strands	External pile damage caused by marine borers Splintered piles Loss of bolts and fasteners Rot or insect infestation	Cracking Delamination Material degradation
III	To detect hidden or interior damage, evaluate loss of cross-sectional area, or evaluate material homogeneity	Thickness of material Electrical potentials for cathodic protection	Location of reinforcing steel Beginning of corrosion of reinforcing steel Internal voids Change in material strength	Internal damage caused by marine borers (internal voids) Decrease in material strength	NA

NA, not applicable.

3.2.2 Method of Inspection and Documentation

New construction inspections are conducted during ongoing construction to ensure quality control for the underwater construction. Additionally, field questions and problems are resolved to ensure that design intent and construction documents are properly interpreted and implemented and to assist in keeping the project within the established budget and schedule.

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 or tactile inspection of the underwater components should be conducted at critical stages during the construction sequence.

However, issues may arise during the construction that warrant more detailed inspection or testing to verify installed components and conditions. For example, placement of a concrete caisson may require two phases of inspection: one to ensure proper preparation and leveling of the site before the installation of the structure, and another to inspect the caisson after placement to ensure that no damage has occurred during placement. Alternatively, a new construction inspection of a wooden pile-supported structure may only require one phase of inspection to confirm that no damage—such as breaching of the protective treatment, which could accelerate deterioration due to marine borer infestation—has occurred to the members. It usually is advantageous to conduct an inspection of piles in a pile-supported structure to ensure that no piles are broken or severely damaged before constructing the deck.

Documentation obtained during a new construction inspection should provide details on 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), and other physical features. Additionally, all underwater field problems and associated resolutions should be documented for future reference.

3.2.3 Recommendations

On completion of the new construction inspection, a list of deficiencies should be prepared and presented to the owner's representative for contractor resolution. It 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 before the owner's acceptance of the structure. If a baseline inspection is not warranted, the recommended interval to the next regularly scheduled routine inspection should be assigned using the guidelines presented in Chapter 2, Section 2.1.4.

3.3 BASELINE INSPECTIONS

3.3.1 Objectives

A baseline inspection should be conducted on a newly constructed structure before acceptance by the owner or 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 before owner acceptance
- establishing a structure/component datum for future reference and comparison
- developing recommendation(s) for follow-up action
- determining the recommended interval to the first routine inspection

In addition, for existing structures that have no drawings available, drawings may be generated as a result of measurements and testing conducted during the baseline inspection. These drawings may serve as as-built drawings and therefore should be of appropriate detail.

3.3.2 Method of Inspection and Documentation

Baseline inspections are conducted to confirm dimensions, component locations, existing conditions, and other physical features. For new construction, the scope and level of effort expended depend on the specific type of construction, material type, and whether the facility has undergone a new construction inspection. Information documented during the new construction inspection can be used 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. Such information may include the thickness of steel members at specific locations or the determination of the channel bottom elevation where future scour may be anticipated.

When conducting a baseline inspection of an existing facility, such as before changes in ownership or when no previous inspection information is available, the scope of the inspection will depend on whether drawings of the facility are available.

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. The scope of work should include confirmation of the dimensions of accessible representative components, verification of the size, identification of the approximate position and number of components, and verification of construction material types. Therefore, the baseline inspection conducted on structures where drawings are available should consist of a Level I inspection conducted over 100% of the structure, supplemented by physical measurements.

For existing structures where design drawings are not available, the baseline inspection should be conducted to gather sufficient information to generate drawings of the facility. The level of detail required for this inspection will depend on what the drawings will be used for. In some cases, it may be sufficient to document the dimensions of individual members and of the overall facility. A Level I inspection supplemented by physical measurements will suffice in this case.

However, where a structural analysis must be performed using the results of the baseline inspection, the inspection must be much more detailed. Level III inspections should be used in such cases. For concrete structures, it may be necessary to establish the location, size, and cover of reinforcing steel. In addition, it may be necessary to measure the compressive strength of the concrete by testing core samples, by nondestructive methods such as Schmidt Hammer or Windsor Probe testing, or by a combination of destructive and nondestructive methods. For structural steel or reinforcing steel, it may be necessary to collect coupon samples to determine tensile strength and other properties relevant to the structural analysis. Similarly, it may be necessary to collect and test wooden samples to establish strength and ductility characteristics. Finally, where connection details are unknown or are not readily apparent, it may be necessary to dissect typical connections to document details.

3.3.3 Recommendations

On completion of the baseline inspection, recommended actions should be assigned to the structure in accordance with Chapter 2, Section 2.5. In addition, the recommended interval to the first regularly scheduled routine inspection should be assigned using the guidelines of Chapter 2, Section 2.1.4.

3.4 ROUTINE INSPECTIONS

3.4.1 Objectives

The routine inspection is the most common aspect of normal maintenance of an underwater structure. Decisions made as a result of the routine inspection dictate the course and priority of future maintenance activity on a structure. Objectives of the routine inspection include

- assessing the overall condition of underwater portions of the structure
- assigning an underwater condition assessment rating

- developing recommendation(s) for follow-up action
- determining the recommended interval to the next routine inspection

3.4.2 Methods of Inspection and Documentation

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

TABLE 3-2. Recommended Minimum Scope of Routine Inspections: Inspection Sample Size and Method(s)[1]

Material	Level	Sample Size (%)	Method
Steel			
Piles	I	100	Visual or tactile
	II	10	Visual: Removal of marine growth in 3 bands
	III	5	Remaining thickness measurement; electrical potential measurements; corrosion profiling as necessary
Large Elements[2]	I	100	Visual or tactile
	II	Every 100 LF	Visual: Removal of marine growth in 1-SF areas
	III	Every 200 LF	Remaining thickness measurement; electrical potential measurements; corrosion profiling as necessary
Concrete			
Piles	I	100	Visual or tactile
	II	10	Visual: Removal of marine growth in 3 bands
	III	0	NA
Large Elements[2]	I	100	Visual or tactile
	II	Every 100 LF	Visual: Removal of marine growth in 1-SF areas
	III	0	NA

continued on next page

A routine inspection should be limited to the collection of sufficient information to address each of the key objectives. In most cases, it is not necessary to document the exact location and size of each observed defect. Rather, it is standard practice to rate components as "no damage," "minor damage," "moderate damage," "advanced damage," or "severe damage." These damage grades must be defined specifically, wherever they are used, in terms of cross-sectional loss, crack widths, cause of damage, position of damage, and so forth. Such descriptions should include information on the approximate zone or elevation where the damage is present such that the significance of the deterioration may be evaluated.

Wherever 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.

TABLE 3-2. *Continued*

Material	Level	Sample Size (%)	Method
Wood			
Piles	I	100	Visual or tactile
	II	10	Visual: Removal of marine growth on 3 bands Measurement: Remaining diameter
	III	5	Internal marine borer infestation evaluation
Large Elements[2]	I	100	Visual or tactile
	II	Every 50 LF	Visual: Removal of marine growth in 1-SF areas
	III	Every 100 LF	Internal marine borer infestation evaluation
Composite			
Piles	I	100	Visual or tactile
	II	10	Visual: Removal of marine growth in 3 bands
	III	0	
Slope Protection/ Channel Bottom or Mudline – Scour			
	I	100	Visual or tactile
	II	AN	
	III		Sonar imaging as necessary

AN, as necessary; LF, linear feet; NA , not applicable; SF, square feet.

1. The minimum inspection sample size for small structures shall include at least two components of each underwater component type.

2. Large (or solid-faced) elements may include bulkheads, retaining walls, dam fascia, tunnel and pipeline walls, piers, gates, and tank walls.

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 the rehabilitation work. In such cases, it may be necessary to expand the scope of the inspection and documentation to include sufficient information to address these issues. It also may be necessary to conduct a special inspection along with the routine inspection to address such issues. The scope of work described in the remainder of this section does not address these additional issues.

3.4.3 Methods of Inspection for Steel Components

Level I inspections for steel structures are visual or tactile. Level II inspections are also visual—on removal of marine growth in areas to be inspected. Level III inspections for steel structures require that the remaining thickness of the underwater 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 using an ultrasonic thickness-measuring device. Specific structures may warrant Level III efforts such as inspecting welds using magnetic particle testing.

If the inspected components exhibit significant corrosion that could affect the load-bearing 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.

For uncoated 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.

For steel members that have been coated, the Level I and Level II inspections should focus on the evaluation of the integrity and effectiveness of the coating. Care should be taken to avoid damaging the coating while removing marine growth for the Level II inspection. Level III inspections for coated steel members should include ultrasonic thickness measurements without removing the coating, where feasible.

For steel members that have been wrapped, the Level I and Level II inspections should focus on the evaluation of the integrity of the wrap. Care should be taken to avoid damaging the wrap while removing marine growth for the Level II inspection. 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 the effectiveness of the wrap is questionable, then a sample of wraps should be removed to facilitate inspection and evaluation. The sample may be limited to particular zones or portions of the member where damage is suspected, for example, at the waterline. The sample size should be determined on the basis of 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. It may be advantageous to cut the wrap over half of the perimeter of the member and then repair it on completion of the inspection.

For steel members that have been encased, the Level I and Level II inspections 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 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 Level II inspections in such cases should concentrate on the top and bottom of the encasement.

3.4.4 Methods of Inspection for Concrete Components

Level I inspections for concrete structures are visual or tactile. Level II inspections are also visual—on removal of marine growth in areas to be inspected. Level III inspections are not typically required on concrete elements.

For concrete members that have been encased, the Level I and Level II inspections should focus on the evaluation of 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 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 Level II inspections in such cases should concentrate on the top and bottom of the encasement. If deterioration, disbondment, or other significant problems with the encasement are suspected, it may be necessary to conduct a special inspection. The special inspection in such circumstances may include coring of the encasement and laboratory evaluation of the materials.

For concrete members that have been wrapped, the Level I and Level II inspections should focus on the evaluation of the integrity of the wrap.

Care should be taken to avoid damaging the wrap while removing marine growth for the Level II inspection. 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 routinely done. However, if evidence of significant damage exists or the effectiveness of the wrap is questionable, then a sample of wraps should be removed to facilitate the inspection and evaluation. The sample may be limited to particular zones or portions of the member where damage is suspected, for example, at the waterline. The sample size should be determined on the basis of the physical evidence of potential problems. 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.

3.4.5 Methods of Inspection for Wood Components

Level I inspections for wooden structures are visual or tactile. An ice pick or awl should be used to probe for softness, except for wrapped members. Level II inspections are also visual—on removal of marine growth in areas to be inspected. Level III inspections conducted on wooden members historically have been conducted by using several different methods. Depending on the intrinsic nature of the material, the rate of deterioration—once initiated—progresses rapidly compared with other materials used in marine construction. Therefore, it is typical to use boring or coring tests to quantify internal deterioration. Bore holes should be filled with oversized treated hardwood dowels, epoxy, or nonshrinking grout.

For wooden members that have been repaired by encasement, the Level I and Level II inspections should focus on the evaluation of the integrity of the encasement. Such encasements should not be removed for a routine inspection. However, if evidence of significant deterioration is present on the encasement or 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 Level II inspections in such cases should concentrate on the top and bottom of the encasement.

For wooden members that have been wrapped, the Level I and Level II inspections should focus on the evaluation of the integrity of the wrap. Care should be taken to avoid damaging the wrap while removing marine growth for the Level II inspection. Level III inspections should consist of removing the wraps from a representative sample of components to evaluate the condition of the wood beneath the wraps. The sample may be limited to particular zones or portions of the member where damage is suspected, for example, at the mudline/bottom of wrap, or in the tidal zone. The sample size should be determined on the basis of 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 removal of the wrap, the wood should be evaluated using visual or tactile means as well as boring or coring tests as described for non-wrapped wooden elements. Wraps that are removed to facilitate such inspections should be restored or replaced in accordance with the wrap manufacturer's installation requirements. It may be advantageous to cut the wrap over half the perimeter of the member and then repair it on completion of the inspection.

3.4.6 Methods of Inspection for Masonry Components

Level I inspections for masonry components are visual or tactile. Level II inspections are also visual—on removal of marine growth in areas to be inspected. Level III inspections are not typically required on masonry elements.

3.4.7 Methods of Inspection for Composite Components

Level I inspections for composite components are visual or tactile. Level II inspections are also visual—on removal of marine growth in areas to be inspected. Level III inspections are not typically required on composite elements.

3.4.8 Methods of Inspection for Slope Protection

Level I inspections on slope protection (such as armor stone, riprap, gabions, concrete liners, and scour protection mattresses) are visual or tactile. Level II inspections are not typically required unless marine growth must be removed from representative areas to judge the condition of the slope protection, as may be the case for concrete liners.

In some cases, it may not be feasible or practical to perform Level I inspections because of waves, currents, or restricted visibility, particularly for the offshore face of breakwaters. In such cases, it may be more cost-effective or technically advantageous to perform the inspection using Level III techniques such as sonar. Common sonar techniques include side-scan 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. Digital Global Positioning System or range-azimuth systems may be used to interface with the sonar system, tidal depth gauge, and so on to locate the anomaly for investigation.

3.4.9 Methods of Inspections for Channel Bottom or Mudline

Level I inspections on the channel bottom or mudline around structural elements are visual or tactile to evaluate scour or changes in the bottom conditions. Level II inspections are not typically required.

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

3.4.10 Structural Evaluation and Rating

A condition assessment rating should be assigned to each inspected structure in accordance with Chapter 2, Section 2.4.2. If significant damage or deterioration is observed that could affect the load-bearing capacity of the structure, then a quantitative engineering evaluation of the effect of the damage on the structural capacity should be conducted before assigning a condition assessment rating. Such a quantitative evaluation should typically be limited to the assessment of individual or typical components and the effect of the damage on the individual component capacity, without considering the actual or anticipated loading (structural demand). It is not the intent of a routine inspection to conduct a detailed structural analysis of the structure. Should the need for a more rigorous structural analysis be apparent as a result of a routine inspection, then an engineering evaluation should be recommended as a follow-up action.

3.4.11 Recommendations

On completion of the routine inspection, recommended actions should be assigned to the structure in accordance with Chapter 2, Section 2.5. In addition, the recommended interval to the next regularly scheduled routine inspection should be assigned by using the guidelines presented in Chapter 2, Section 2.1.4.

3.5 REPAIR DESIGN INSPECTIONS

3.5.1 Objectives

A repair design inspection should be conducted only after the decision to proceed with repair has been made. Data collected during a repair design inspection will be used to prepare contract bid documents for the repair of specific defects. Information gained from previous inspections should be used as appropriate to supplement the repair design inspection. Specific objectives of a repair design inspection may include

- documenting the location and size and selecting the method of repair for each defect or component to be repaired
- preparing quantity estimates for the repair project
- recommending appropriate follow-up action

On completion of the repair design inspection, bid documents are prepared for the repair work. Bid documents typically include drawings and specifications covering each aspect of the work, bid forms, repair quantity estimates, and estimates of probable costs of the repair work. Discussion of bid document preparation is beyond the scope of this manual.

3.5.2 Methods of Inspection and Documentation

The repair design inspection should include the documentation of only those defects that are intended to be repaired. For this reason, it is important to define specific repair criteria before executing the repair design inspection. Defects that do not meet this predefined repair criteria should not be recorded, thereby improving the efficiency of the field inspection work.

The information required to prepare contract bid documents from the results of the repair design inspection typically includes the following information for each defect:

- type of defect
- location of the defect on the structure (component ID)
- position of the defect on the component
- size of the defect
- method of repair for the defect

Documentation of size should always consider the size the defect will be after being prepared for repair, as in the case of concrete spalling. It also may be advantageous to assign a priority to each defect, because some defects will require repairs more urgently than others. Such prioritization will allow the repair project to be readily altered to focus on the most important defects if funding is restricted.

Ideally, the repair design inspection will be conducted very soon after the decision to repair the structure has been made (or immediately before repair work) and will focus on only the portions of the structure identified in previous inspections to be in need of repair. Should there be a lengthy time between the original inspection and the implementation of the repair work, additional investigation and effort may be required to inspect components that, although they did not require repair at the time of the previous inspection, might have sustained additional deterioration since and thus require repair.

The method of investigation used in conducting a repair design inspection may have significant implications on the amount of time required to conduct the inspection. The key to determining the appropriate method of investigation is to understand the types of repairs to be executed for the repair project. For example, if concrete piles on a wharf exhibit extensive underwater defects such as underwater cracks, then it is critical to know at the outset of the repair design inspection the cause of the cracks and whether the cracks will be repaired by jacketing, epoxy injection, sealing, or replacement. If the cracks are to be repaired by epoxy injection or sealing, then it will be necessary to record the location and size of each crack to produce repair plans and properly estimate repair quantities. However, if the cracks are to be repaired by jacketing, it may be sufficient to know only that cracks meeting the predefined repair criteria exist on the pile and that it should be jacketed. The specific attributes of each crack are irrelevant in this case. The difference in inspection time required to support these two scenarios may be very significant. The documentation of every defect requires removing all marine growth from each pile. By contrast, to establish whether cracking is present requires removing only enough marine growth to reveal cracks that meet the repair criteria. Therefore, it is critical to understand this issue and to tailor the methodology of conducting the repair design inspection to the repair method to be used.

In some cases, defects may be encountered during the repair design inspection for which the need to repair or the repair method is not clear to the inspectors. Such defects should be thoroughly documented using both measurements and photos for later review and decisionmaking.

3.5.3 Recommendations

On completion of the repair design inspection, recommended actions should be assigned to the structure in accordance with Chapter 2, Section 2.4. Typically, the structure should be ready to have bid documents prepared at this stage, using the results of the repair design inspection.

3.6 SPECIAL INSPECTIONS

3.6.1 Objectives

Special inspections should be conducted with a specific purpose in mind. Such purposes may include

- further quantification of the extent of the observed deterioration, where not readily apparent

- identification of the cause of observed deterioration to develop the appropriate repair method or to prevent it in the future
- determination of the structural significance that the observed deterioration has had on a structure
- determination of the significance of observed deterioration on future durability
- development of recommendation(s) for follow-up action

3.6.2 Methods of Inspection and Documentation

Special inspections may include field testing, laboratory testing, laboratory analysis, or a combination thereof. The scope of special inspections will be dictated by the type of testing or analysis to be performed. Standard test methods exist for many special inspection types. Such methods are typically defined by organizations such as the American Society for Testing and Materials (ASTM) and the American Association of State Highway and Transportation Officials (AASHTO).

Documentation obtained during the special inspection will vary greatly depending on the specific investigation technique and objective. Recorded information may include field testing results, laboratory testing results, and materials analysis results.

3.6.3 Recommendations

On completion of the special inspection, recommended actions should be assigned to the structure in accordance with Chapter 2, Section 2.5. 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 by using the guidelines in Chapter 2, Section 2.1.4.

3.7 REPAIR CONSTRUCTION INSPECTIONS

3.7.1 Objectives

A repair construction inspection should be ongoing with the repair construction, providing inspection at strategic points during the underwater work. Timely execution of the repair construction inspection often can prevent costly remobilization costs, back charges, and so forth. The primary objectives of the repair construction inspection are

- quality control to verify compliance with repair design documents
- verification of repair quantities for contractor payment

- response to field questions and resolution of field problems
- development of a list of deficiencies for which contractor is to take corrective action

3.7.2 Methods of Inspection and Documentation

Repair construction inspections are conducted during construction to ensure quality control for the underwater repairs. Additionally, field questions and problems are resolved to ensure that design intent and repair construction documents are properly interpreted and implemented and to help keep the project within the established budget and schedule.

The scope of repair construction inspections will be dictated by the repair methods used for specific projects. Repair construction inspections should be conducted throughout the repair process rather than at the end of the project, because the success and longevity of repairs often depend on proper surface preparation, and such preparation typically is visible only in process. For example, placement of a wooden pile post with a concrete collar around the mudline connection may require three phases of inspection: first, to ensure the soundness and elevation of the existing cutoff pile stub; second, to inspect the placement of formwork, internal reinforcement, and attachment of the wooden sections; and third, to inspect the final concrete placement and condition. However, repair construction inspection for patching a steel sheet pile wall may only require two phases of inspection: first, to confirm the proper surface preparation, and second, to visually confirm the quality of the underwater 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. Additionally, all underwater field problems and associated resolutions should be documented for future reference.

3.7.3 Recommendations

On completion of the repair construction inspection, a list of deficiencies should be prepared and presented to the contractor for resolution. This task should be done ideally on a continuous or periodic basis throughout the repair project.

3.8 POST-EVENT INSPECTIONS

3.8.1 Objectives

Post-event inspections should be conducted after a significantly potential damage-causing event such as a major storm, earthquake, flood, vessel impact, fire, a significant structural change, or a similar incident. The objectives are as follows:

- Conduct a rapid investigation to determine whether any underwater 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.
- Develop recommendation(s) for follow-up action.

3.8.2 Methods of Inspection and Documentation

Post-event inspections should be relatively rapid visual or tactile inspections. The focus of the post-event inspection should be on damage that was likely to have been caused by the event: breakage, overstressing cracks, buckling, settlement, slope failure, and so forth. 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 often can be observed and differentiated by noting fresh breaks or changes that are devoid of marine growth.

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

Major flooding typically should trigger an underwater post-event inspection for bridges over waterways, with the inspection focused specifically on scour assessment. The timing of such inspections should consider the possibility of backfilling scour holes during or after extreme water events. Similarly, major storms or tsunamis may trigger underwater post-event inspections of breakwaters or other structures in the path of the event. Many US waterways have United States Geological Survey (USGS) Web sites with real-time and historical flow data. Similarly, USGS marine buoys record historic wave height, wave period, wind speed, and direction.

Alternatively, damage caused by earthquakes or vessel impacts on structures such as pile-supported waterfront facilities often occurs both above and below water. The below-water post-event inspection therefore may 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 or economic impact.

The methodology of conducting an underwater post-event inspection should depend on 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 should typically be removed on a representative sampling of components in accordance with the Level II inspection requirements described in Section 3.1.3.

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

3.8.3 Rating and Recommendations

A post-event condition rating should be assigned to each inspected structure in accordance with Chapter 2, Section 2.4.3. This rating system is different than 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. It is not the intention of a post-event inspection 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, repair design inspection, or engineering evaluation should be assigned as appropriate in accordance with Chapter 2, Section 2.5.

Chapter 4

DOCUMENTATION AND REPORTING

4.1 GENERAL

An engineering report, including documentation, generally provides a systematically organized record of the underwater inspection and the conditions encountered during the inspection; the analyses, assessments, and judgments made by the responsible engineer; and recommendations for future use and remedial measures. The report may range from a relatively 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 facility 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 structure's existing condition; the anticipated use and distribution of the final report; and the potential for public involvement and litigation related to the facility.

The type of report to be prepared may influence the extent of data collection and documentation necessary, but even relatively simple letter reports, which essentially 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 of the report.

4.2 ROUTINE INSPECTION REPORT

The following section describes the contents of a comprehensive report for a routine inspection. Some items may not apply to all reports, and additional items may be essential to some reports. Although the length, detail, and organization of specific items within a report may vary, reports generally should include the following sections.

4.2.1 Introduction.

- Scope of work, including enumeration of any items specifically excluded, and any limitations on inspection, or analysis dictated by the owner or site conditions.
- Description of the facility, including the availability of original design drawings. This section may include information on usage and loadings.
- Description of the inspection, testing, and analysis methods. If lengthy, this information may also be included in one or more appendices.
- Administrative details, such as coordination and point-of-contact information.

4.2.2 Existing Conditions. This section should include the results of the underwater inspection, any special testing accomplished in the field, and the results of any laboratory testing. The inspection information should be reported in a factual manner without comment or analysis at this time. This section serves as the basis for further assessment and evaluation and should contain only data that is reproducible and would be accepted by another competent engineer conducting a similar inspection. These results should be documented with notes, sketches, still photography, and videotape as appropriate. This section, or the Introduction, will generally contain drawings depicting the structural configuration of the structure.

4.2.3 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 previous 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, then comments on changes since the previous inspections and estimates of rates of deterioration should be included. If a reported condition has not had an adverse effect on the structure, that should be noted. This section may also contain a narrative description of causes contributing to the observed conditions as well as the engineer's assessment of the structure and the rationale for that assessment. If a numerical condition assessment rating system is used, such as described in Chapter 2, then that rating should be assigned. Although the assessment should be based on sound engineering judgment and accepted standards of good practice, the assessment and the recommendations that proceed from the assessment may vary between engineers.

4.2.4 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; and recommendations for future inspection frequency and levels of inspection effort.

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

4.3 DOCUMENTATION

The type and extent of documentation of existing field conditions will usually be defined in the scope of work or agreement for the work. Documentation may vary from handwritten field notes to underwater still photography and videotapes. The type of documentation required can have a significant effect on the cost of conducting an underwater inspection.

Detailed field notes and sketches should always be prepared and maintained as a record of the inspection. They may be handwritten or may be produced with the use of field hand-held computer devices. Written field notes should be prepared with the care that would be used for survey notes; they could become a part of legal proceedings. The level of detail necessary will depend on the type of inspection being conducted. An inspection made in anticipation of preparing repair plans and detailed cost estimates, for example, would generally be more detailed than those prepared during a routine inspection.

Underwater color photography can be used to depict both typically defective and sound areas of the structure. Still photography in clear, calm water is relatively inexpensive. In turbid waters, where special techniques such as a clear water box must be used, or in high current, the cost increases. However, the value of photographs, especially to a lay audience, usually outweighs the cost. Photographs can be extremely useful to illustrate conditions in order to obtain funding and to assist in the evaluation and preparation of repair documents. The additional cost for most inspections is relatively small.

Typical conditions should be photographed, but not every defect needs to be shown in the photograph. A minimum number of photographs may be required at each structure, including overall views of the facility, but there should be flexibility in the scope of work to permit reducing the number of photographs when the structure is in good condition. Quality of the photographs should be assessed before leaving the geographic area of the inspection.

Underwater videotapes also may be used for documentation, alone or in combination with still photography. Videotaping may require more diving time than still photography; additional time may also be required to view and edit the tapes. The video camera should record the diver's comments and descriptions, and later editing may be used to add to or clarify comments. Video documentation of an entire structure is almost never warranted. The value of video documentation is limited by the ability of the diver to recognize the significance of underwater conditions and point the camera at those conditions. Videotaping is not considered a substitute for using qualified personnel as described in Chapter 2.

In videotaping, much meaningless material is recorded: starting, stopping, moving among substructure units, adjusting lighting, and malfunctions. If an engineer or owner has to review hours of tape, he quickly will become inattentive. Original copies of the videotapes should be maintained, but editing may be used to produce an executive summary and to remove meaningless portions of the recordings. The use of an on-screen clock or counter will be useful in reviewing the tapes and finding specific portions.

Chapter 5

ADMINISTRATIVE CONSIDERATIONS

5.1 AGREEMENTS

Underwater assessments may be conducted by the facility owner's staff members or by independent engineering organizations engaged for a particular assignment. The use of independent engineering organizations or consultants may be advantageous to the owner because of specialized expertise and equipment that could be available for a particular task.

The final agreement between the facility owner and an independent engineer should be developed after discussion and mutual understanding of the scope of the project. The agreement may contain specific tasks to be performed but should permit adjustment of the scope of the assessment by the consultant based on findings as the work progresses.

The scope of services generally contains the following items:

- description of the facility to be inspected, including its limits and an estimate of the number and type of structural components
- statement of the purpose and type(s) of inspection(s)
- list of deliverables (for example, engineering report, repair drawings, and cost estimates)
- statement that the extent of the inspections to be conducted may be revised, after an initial field assessment, to concentrate the work in areas determined to be more significant to the condition of the structure
- acknowledgment that good engineering practice may, in some situations, not require inspection of all elements
- description of the content of reports, if appropriate (for example, existing conditions, engineering assessment, recommendations, estimates of probable cost, and detailed lists of defects)
- time for completion and times for intermediate submissions, including a statement that it is recognized that weather and water condi-

tions, over which the consultant has no control, may delay completion of the work
- statement that all work shall be conducted under the direction and direct control of an engineer licensed or registered, as appropriate, in the jurisdiction of the facility

The owner and the consultant should agree on the method and amount of compensation for the work. Because of the specialized nature of the work, the special equipment that may be needed, and the effect that weather and water conditions may have on the work, provisions should be included to compensate the engineer for changes in conditions beyond his or her control.

The owner of the facility 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.

5.2 INSURANCE

All types of engineering field and office work have associated risks. Work in and over water poses special risks. Careful planning and conduct of the work can reduce those risks to some extent, but insurance also should be required and in many instances is required by law. An understanding of the proper insurance requirements is essential to protect the individual employee, the general public, consultants, and client organizations involved in or affected by the work. The types of insurance coverage that are required for a particular project vary but may include comprehensive general liability and property damage insurance, automobile liability and physical damage insurance, workers' compensation (WC) insurance, United States Longshoremen's and Harbor Workers' Insurance, Jones Act Maritime Insurance, and professional liability insurance. Some owners or governmental agencies also may 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, may be provided by individual policies in each of these categories or may be provided by basic policies in conjunction with an umbrella policy to raise the limits of the underlying policies.

5.2.1 Comprehensive General Liability and Property Damage Insurance

Comprehensive general liability and property damage insurance can provide a wide range of coverage to protect the engineer and owner from losses and claims due to personal injury and damage to the property of the owner or third parties. This policy normally would cover damage caused by the engineer's operations, but special endorsements may be necessary to cover watercraft operations. Typical coverage limits range from $1 million to $5 million.

5.2.2 Workers' Compensation Insurance

WC insurance is basically 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 does not have to prove his or her employer was negligent to be compensated for medical expenses and lost time, or for a partial or complete disability. This insurance requirement is mandated by the state, and its benefits are administered by individual state boards. WC provides coverage for work on land and on, over, under, or adjacent to waters that are considered to be nonnavigable.

The WC rates for diving operations are quite high, in the order of 35%–50% or higher, of direct labor costs. These high rates apply even to relatively 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 in deep, dangerous locations.

5.2.3 Longshoremen's and Harbor Workers' Insurance

US Longshoremen's and Harbor Workers' (USL&H) Insurance is similar to WC insurance, but it provides coverage for employees working on, over, and adjacent to navigable waters of the United States. It is a federally mandated insurance and generally provides greater benefits to the employee than WC insurance. Benefits are monitored by a federal board, but the coverage must be purchased from a private insurance company. WC insurance coverage does not include USL&H coverage unless it is specifically added as an endorsement to the WC policy. The determination of when state WC laws apply and when the US Longshoremen's and Harbor Workers' Act applies is not always apparent, especially in cases when the location where the injury or disability occurred is not clear or when the limits of the navigable waterway are not well defined.

5.2.4 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 crews on vessels. Because divers and their support personnel may at times work from a boat, Jones Act Maritime Insurance may apply to some underwater inspections. In the past, it generally was not considered applicable to diving work unless the diver was regularly assigned to a vessel. Court decisions on this coverage, however, have not been consistent, and prudence would dictate that the coverage be provided for underwater inspections to prevent a possible gap in the coverage.

5.2.5 Professional Liability Insurance

Professional liability insurance, sometimes called errors and omissions insurance, protects the engineering consultant from claims by the owner or third parties alleging malpractice and similar professional errors. If, for example, an engineer made an error in the inspection and evaluation of a structure that later led to injuries, property damage, contractor's claims for extras, owner's claims, or similar claims, the professional liability insurance would be available to protect the client or owner. In today's litigious society, professional liability limits of at least $1 million are appropriate.

5.2.6 Certificates of Insurance

Certificates of insurance are issued by insurance companies or their authorized representatives (usually insurance brokers) as evidence of the insurance coverages provided. 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 also will indicate a minimum number of days' notice that will be given to the certificate holder before cancellation of the insurance. It also may indicate special endorsements such as the inclusion of additional insured parties.

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.

The consultant should, as a minimum, provide evidence of insurance that includes professional liability insurance, a comprehensive general liability insurance (personal injury and property damage) that includes automobile insurance for vehicles on the site; WC insurance; USL&H Insurance, when working in or adjacent to navigable waters; and Jones Act Maritime Insurance, when working from a vessel. Coverages should be specifically enumerated on the insurance certificates provided by the insurance company or its authorized representative. These and other coverages may be mandated by law. Those enumerated here are for work in the United States. Similar coverages should be provided in other countries.

Appendix A

SPECIAL CONSIDERATIONS FOR SPECIFIC STRUCTURE TYPES AND SYSTEMS

This appendix is meant to serve as a general reference document for users and providers of underwater investigation services. Its purpose is to provide a general description of the most common problem areas associated with underwater 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, it is not possible to present an all-inclusive listing of what to look for during an underwater investigation at a specific site. Instead, the information contained in this appendix should 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 here refer primarily to considerations during routine inspection and generally would not apply to other types of inspections, which may be focused on specific areas.

A.1 BRIDGES

A.1.1 General Description

The American Association of State Highway and Transportation Officials (AASHTO) defines a bridge as "a structure including supports erected over a depression or an obstruction, such as water, highway, or railway, and having a track or passageway for carrying traffic or other moving loads, and having an opening measured along the center of the roadway of more than 20 feet between undercopings of abutments or spring lines of arches, or extreme ends of openings for multiple boxes; it may also include multiple pipes, where the clear distance between openings is less than half of the smaller contiguous opening."

Underwater inspections are conducted to supplement above-water inspections by focusing on substructure bridge elements that cannot be visually inspected from above because of excessive water depths or turbidity. A typical underwater inspection will include each submerged bridge substructure component from the mudline to the high water line. It also should include measurements of bottom scour (or infilling/siltation) and an evaluation of protective fender systems in navigable waterways.

A.1.2 Basic Techniques

Before beginning any underwater bridge inspection, the inspector should conduct two fundamental and often overlooked visual procedures. First, each side of the bridge should be sighted (with the naked eye or with binoculars) parallel with its axis to check for any apparent vertical or horizontal misalignment. The ideal vantage point would be at or near the roadway elevation. Second, sighting along each side of, and parallel to, each pier or pile bent would check for plumb. The best vantage point probably would be from a boat, upstream or downstream. If misalignment or an out-of-plumb condition is detected, it likely will indicate a problem with one or more substructures.

Another advisable approach is to perform soundings at each pile bent or pier before the physical dive inspection. The soundings then can be compared with construction drawings to determine what the inspector should look for or what might be expected underwater. For example, an inspection can be significantly more effective if the inspector knows to look for a likely exposed or undermined footing, as might be indicated by elevation comparisons.

A.1.3 Typical Underwater Components and Common Problem Areas

Bridge substructures generally are divided into three main types: abutments, piers, and pile bents. The function of a substructure is to transfer loads imposed by the bridge superstructure and other loads acting directly on the substructure, such as wind and water currents, to the underlying soil or rock foundation. In addition to their function as the primary load-transfer component in a pile bent, piles also may be used as deep foundations for abutments and pier footings.

Table A-1 summarizes the specific components of the different types of bridge substructures and the typical areas of concern for each component. Issues dealing with bottom scour and fender systems are also included.

A.1.3.1 Abutments. Abutments are located at each end of a typical bridge. The basic components of an abutment include the cap or bridge seat on which the superstructure rests, columns or walls that transfer

TABLE A-1. Checklist for Underwater Inspections: Bridges

Component and Section/Part	What to Look For	Comments
Abutments		
Cap/Seat	Alignment (rotation) Shear failure Deterioration Condition of bridge bearings	May need to be inspected by divers if not accessible by other means.
Columns/ Walls	Check for alignment and plumb, signs of backfill loss Deterioration of surfaces, physical damage	
Footings/ Piles	General condition Bottom scour, undermining of foundations, exposure of piles (for piled foundations)	For pile foundations, check for deterioration at pile–footing interface if accessible.
Piers		
Cap/Seat	Alignment (rotation) Shear failure Deterioration and physical damage Condition of bridge bearings (if not conveniently inspected from above water)	
Columns/ Walls	Check for alignment and plumb Deterioration of surfaces, physical damage Accumulation of drift or debris	
Footings/ Piles	Same as for abutments	
Pile Bents		
Cap/Seat	Alignment (rotation) Deterioration, physical damage, signs of distress at pile connections	
Piles and Bracing	Damaged or displaced piles, alignment (straightness) of piles from top to bottom, scour pits at mudline Deterioration of piles Loose or missing bracing members, condition of connections and hardware Accumulation of drift or debris	
Fenders	Alignment (displacement), missing or damaged members or components Condition of hardware Accumulation of drift or debris	
Channel	Scour patterns, migration of channel, accumulation of drift or debris	

loads from the bridge seat, and footings or piles that transfer the loads into the underlying soil and rock. The abutments may also function as retaining structures for the approach roadway fill.

Unless the abutments are retaining structures, they typically will be obscured from view by the approach roadway fill on the back side and protective riprap on the channel side. In this case, because they may not be designed to resist lateral loads and typically may support only about half of the normal superstructure span load imposed on an interior bent, the footing or pile depths could be relatively shallow.

Channel scour that exposes the abutment components could subject them to lateral loads or undermine them altogether. Exposure also could accelerate deterioration because the materials may not have been treated or coated for direct exposure to the environment.

If the abutments are designed as retaining structures, the lower parts of the abutment walls may be located below water and subject to the same kind of deterioration as the piers. Again, the channel bottom should be checked for excessive scour that could have altered the design conditions and lateral design loads for the abutment. Undermining of the foundations and potential loss of bearing area for footings or exposure of piles would also be a concern.

A.1.3.2 Piers. Similar to bridge abutments, the basic components of a bridge pier include the cap or bridge seat on which the bridge superstructure rests, columns or walls that transfer loads from the bridge seat, and footings or piles that transfer the loads into the underlying soil or rock. However, unlike most bridge abutments, bridge piers are typically exposed to wind, wave, water current, and ice forces, as well as to the erosive and corrosive effects of the environment. The pier columns or walls typically rest on a footing that is either supported directly on a firm strata such as rock or shale or on piles driven into an underlying strata. Unless excessive scour has occurred, the footings probably will not be exposed, limiting the inspection to the column or wall surfaces. They should be thoroughly examined for cracks, spalls, and impact damage or other types of deterioration relevant to the material in question. The surfaces of exposed footings should be similarly checked.

Footings resting on firm strata should not be undermined. If this condition is encountered, the stability of the pier is likely in question. Footings resting on piles may be found undermined. Each pile should be checked for cracks, spalls, corrosion, marine borers, and other damage. When the piers have been subjected to excessive lateral loads or impact, shear cracks in concrete piles usually occur at or near the pile/footing interface. A close inspection at that location is advisable.

Seal slabs of low-grade, unreinforced concrete should not be confused with the footings. Typically, they are of no structural significance after construction. However, exposed seal slabs usually indicate excessive bottom scour, and poor-quality concrete may expose untreated or uncoated piles to the environment. This condition is particularly worrisome in older bridges, which often were constructed with untreated timber piles.

In some cases, drilled-shaft concrete columns are used to transfer loads directly from the bridge seat into the underlying soil strata. The columns may have been formed in a permanent pipe casing that will extend some length up the column from the mudline. Inspection in this case will be limited to the exposed underwater concrete surfaces.

A.1.3.3 ***Pile Bents.*** The basic components of a bridge pier include the cap or bridge seat on which the bridge superstructure rests and the piles that transfer the loads into the underlying soil or rock. Typically, some of the piles are battered to resist lateral and longitudinal loads. Piles may be steel, concrete, or timber. Each pile should be inspected from waterline to mudline to check for cracks, spalls, impact damage, corrosion, abrasion, or marine borer damage, depending on the pile material.

Composite piles of reinforced concrete with an embedded steel pile end for driving are often encountered. The steel pile sections may not be coated, and excessive bottom scour could have exposed them. Special care should be taken to locate these exposed steel sections, because marine growth may obscure or disguise them; they may appear to be a continuation of the concrete pile.

Timber pile bents often are braced with treated wood connected with galvanized hardware. The ends of submerged bracing members are particularly vulnerable to marine borers because field cutting may have exposed the untreated inner core. Likewise, submerged hardware, or hardware in the splash zone, should be examined carefully for loss caused by corrosion.

A1.3.4 ***Fender Systems.*** In navigable waterways, fender systems usually are installed on each side of the channel to protect the adjacent piers or pile bents. Center-located swing-bridge piers are similarly protected. Fender systems typically consist of vertical and batter piles connected with horizontal "rub rails." The most common material is treated timber, but steel and concrete piles also can be encountered. Dolphins consisting of tied pile clusters are found commonly at the ends of the timber fender system. The piles, rails, and hardware should be checked for damage to ensure that they are still protecting the bridge substructure.

A.1.3.5 ***Bottom Scour.*** As previously noted, bottom scour can expose components of the pier footing and piling that are not meant to be exposed. One concern with this unplanned exposure is material deterioration that can lead to structural weakening. Another concern is loss of pile capacity caused by embedment loss or an increase in the unsupported length of the pile. Under extreme conditions, the slenderness ratio of a pile can be exceeded or a pile could be completely undermined, in which case it becomes an external load that must be carried by other piles.

A.1.3.6 Drift and Debris. The inspection should include a rough quantification of the drift (floating) and debris (sunken) material that has been lodged against the upstream face or edge of piers and pile bents. A large accumulation could subject the substructure to unusually high lateral loads caused by water currents against the surface area of the accumulation. Bottom scour also might be accelerated in areas where accumulation has significantly reduced the channel cross section.

A.2 OPEN-PILED STRUCTURES

A.2.1 General Description

Open-piled structures generally consist of a solid deck supported on piles driven or drilled into the bottom. They are commonly used in various configurations as piers, jetties, dolphins, and as marginal wharves at ports and other marine facilities. Horizontal loads on the structure are often resisted by batter piles, but vertical-only pile structures are becoming increasingly common. In such cases, frame action and moment connections between the deck structure and the vertical piles can be used to absorb horizontal loads.

Open-piled structures can be constructed of concrete, steel, composites, timber, or a combination of these materials. To a large extent, deterioration patterns for the various structures are directly related to the materials used. However, some of the common areas of concern are highlighted in this section.

Currently, the most common material used for the deck of an open-piled structure is concrete because of its durability, versatility, and ability to support heavy loads. Timber decking is common on lightly loaded structures and was historically predominant for decking and decking substructure because of its availability and ease of construction. All-steel decking (e.g., heavy-duty steel grating) is also found at modern port structures.

The supporting substructure of an open-piled structure may be composed of piles, pile caps, and bracing, depending on the material used. The substructure may be steel, concrete, or timber and does not have to be of the same material as the deck structure.

A.2.2 Typical Underwater Components and Common Problem Areas

The deck of an open-piled structure usually is located above the intertidal or flood zone. However, in some instances, the underside of the deck becomes partially submerged on a regular basis or, because of site constraints, can best be inspected by a diver. The underwater portions of the structure include piles, bracing, and pile caps. In addition, some structures may have fender system and cathodic protection system components located below the waterline.

Table A-2 is a summary of some of the common problem areas associated with the underwater components of open-piled structures.

A.2.2.1 Deck. The underside of the deck structure should be inspected by the underwater team if the deck is located close to the waterline or if the underside of the deck is accessible only by an inspector in the water (i.e., a

TABLE A-2. Checklist for Underwater Inspections: Open-Piled Structures

Component and Section/ Part	What to Look For	Comments
Deck Structure		
Underside of Deck	General condition and deterioration of decking and expansion joints	May need to be inspected by diver if inaccessible by other means.
Fenders	Torn, damaged, or aging (if rubber) fenders; integrity and condition of hardware	
Pile Caps		
System	Alignment (rotation)	
Surfaces	Deterioration, physical damage, signs of distress at pile connections	
Piles		
System	Damaged or "missing" piles, alignment (straightness) of piles from top to bottom, scour pits at mudline	
Surfaces	Deterioration, mechanical damage	Special concerns:
		Accelerated rates of erosion or corrosion for steel piles in splash zone, at mudline, and at welded splices
		Loss of cross section at waterline due to ice abrasion
Bracing		
System and Surfaces	Loose or missing members, general condition of bracing and connections	

"floater"). In many case, the inspector must swim under fendering or other structural features to gain access to the underside of the pier. The kinds of deterioration to look for depend on the deck material; areas meriting particular attention may include deck expansion joints, hardware attachments, and anchor bolts.

A.2.2.2 ***Pile Caps.*** Pile caps, in general, are the structural members that transfer load from the deck to the piles. The pile cap should be inspected for potential dislocation or overstress at the joint between cap and pile, particularly in areas of force concentrations such as at batter piles. The kind of deterioration to expect depends on the material of the pile cap.

A.2.2.3 ***Piles.*** Piles need to be checked for general condition and for mechanical damage that could result in loss of pile strength. Piles located near the edges of the structure are particularly susceptible to impact damage and should be checked for misalignment, dents, spalls, damage to protective coatings, and other signs of physical damage.

Ice may cause damage to open-piled structures in several ways. Floating ice could strike piles along the exterior face of the structure. Vertical jacking of piles may be a concern in areas of fluctuating water levels where the piles are embedded in surface ice. Surface ice is also known to accelerate corrosion and abrasion of the pile at the waterline caused by repeated rubbing from the ice layer.

Other areas of concern include scour at the mudline caused by currents and propeller wash. Deep scour pits can increase the unbraced length of the pile, thereby affecting its bearing capacity.

A.2.2.4 ***Bracing.*** Bracing should be checked for loose or missing members and for overall condition, with particular care given to the ends and the connections where deterioration may occur more rapidly. Mechanical connections (e.g., bolts) must be checked for integrity and corrosion. Protective coatings should be inspected for mechanical damage and signs of deterioration.

A.3 GRAVITY AND RETAINING STRUCTURES

A.3.1 General Description

Gravity structures are generally cellular structures filled with granular material that rely on their weight for stability. The structural cells can consist of steel, concrete, or timber. Gravity structures are used as piers, jetties, marginal wharves, breakwaters, and numerous other applications in the marine environment.

Retaining structures are shoreline structures that usually define a shoreline boundary and retain upland soil. They can be broken down into three primary groups depending on the structural configuration: bulkheads, revetments, and gravity seawalls.

A.3.1.1 Gravity Structures. The cellular types of gravity structures used in ports and harbors generally fit into one of three basic categories: sheet pile cell structures, concrete crib structures, or timber crib structures. The stacked-block seawall and the concrete buttress wall, both usually used as retaining structures, also can be considered gravity structures.

The *sheet pile cell structure* consists of enclosed circular cells filled with granular material and usually capped with concrete. The cells can be individual and freestanding, or interconnected in various configurations to form a continuous structure. Possible failure modes for a sheet pile cell structure include sliding on its foundations; vertical shear failure in the cell fill or between the fill and the sheeting; and failure of the sheet piling as a result of corrosion, interlock tension, or physical damage.

The *concrete crib structure* (or *concrete caisson structure*) generally consists of a precast concrete box with dividing interior walls, filled with granular material and capped with concrete. The cribs usually are built in two stages. The bottom section is built in the dry (on land or in a dry dock), and the upper walls are added while the crib is floating. The finished cribs are then floated out into position, sunk onto a prepared bed, and filled with ballast. Potential failure modes for concrete crib structures include sliding and foundation failure as well as concrete overstress and deterioration.

Timber crib structures consist of cellular open- or closed-face compartments, with or without floors, formed with timbers. The cribs usually are built on land and then floated out to location and sunk onto a prepared gravel bed. The crib compartments are then filled with rock and decked with timber or concrete. Timber cribs, being quite flexible, are less sensitive to differential settlement than are concrete cribs. Although relatively rare in new construction, timber cribs were widely used in the past, particularly in rivers, on the East Coast, and in the Great Lakes.

Stacked-block seawall structures historically were built with cut stone placed on sunken timber mats, with little quality control in the deeper regions. Modern seawalls are typically constructed of cast-in-place concrete or precast concrete block and precast concrete interlocking units filled with earth after placement. Cyclopean seawalls are mass gravity structures composed of large stones (up to 4–5 tons) bonded together with concrete. Such seawalls can have vertical or sloping faces.

The buttress wall consists of a concrete face wall and footing, generally in an L-shape, stiffened with concrete counterforts and backfilled with earth to form a retaining structure. For stability, the structure relies on the weight of the backfill. The wall sections can be built in situ in the dry at locations where dewatering is possible, or they can be precast in sections and lowered into place using cranes.

*A.3.1.2 **Retaining Structures.*** The most common type of retaining structure at marine facilities is the bulkhead, which consists of vertical interconnected sheeting driven into the soil to form a solid face and then backfilled on one side. Bulkheads can be cantilevered or anchored. The cantilever bulkhead relies on the bending capacity of the sheeting and embedment in the underlying soil for its stability. The anchored bulkhead is tied back to an anchoring system at one or several levels between the mudline and the top of the wall. The tieback system may be made of buried steel rods connected to a deadman or of ground anchors drilled into soil or rock. Materials used for bulkheads include interlocking sheet piles of steel, timber, or concrete as well as panels of concrete, timber, vinyl, or other materials between intermittent steel or concrete soldier piles. The routine underwater inspection typically focuses only on the exposed face of the bulkhead; except for exposed fasteners and tie-rod ends, the anchor system and other buried components need to be inspected by other means.

Revetments may be considered a type of retaining structure insofar that its main purpose is to protect or "retain" the earth slope behind it. In general terms, a revetment is an armored, sloped bank that fronts an open coastline, river, or lake. Riprap revetments consist of armor rock placed on a filter layer of smaller rock or on an artificial membrane (e.g., filter fabric). Gabion revetments typically consist of rock-filled wire baskets. Gabions can be constructed of different dimensions and can be stacked to create a stepped, near-vertical wall similar to the stacked-block gravity wall. The basket wire for gabions is usually galvanized but may also be vinyl coated for increased corrosion protection. Concrete also is used as a revetment material, either cast in place or precast (e.g., fabric mats can be laid out over a slope and then pumped full of concrete or grout, or interconnected precast concrete blocks can be preassembled into large flexible mats).

All the gravity structures mentioned in Section A.3.1.1 also can be used as retaining structures.

A.3.2 Typical Underwater Components and Common Problem Areas

As with other marine structures, deterioration of gravity and retaining structures directly depends on the material used in the construction and the environment to which it is subjected. However, some of the typical problem areas that are common to the specific types of structure and not necessarily related to material degradation are briefly described in the following section. Table A-3 is a summary of this information.

TABLE A-3. Checklist for Underwater Inspections: Gravity and Retaining Structures

Structure and Section/Part	What to Look For	Comments
Sheet Pile Cell Structures		
System	Misalignment and plumb of structure, bottom scour	
Steel Sheeting	Split interlocks caused by stress or impact; corrosion or abrasion	
Concrete and Timber Crib Structures, Buttress Walls		
System	Plumb of individual units, differential settlement between units, bottom scour, and undermining of foundations	For timber cribs, bulging of face timbers may suggest loss of support from interior cross timbers.
Concrete/Timber Surfaces	Surface deterioration, signs of overstressing, mechanical damage, condition of joints between units	For timber members, check condition of connectors.
Stacked Block and Cyclopean Seawalls		
System	Misalignment of wall, signs of settlement or instability, bottom scour	
Units	Surface deterioration, integrity of individual units, loose or missing blocks or stones, condition of joints between units	
Bulkheads		
Sheeting	Plumb of structure, integrity of interlocks, corrosion and abrasion, impact damage, bottom scour	
Anchorage	Condition of connecting elements at face of sheeting	
Revetments		
System	Slope alignment, signs of settlement or instability (slip failures), toe erosion	
Protective Surface Layer	Integrity of layer, displacement of individual stones, condition of gabion basket wire	Ice pile-ups may cause gouging of riprap or "plucking" of armor stones.

A.3.2.1 Gravity Structures. Because all gravity structures rely on their own weight for stability, the integrity of the structure and the foundations becomes particularly important. Accordingly, areas that require special attention during an underwater inspection include the foundation and the containment skin of the structure. Some common causes of concern for the different kinds of gravity structures are as follows.

A.3.2.1.1 Sheet Pile Cell Structures.

- overdredging or bottom scour near the structure, resulting in instability (tilting) or overstressing of the interlocks
- splits in interlocks from improper installation or from overstressing, causing loss of cell fill and reduced structural integrity
- ship impact damage
- excessive corrosion or abrasion from waves and ice, particularly in the splash zone

A.3.2.1.2 Concrete and Timber Cribs, Stacked-Block or Stone Seawalls, and Buttress Walls.

- loss of foundation support at the toe of the structure caused by overdredging or scour, resulting in instability and excessive stresses
- differential settlement of individual units, causing joint displacement and cracking of units and possible loss of fill
- impact damage caused by vessels, ice, or floating debris
- timber and joint hardware deterioration, causing dislocation of crib face timbers and potential loss of fill (for timber cribs)
- concrete deterioration caused by corrosion, volumetric expansion, and so forth
- in cyclopean seawalls, loss of bond between concrete and stones causing unraveling

A.3.2.2 Retaining Structures. As for the gravity structures, the integrity of the "skin" and the stability of the foundation are of particular relevance to the retaining-type structures. For instance, all bulkheads depend on the toehold of the sheeting for stability. Loss of ground at the toe caused by overdredging or scour can therefore have a detrimental effect, causing overstressing and bulging of the sheeting or complete failure and dislocation at the toe. Impact damage is another cause for concern, as is the presence of any split interlocks. As with all marine structures, higher rates of corrosion or abrasion can be expected in the splash zone, especially at anchored bulkheads, because the anchor hardware is usually located at or near the waterline.

Revetments also need to be investigated as to the integrity of the surface layer (the "skin") and the stability of the foundation. Although some types of revetments are less sensitive to foundation settlement (e.g., riprap), the consequences for other types could be more severe (e.g., cracking and disintegration of cast-in-place concrete mats, displacement and breakage of gabion baskets). Scour at the toe of the revetment is another possible cause for concern. As for the integrity of the skin, displacement of riprap armor caused by wave attacks should be checked. Gabion basket wire may be susceptible to corrosion and abrasion damage, causing potential unraveling of the revetment. In colder regions, the gouging of riprap by ice pile-ups and the plucking of armor units by surface ice also may be concerns.

A.4 MARINAS

A.4.1 General Description

Marinas and small-craft harbors may consist of various marine structures, many of which are common to other types of port facilities. Open-piled piers, bulkheads, timber cribs, and breakwaters may form part of a marina and are described elsewhere in this appendix. This section deals specifically with marine underwater components that are unique to marinas, such as floats and anchor systems, wave attenuators, and utilities and outfalls. Table A-4 summarizes some of the more common problem areas associated with the underwater components specific to marinas.

A.4.1.1 Floats. Floating docks at marinas typically consist of floating units that are anchored by piles or by chains and anchors. Floats can be made of many materials, such as timber, concrete, aluminum, metal, or composites. Hardware used for floats is generally hot-dip galvanized.

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 floatation billets to improve buoyancy. *Concrete floats* are one of the more common types of modern floats. They usually are made from lightly reinforced or plain concrete and can be hollow or filled with foam. *Fiberglass floats* are similar to concrete floats as to the type of construction. They usually are ballasted for stability because they tend to be quite lightweight and therefore potentially unstable. *Metal floats* are commonly used as floating docks. The flotation units may consist of sealed pipes or rectangular pontoons and may be steel or aluminum.

Other materials used in float construction include foam and rubber. These materials are also used in conjunction with some of the other materials noted above. Foam billets may need to be coated to protect against deterioration caused by fuel and oil in the water.

TABLE A-4. Checklist for Underwater Inspections: Marinas

Component and Section/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 or excessive marine growth.
Shell	Surface deterioration, physical damage (dents and holes) Loose or leaking access hatch covers	Check for waterlogged filler.
Joints between Float Units	Damaged, loose, or deteriorated connecting hardware Excessive float misalignment	
Fenders/Rubbing Strips	Deterioration, missing or loose members, condition of hardware	
Anchors and Anchor Chains		
Anchor Chain and Connecting Hardware	General condition, wear and corrosion, distortion	
Anchors	Misalignment or movement, instability, inadequate embedment	
Cathodic Protection	See Section A.14, Cathodic Protection Systems	

continued on next page

A.4.1.2 Anchors and Anchor Chains. Anchors for marina floats usually consist of precast concrete blocks or mushroom anchors placed directly on the bottom. They are most suitable for soft bottom conditions where they can improve resistance against sliding. Screwed-in helical piles also may be used as anchors. Chains usually are used to secure the float to the anchor.

A.4.1.3 Anchor Piles. Materials used for anchor piles may be steel, concrete, timber, or composites. The design of the anchor system usually allows for vertical movement in response to fluctuations in water level. The connection between float and pile is a critical system component subjected to heavy wear and repeated load reversals. However, this connection is usually located above the waterline.

TABLE A-4. *Continued.*

Component and Section/Part	What to Look For	Comments
Anchor Piles		
System	Damaged or "missing" piles, alignment (straightness) of piles from top to bottom	Check for "ice jacking" in cold climates.
Surfaces	Deterioration, wear and corrosion, mechanical damage	Special concerns: Integrity and condition of pile–float connection
Wave Attenuators		
Fixed Supporting Structure (Piles, Pile Caps, Deck)	See Section A.2, Open-Piled Structures	Check for bottom scour caused by down-rush of waves.
Floating Supporting Structure (Floats and Anchor System)	See applicable structure component above	
Wave Reflection Panels	Damaged or missing panels, surface deterioration, loose or deteriorated connecting hardware	

A.4.1.4 Wave Attenuators. Commonly found at marinas to reduce the effects of wind-driven waves or boat wakes, wave attenuators are most efficient for short-period waves and may consist of fixed or floating structures.

The fixed structure is typically composed of an open-piled structure with vertical wave-reflection panels that protrude below the waterline. The transmitted waves are primarily reduced in height by reflection. The fixed structure may be constructed of steel, timber, concrete, composite materials, or a combination of these materials.

The floating wave attenuator usually is composed of floating dock sections, often complemented with vertical reflection panels that extend below the floats. The transmitted wave energy is dissipated in three ways: reflection by the float and the panel, friction as the wave passes under the floating structure, and inertia from the vertical and horizontal movement of the floating system. The floating docks can be constructed of timber, steel, aluminum, concrete, or composite materials.

A.4.1.5 Utilities and Outfalls. Utilities (potable water, electrical cables—including cable TV and telephone—and piping for sewage pumpouts) as well as storm sewer outfalls for upland drainage usually are found at marinas. The underwater components of these installations should be inspected as outlined in Section A.6, Pipelines and Conduits. Special care should be taken to check the conditions of flexible utility sections that span individual float units.

A.4.2 Typical Underwater Components and Common Problem Areas

A.4.2.1 ***Floats.*** Divers must inspect floating docks that are actually in the water at time of inspection. Typical problems encountered on floats usually are related to deterioration of the specific float material. Some areas of more general concern include

- impact damage, particularly for concrete and fiberglass floats that may be more susceptible to cracking and leaking
- leakage through the shell or at manhole openings
- loss of buoyancy caused by accumulation of marine growth on floats and anchor chains or by deterioration of the foam buoyancy units
- wear and stress or fatigue damage of float connecting components
- marine borer attack on timber
- coating failure on metal floats
- loss of anode mass

A.4.2.2 ***Anchor Systems.*** Buried anchors usually are not uncovered for inspection. However, wherever possible, the connection between the anchor and the anchor chain should be inspected for wear and corrosion. The anchor chain and the connecting hardware at the float also should be inspected for general condition. Periodic visual inspection of the anchor and anchor chain systems are necessary to verify integrity.

Anchor piles need to be inspected for general deterioration. Special attention needs to be paid to the sliding connections between pile and float, an area that is subjected to particularly heavy wear and abrasion from component interaction. In colder climates, vertical jacking of piles by ice is a concern.

A.4.2.3 ***Wave Attenuators.*** Wave attenuators should be inspected for structural integrity and material degradation. The particular problem areas associated with underwater portions of fixed structures are similar to open-piled piers and wharves. Underwater portions of floating structures are similar to floating docks. For both fixed and floating wave attenuators, special attention should be paid to the wave-reflector panels and the related connecting hardware.

A.5 HYDRAULIC STRUCTURES

A.5.1 General Description

Hydraulic structures include water-conveying or water-retention structures such as intakes, outfalls, dams, powerhouses, tunnels, and penstocks. The layout, design, and construction typically are influenced by topography, volume of water to be conveyed or retained, environmental and geotechnical factors, and the availability of construction materials and equipment.

A.5.1.1 Intakes and Outfalls. Intakes and outfalls are commonly associated with power stations, industrial process facilities, water supply facilities, and stormwater and wastewater discharge facilities. They may be located in freshwater or saltwater, and their construction may be open, closed, or a combination. Open structures such as canals usually are lined with concrete. Closed structures may be round, horseshoe-shaped, rectangular, or multibarrel. They may be lined or unlined, and they may be completely or partially buried or submerged. The most common construction material for intakes and outfalls is concrete, either precast or cast in place. However, many older facilities may be lined with brick, cast iron, steel, or timber.

A.5.1.2 Dams. Dams may range from small, low-risk earthen embankment structures to enormous high-head concrete arch structures. Low-risk facilities pose no major threat to life or property if breached, whereas moderate- to high-risk facilities may pose grave danger to population centers in the event of a breach. Dams are therefore licensed and regulated by the Federal Emergency Regulatory Commission based on risk assessment parameters.

Typical dam construction types include earthen, roller-compacted concrete; cast-in-place concrete; and timber cribs. Dams are constructed in many configurations depending on the topography and volume of retention. Components of dams typically include the dam structure, gates, spillways, fish ladders, and aprons.

A.5.1.3 Powerhouses. Dams are often accompanied by powerhouses located within a riverine environment. Powerhouse structures usually are founded on concrete foundations and often are equipped with intake structures, turbines, draft tubes, and discharge structures. Such facilities are commonly subjected to high flow rates and turbulence and therefore are susceptible to erosion and scour of the structure itself, the foundation, and the rock or other material beneath the foundation.

A.5.1.4 ***Tunnels and Penstocks.*** Tunnels and penstocks may be associated with power stations, industrial process facilities, water supply facilities, and wastewater or stormwater discharge facilities. Tunnels are buried and may be partially or completely submerged. They are most often constructed of precast or cast-in-place concrete and may be lined with brick, cast iron, steel, or timber. Many tunnels are excavated or bored through self-supporting material and remain unlined, although lining of tunnels is also commonly used to improve hydraulic performance.

Penstocks may be above ground or buried and typically are associated with water under high pressure or velocity. Therefore, penstocks are most often constructed of steel or prestressed concrete.

A.5.2 Typical Underwater Components and Common Problem Areas

Table A-5 summarizes some typical problem areas that may apply to hydraulic structures.

A.5.2.1 ***Intakes and Outfalls.*** Intake and outfall structures typically consist of the transitional structure at the water end, the conveyance portion, and the transitional structure at the landside or service end. The transitional structures may consist of headgates, sluicegates, widened configurations, bifurcations, or other structural features. Other components of intake transitional structures may include trash racks, traveling screens, or other similar devices to keep debris or other undesirable material from passing. Outfalls may or may not be so equipped, depending on the environment. Inspection of such transitional structures should focus on not only the structure itself but also the interface between the transition element(s) and the conveyance element(s). In addition, gate tracks, gate structures, and gate sealing edges are prone to damage because they are moving elements. Finally, the transition structures often include structural framing to support trash racks, traveling screen, and other elements. This framing is often a weak link in the system as a result of corrosion or fatigue damage.

The conveyance portion of intakes and outfalls are susceptible to typical corrosion, overstress, marine borer, chemical deterioration, and other defects depending on the construction materials. Particular attention should be focused on joints, transitions, and bends, where stress concentrations may occur.

A.5.2.2 ***Dams.*** The equipment and methods for inspecting dams can vary enormously with the size and water depth at the facility, but the critical elements remain essentially the same. The most common cause of dam failures is scour or erosion. Therefore, the inspection should focus on areas where the potential for scour is the greatest: the upstream dam–mudline

TABLE A-5. Checklist for Underwater Inspections: Hydraulic Structures

Type, Component, and Section/Part	What to Look For	Comments
Intakes and Outfalls		
Gates, Trash Racks, Screens		For inspection of cathodic protection systems (if applicable), see Section A.14, Cathodic Protection Systems.
Seals	Torn, damaged, or aging seals causing leakage	
Tracks and support framing	General condition, mechanical damage	
Gate skin, screen bars	Surface deterioration, debris, or blockage	
Conveyance Structures	Depends on type of structure; see Section A.6, Pipelines and Conduits	
Dams		
Dam Structure		
Foundation and abutments	Erosion and scour	
Dam core	Deterioration, signs of overstressing	Type of degradation will depend on material.
Gates	See Intakes and Outfalls above	
Spillway and Apron: Foundation Interface	Erosion and scour, debris accumulation	
Powerhouses		
Main Structure: Foundation Interface	Erosion and scour	
Intakes, Discharge Structures, Gates, Trash Racks	See applicable structure type and section above	
Tunnels and Penstocks		
Conduit		
Shell or Lining	Deterioration, signs of overstressing or leaks	For unlined tunnels in rock, check for rock falls.
Fittings (bends, bifurcations, transitions)	Scour and erosion, overstressing, leaks	

interface, the downstream apron areas, and transitions (e.g., spillways and abutments). The downstream dam toe should be checked for signs of leakage and piping. Older concrete dams often are susceptible to chemical damage such as alkali–silica reaction or sulfate attack as well as physical damage above the waterline from freeze–thaw effects. Gates should be inspected carefully, including tracks, structure, and seals.

*A.5.2.3 **Powerhouses.*** Powerhouses are susceptible to problems similar to dams. Components such as foundations, particularly in discharge areas, often are subject to scour from the turbulent flow of sediment-laden water. Footings founded on soft rock have been known to be undermined extensively in such areas. Powerhouses also may be subjected to large lateral forces during flood events. The buildup of debris and the high water pressure can cause overstressing damage; therefore, an inspection should focus on areas that are susceptible to such damage or where such damage may be manifested.

Powerhouses may be equipped with stoplogs, gates, draft tubes, wet wells, trash racks, intake structures, and discharge structures. These areas are subject to debris accumulation and damage, strong currents, and turbulent flow and therefore are susceptible to damage caused by scour, erosion, and fatigue. Finally, older powerhouse structures constructed of concrete are often susceptible to chemical damage such as alkali–silica reaction or sulfate attack as well as physical damage above the waterline from freeze–thaw effects.

*A.5.2.4 **Tunnels and Penstocks.*** Tunnels and penstocks under moderate to high head may be susceptible to significant stress that can cause overload damage. Concrete-lined tunnels have been known to crack extensively, leading to leakage into porous founding material. Dewatering such facilities can lead to implosion from reversal of stresses. Tunnels and penstocks constructed of prestressed concrete may be susceptible to corrosion, which may be exacerbated by conductive soil conditions in some areas. Wastewater tunnels constructed of concrete may be susceptible to attack from external chemical sources that can cause deterioration of the concrete matrix. The inspection of tunnels and penstocks should concentrate on joints, transitions, bifurcations, elbows, bends, and other areas where stress concentrations can form and leaks can develop.

A.6 PIPELINES AND CONDUITS

A.6.1 General Description

Submarine pipelines are used to convey water, gas, and oil across a body of water. Pipes used to encase or protect electrical cables or communication wires are usually referred to as *conduits*. Submarine pipelines and conduits can be divided into two broad groups: buried and exposed. The buried pipeline or conduit is placed in a trench below the mudline, which is then backfilled or placed on the bottom and covered with earth material and riprap or concrete protection. The exposed pipeline or conduit would be placed directly on the bottom and left uncovered. Intermittent structural pipe cradles or hold-down devices may be used to support and anchor the pipeline or conduit.

Materials used for submarine pipelines include precast and prestressed concrete, steel, cast iron, and plastic piping such as polyethylene and polyvinyl chloride (PVC); in the past, brick and masonry pipes were used at locations where the pipes could be laid in the dry, and the area was subsequently flooded. Conduits are commonly made from steel (with or without armored wrap) or PVC.

This section covers only the external inspection of pipelines and conduits. Internal inspections of pipelines in a flooded condition, when required, can be carried out by penetration dives (provided the pipeline is of sufficient size) or by self-propelled equipment controlled remotely.

A.6.2 Typical Underwater Components and Common Problem Areas

The inspection of buried pipelines and conduits usually is limited to verification of the integrity of the cover material. Scour as well as gouging from ice, boat anchors, or submerged logs could affect the protective cover over the pipeline or conduit and ultimately damage the installation. One area of particular concern is the transition zone from water to land, where the cover material may be subjected to wave attack.

The exposed pipeline or conduit should be checked for alignment, breaks, and signs of leakage as well as general deterioration typical to the material in question. Steel pipe may be wrapped with a protective tape, in which case the integrity and condition of the wrapping should be verified. The pipeline joints, if visible, should be inspected for general condition and tightness, and any mechanical hardware (e.g., bolts, flanges, and couplings) should be checked.

The most common types of pipeline supports and hold-down devices consist of concrete or steel cradles anchored to the bottom, and concrete collars bolted to the pipe and loosely laid on the bottom. The hardware between the pipe and the support needs to be checked for loose and missing components and general condition. Erosion and scour at the supports could affect the stability of the support and the pipeline.

Table A-6 is a summary of the main concerns regarding submarine pipelines and conduits.

TABLE A-6. Checklist for Underwater Inspections: Pipelines and Conduits

Type and Component	What to Look For	Comments
Buried Pipelines and Conduits		
Protective Cover Layer	Erosion and scour Damage to riprap or concrete cover	Special attention may be required at landfalls of buried pipelines and conduits.
Exposed Pipelines and Conduits		
System	Misalignment and breaks Signs of leakage Erosion and scour	Check pipe for loss of support, measure freespan (if applicable).
Pipe Conduit and Joints	Deterioration of material Mechanical damage Condition and tightness of joints Signs of overstressing	If pipeline or conduit is wrapped or armored, check integrity, condition, and continuity of wrapping.
Pipe/Supports and Hold-Down System	Condition of supports and anchors Deterioration and wear of pipe and connecting hardware Erosion and scour at supports	For pipelines provided with anti-buoyancy collars, check number and spacing.
Cathodic Protection	See Section A.14, Cathodic Protection Systems	

A.7 DRY DOCKS

A.7.1 General Description

Dry docks may be defined as any structure or vessel, the primary function of which is to create dry access to ships for purposes of new construction, inspection, cleaning, or repair. Dry docks are divided into four types: basin dry docks, floating dry docks, marine railways, and vertical lifts.

Basin dry docks (sometimes referred to as *graving docks*) are excavated into the earth adjacent to the waterfront with one end accessible to the water via a gate. To allow a ship access, the basin dry dock is flooded and the gate is opened. After the ship has entered the dry dock, the gate is closed and the water pumped out.

Floating dry docks are vessels that have a pontoon and wing walls that lift the ship out of the water by displacement. When water is added to the ballast tanks, the dry dock sinks enough to allow the ship to enter. Once the ship is properly positioned and supported, the ballast tanks are pumped out, thereby raising the ship out of the water.

The *marine railway dry dock* operates on the principle of the "inclined plane" to transfer the ship out of the water to above the tidal range. A carriage on wheels and rollers is moved on tracks down a submerged ramp to a depth where the ship can be floated into position over the carriage. When the ship is secured on the carriage, it is pulled up the ramp, bringing the ship out of the water. Marine railways can be of either an end-haul or a side-haul configuration.

Vertical lift dry docks consist of a horizontal deck fabricated of steel beams and girders suspended from cables, chains, or hydraulic components located on fixed piers along each side of the platform. The ship is centered over the lifting platform, which is then hoisted out of the water. The system can be designed for end or side transfer of the vessel onto shore-based work bays.

Another type of structure that may also be considered a dry dock is the *gridiron*. Gridirons are fixed horizontal platforms consisting of a grillage of timbers supported on piles or footings. The platform is built at an elevation within the tidal range to allow a ship to float in over the gridiron at high tide and to support the ship as the water falls to below the platform level at low tide. This kind of structure is suitable only for areas of large tidal variations, and it is limited as to the type of work that can be performed on the ship during the low tide cycle.

A.7.2 Typical Underwater Components and Common Problem Areas

Because dry docks are designed to bring in-water ships out of the water, many of their components are accessible for inspection in the dry at one time or another. Generally, therefore, only sections that are continuously submerged need to be inspected underwater.

Table A-7 is a summary of the specific components of the types of dry docks that usually need to be inspected while submerged as well as the most common areas of concern for each component. To dry-dock US government vessels, the dry dock must be certified safe in accordance with US MIL STD 1625(c).

A.7.2.1 Basin Dry Docks. The basic components of a basin dry dock are floor, sidewalls, gate(s), service galleries, inlet and outlet culverts, and mechanical and electrical appurtenances. Generally, only the gate(s), the outer sill and seats, the inlet grates, and the outer face of the dock front require underwater inspection by divers. Other components usually can be inspected in the dry.

The most common type of dry dock gate is the floating gate, often called a caisson gate. Other types include hinge gates, sliding gates, miter gates, and flap gates. The caisson gate is usually reversible, and the seat configuration often includes an inner seat and sill and an outer seat and

TABLE A-7. Checklist for Underwater Inspections: Dry Docks

Type, Component, and Section/Part	What to Look For	Comments
Basin Dry Docks (Graving Docks)		
Gate		
Seals	Torn, damaged, or aging seals causing leakage	
Skin	Deterioration	If gate is reversible, inspection of both sides made in the dry.
Seat/Sill		
Vertical Sides	Surface deterioration	
Horizontal Surface	Surface deterioration, debris, mechanical damage	Also check for scour or siltation in front of sill.
Culvert Inlet/Outlet: Grate at Face Wall	General condition, debris	
Floating Dry Docks		
Pontoon Hull: Submerged Portions	Deterioration, mechanical damage	Special concerns: Timber hulls: connectors, marine borers, tightness of hull and ballast tanks Steel hulls: welded and bolted connections, remaining plate thickness, and overall strength Concrete hulls: cracking, spalling, and external damage
Water Intakes: Valves and Piping	General condition	

continued on next page

sill. The inner seat and sill is easily inspected in the dry, yet the outer seat must be inspected by divers.

A.7.2.2 Floating Dry Docks. The floating dry dock consists of a pontoon with a stabilizing wing wall(s) and with the mechanical and electrical equipment to permit the controlled flooding and emptying of the ballast tanks. A floating dry dock is most conveniently inspected by having it dry-docked as a unit and performing the inspection in the dry. Self-docking may be an alternative for some floating dry docks, whereby portions of the structure are removed and dry-docked on the remaining structure.

TABLE A-7. *Continued.*

Type, Component, and Section/Part	What to Look For	Comments
Marine Railways		
Track Structure		
Foundation	Scour, siltation	
Track	Alignment, deterioration, condition of rail anchorage	If track is supported on timber supports, check for marine borers.
Cradle: Rollers	Deterioration, consistent diameter	
Cable/Chain System: Sheaves/Sprockets	Deterioration, satisfactory operation, condition of anchorage	
Vertical Lifts		
Supporting Piers	Depends on type of pier, see Section A2 or A3	
Platform and Appurtenances	Normally inspected above water	
Gridirons	Normally inspected above water	

In some cases, access to submerged portions of the pontoon is possible by creating controlled list or pitch of the dry dock through the flooding of selected ballast compartments.

The portions of the floating dry dock that may require underwater inspection include the pontoon hull and water intakes.

A.7.2.3 Marine Railways. The main components of the marine railway are the track structure, the cradle, and the winching system.

The cradle rests on either a system of free rollers between the cradle and the track or a wheel system built into the cradle. The portions of the marine railway that must be inspected underwater are the segments of the track and winching system that are permanently below water, as well as any portion of the cradle that does not fully emerge as it is pulled to its full-up position.

A.7.2.4 Vertical Lifts. The vertical lift consists of the two fixed piers, each supporting a series of winches equipped with cables or chains that suspend the transverse lifting beams and the lifting platform. All of the platform and the rigging usually can be lifted out of the water, making it possible to inspect the various components in the dry. The submerged portions of the fixed piers will need to be examined in the same manner as any other pier (discussed in Sections A.2 and A.3).

A.7.2.5 Gridirons. By their nature, gridirons are usually exposed at low tide, making it possible to carry out the inspection in the dry. In some cases, underwater inspections may be necessary (e.g., to examine mechanical damage caused by ship impact or to deal with similar emergency situations).

A.8 LOCKS AND GATES

A.8.1 General Description

Locks serve as lifting or lowering facilities for vessels in a waterway and often are a part of a dam structure. They also may act as a separator between two bodies of water. They usually are constructed of concrete and may be supported on timber, steel, or concrete piles. The floors and walls of older locks may be constructed of timber.

Gates at each end of the lock chamber usually are constructed of steel, but some older gates are made of timber. Steel gates usually are installed in pairs at each end of the lock and swing horizontally to open and close. They may be operated by hand, by geared machinery, or by hydraulic rams. Gates also may roll horizontally into recesses in the lock walls. Steel gates may be constructed as hollow, floating structures that are seated in guides on the lock when in use and floated to an adjacent area when the gate is opened. Gates, particularly those constructed of timber, also may be hinged at the floor of the lock and rotate to open and close assisted by flotation.

Lock approach structures may consist of open-piled structures (described in Section A.2) or gravity or retaining structures (described in Section A.3).

A.8.2 Typical Underwater Components and Common Problem Areas

Some of the areas of concerns related to the underwater components of locks and gates are summarizes in Table A-8.

A.8.2.1 Lock Walls and Floor. The floors and walls should be inspected for typical types of underwater deterioration common to the particular material type. The floors of locks may be covered with sediment and debris that will have to be removed, at least in selected locations, to conduct the inspection. The floors and walls should be inspected for cracking

TABLE A-8. Checklist for Underwater Inspections: Locks and Gates

Component and Section/Part	What to Look For	Comments
Lock Structure		
Walls and Floor	Misalignment or differential settlement between monoliths Signs of leakage or boiling Surface deterioration, cracking, spalling Excessive accumulation of sediments and debris	
Gate Seat/Stop and Gate Recess	Surface deterioration, wear, abrasion Accumulation of debris Mechanical damage	Check for conditions that may interfere with gate operation. Also check for scour or siltation in front of the sill.
Gate		
Seals	Torn, damaged, or aging seals causing leakage	
Skin	Misalignment/warping Surface deterioration, physical damage	
Mechanical Components	General condition	Check hinges, guides, rollers, sheaves, ropes, and chains depending on the type of gate operating system.
Culvert Inlet/Outlet		
Grates at Face Wall	General condition Accumulation of debris	

and differential settlement, especially that which could interfere with gate movement. In the vicinity of the gates, the floor should be inspected for signs of wear and abrasion. With the gates open, the floor should be inspected to determine the condition of gate stops.

The floor and walls should also be observed underwater under different conditions of hydraulic head to determine whether there is leakage or boiling.

A.8.2.2 Gates. Gates should be inspected for alignment and fit below water. The presence and condition of gaskets and seals should be determined. Operating machinery components and hydraulic rams should be inspected for alignment, and their operating paths should be inspected for clearance.

Floating gates should be inspected similarly to floating caissons of dry docks as discussed in Section A.7.

A.8.2.3 Intake and Discharge Piping. Intake and discharge piping for raising and lowering the water level within the lock should be inspected to ensure that screens and grating are in place and intact, and that there is no debris or silt accumulation adjacent to or within the piping.

A.9 FLOATING STRUCTURES

A.9.1 General Description

The two main types of floating structures are floating bridges and floating piers. Floating structures are used when great water depths or poor channel bottom conditions preclude the use of ordinary substructure units, or at sites where large fluctuations in water level need to be accommodated.

Floating bridges typically consist of concrete pontoons at the water surface held in place by cables that extend down to anchors at the channel bottom. The pontoons are either the bridge superstructure themselves or serve to carry a bridge superstructure. The position of the pontoons is maintained by anchor cables that inhibit movement by working against the buoyancy of the hollow design of the pontoons.

The anchor cables of floating bridges are typically structural strand made up of small-diameter stranded steel wires. An anchor cable may 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 stabilize it.

A wide variety of anchor designs are used for floating bridges, including large concrete blocks, segmental block assemblies, hollow concrete cylinders or boxes filled with ballast, and driven steel pile assemblies. At times, the various anchor designs also incorporate fluke shapes, keys, or riprap to assist anchor stability, depending on channel bottom conditions.

Floating piers typically consist of a deck that is made of one or more concrete or steel pontoons anchored to the channel bottom through spud piles or tension lines and connected to the shore via bridges or ramps. Typically, the spud piles of floating piers are made of steel or concrete, and the tension lines are composed of either steel cable or chain. When tension lines are used, the channel bottom anchors are usually concrete blocks or large fluke-type anchors made of steel.

A.9.2 Typical Underwater Components and Common Problem Areas

Table A-9 is a summary of the specific components of the floating structures that are typically inspected below water as well as the typical items of concern for each component of the structures.

A.9.2.1 Floating Bridge Pontoons. Because floating pontoons are usually constructed of concrete, their submerged surfaces need to be inspected for typical concrete deficiencies. Of particular concern is any cracking or deep section loss that could allow water to infiltrate the interior cavities of a pontoon. Where a series of pontoons is used, the rubber membrane or grout that is typically used in the joints between pontoons should be inspected for indications of a lack of integrity. Pontoon alignment across the joints should be examined for indications of excessive differential movement.

A.9.2.2 Floating Bridge Anchor Cables. Floating bridge anchor cables should be inspected for the condition of protective coatings, the extent of corrosion, and the amount of loss of individual wire sections. At pontoon ports, any inspection should check for cable misalignment and wire abrasion. At the anchors, the attachment assemblies or jewels should be examined for any deterioration, looseness, or misalignment as well as any adverse effects to the anchor cable. It is particularly important to identify any broken wires along the cable and, when possible, to determine the source of wire breakage related to abrasion or stress, because stress breaks on the exterior typically suggest a comparable number of broken wires on the interior. Wire breakage also indicates that the end of the cable's useful life is nearing. The inspection of each anchor cable also should identify any potential sources of cable abrasion, such as items hung on the cable (e.g., netting or anchor ropes) or obstructions at the channel bottom.

A.9.2.3 Floating Bridge Anchors. Floating bridge anchors should be inspected primarily for overall stability and checked for indications of anchor movement or misalignment and any undermining of the anchor structure. Where flukes, keys, or riprap is used, the amount of anchor embedment should be examined for adequacy. For box- or cylinder-type anchors, the amount of ballast should be checked to ensure its adequacy.

A.9.2.4 Floating Pier Pontoons. The submerged portions of concrete or steel floating pier pontoons should be inspected for the typical material deficiencies found above water. Of particular importance is any cracking, holes, or deep section loss that may allow water to infiltrate the interior cavities of a pontoon. Where Styrofoam filler is used in steel pontoons, any exposed filler should be examined for material integrity and any indica-

TABLE A-9. Checklist for Underwater Inspections: Floating Structures

Type, Component, and Section/Part	What to Look For	Comments
Floating Bridges		
Pontoon		
Submerged Concrete Surfaces	Cracks, spalls, and loss of section	Cracks or deep section loss may allow water infiltration.
Joints	Torn, loose or bulging rubber membrane Exposed or deteriorated grout Excessive pontoon misalignment	
Anchor Cable		
Pontoon Port	Misalignment and cable abrasion	
Cable	Coating condition, corrosion, wire section loss, broken 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	Misalignment or movement, instability, undermining, and inadequate embedment or ballast quantity	

continued on next page

tions of being waterlogged. The joints between pontoons and related connections or fillers should be inspected for deterioration, damage, missing or deficient items, and the other considerations described in Section A.9.2.1, where applicable.

A.9.2.5 Floating Pier Spud Piles or Tension Lines. Floating pier spud piles should be examined for the conditions described in Section A.2 for piles. In addition, the piles should be checked for any excessive wear or abrasion resulting from misalignment. Where tension lines are involved, the lines and attachment assemblies at either end should be examined for deterioration, breaks, abrasion, and the other considerations described in Section A.9.2.2, where applicable.

TABLE A-9. *Continued.*

Floating Piers		
Pontoon		
Submerged Surfaces	Material deterioration Water logged Styrofoam filler	Cracks or deep section loss may allow water infiltration.
Joints	Damaged 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/Anchor Attachments	Corrosion, misalignment, looseness, and line abrasion or strain	
Cable or Chain	Corrosion, cathodic protection anode consumption (chains), breaks 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	

A.9.2.6 Floating Pier Anchors. Floating pier anchors should be inspected for adequate embedment and overall stability while checking for any indications of movement, misalignment, and the other considerations described in Section A.9.2.3, where applicable.

A.10 BREAKWATERS

A.10.1 General Description

Breakwater structures protect shore areas, harbors, vessel anchorage sites, navigation channels, offshore structures, and basin facilities from wave action and usually are classified as either shore-connected or offshore breakwaters. Breakwaters can be constructed as flexible rubble-mound structures, as more rigid gravity base structures such as cellular sheet pile cells and concrete caissons, or as a combination of these types. Historically, timber crib breakwater structures have been constructed in low energy areas. Floating wave attenuators are discussed in Section A.4.

Rubble-mound breakwaters are typically constructed of multiple layers of stones of varying sizes and shapes designed to resist the storm wave conditions of the site. Such structures are the most widely used breakwaters in North America and can be successfully located in a broad range of water depths and site conditions. The protective surface layer of a rubble-mound breakwater (i.e., the armor) can be made up of large natural rocks or, at sites where rock of adequate size is not available in sufficient quantities, artificial concrete armor units. Artificial armoring can be found in a broad variety of complex shapes, such as cubes, dolos, tetrapods, tribars, Accropods, and Core-locs. These armor units are usually constructed of precast concrete and may contain reinforcing steel. Rubble-mound structures can be constructed with cementitious or stone-asphalt grout injected into the stone core or the surface layer of the breakwater for the purpose of reducing permeability and wave transmission through the structure, or to bond individual rocks to enhance stability.

Steel sheet pile cells, concrete caissons, and timber cribs are gravity structures that are used in many applications at marine installations, including breakwaters. These kinds of gravity structures are described in Section A.3. They generally consist of cellular bottom-founded structures of steel, concrete, or timber that are filled with granular material and capped with concrete. When used as breakwaters at sites with erodible bed materials, a riprap toe apron is often placed at the bottom along the face of the vertical-walled structure.

Floating breakwater structures may be used to protect marinas and small-craft harbors in areas of less wave exposure. Most floating breakwaters incorporate pontoons to which submerged baffles may be attached. Different types of floats used in marine facilities are described in Sections A.4 and A.9.

A.10.2 Typical Underwater Components and Common Problem Areas

Breakwater structures are inherently subjected to high wave energies and often are located near navigation channels. Environmental loads and exposures may be severe, and vessel impacts on these structures can occur. Rubble-mound structures may be subjected to reshaping. Gravity structures may become dislodged and overstressed. Bottom materials may erode. Toe aprons may scour. Although signs of severe distress and instability of breakwater structures may be visible from above water, regular underwater inspections and monitoring could discover the early warning signals needed for early detection.

Table A-10 is a summary of the problem areas that are common to breakwater structures. For gravity structure and floating breakwaters, see Sections A.3, A.4, and A.9.

TABLE A-10. Checklist for Underwater Inspections: Breakwaters

Type and Component	What to Look For	Comments
Rubble-Mound Breakwaters		
System	Slope alignment Signs of settlement or instability (slip failures) Toe erosion	
Protective Surface Layer	Integrity of layer Displacement of individual armor units Deterioration, cracking, or breaking of individual armor units	Ice pile-ups may cause gouging of armor layer or "plucking" of armor units.
Gravity Structure Breakwaters	See Section A.3, Gravity and Retaining Structures	
Floating Breakwaters	See relevant parts of Section A.4, Marinas, and Section A.9, Floating Structures	

A.10.2.1 Rubble-Mound Breakwaters. The typical forms of deterioration of rubble-mound breakwaters are slip failures, deterioration of the protective armor layer, and undermining of the toe. Slip (or slope) failures usually involve downward and outward movement of the sloped face of the breakwater (or a portion of the slope). For a rubble-mound breakwater consisting of free-draining rock and gravel core material, the cause of the slope failure usually is toe undercutting caused by scour.

Deterioration of the protective armor layer can cause rapid and complete failure of the underlying slope. Possible causes of damage to the armor layer include

- loss or displacement of individual armor units on the seaward side caused by breaking wave attack, ice action, and so forth
- loss or displacement of individual armor units on the leeward side caused by wave overtopping or ice attack
- weathering and disintegration of rock armor units caused by freeze–thaw action
- breaking or deterioration of artificial armor caused by armor unit movement under wave attack, thermal cracking, weathering, and so forth

Undermining of the toe and erosion of the toe apron usually are caused by scour from waves breaking on the breakwater slope. If left unattended, the damage at the toe may lead to progressive failure of the armor layer and the breakwater as a whole.

In addition to a visual inspection by divers, sounding surveys across and along the slope of the breakwater and at the toe may be helpful in assessing any reshaping that may take place. Records over time are particularly useful in determining changes in profile.

A.11 TOWER BASES

A.11.1 General Description

For the purpose of this section, the term *towers* refers primarily to transmission and communication towers installed in the near and offshore zone and in rivers. It does not include large-scale offshore towers and platforms used for exploration or production of oil and gas and similar activities, which tend to be complex and unique and may require adherence to facility-specific procedures during underwater inspections.

Tower bases may consist of various foundations, many of which are common to other kinds of marine facilities. For instance, gravity structures such as steel sheet pile cells, concrete cribs, and timber cribs can be used at locations with moderate to shallow water depth. Open-piled structures that consist of a concrete cap supported on a cluster of piles are commonly used. These kinds of structures are described in Sections A.2 and A.3.

A.11.1.1 Tubular Welded Steel Frame Bases. One type of structure that is typically used for tower bases is the prefabricated tubular welded steel frame structure. The structures generally consist of braced frames made from steel pipe. The frames are anchored to the bottom by gravity mats or driven piles. *Gravity mats* consist of a latticework of steel members at the base of the structure, weighted with evenly distributed stone or concrete ballast. *Anchor piles* are usually driven through and connected to sleeves attached to the bottom of the main pipe legs of the tower base.

A.11.2 Typical Underwater Components and Common Problem Areas

Table A-11 is a summary of the more common areas of concern when conducting an underwater inspection of a typical tower base structure.

A.11.2.1 Open-Piled and Gravity Structures. Tower bases consisting of open-piled or gravity structures typically have the same characteristics as other marine facilities where these types of structures are used. Therefore, the issues discussed for these particular structures in Sections A.2 and A.3 apply. However, given that tower bases may be subjected to more severe environmental conditions and may be situated in relatively deep water,

TABLE A-11. Checklist for Underwater Inspections: Tower Bases

Type and Component	What to Look For	Comments
Tubular Welded Steel Frame Structures		
Frame Structure	Distortion, tilt of structure as a whole Bent, broken, missing members Damaged, dented, flooded members Signs of overstressing Cracking or pitting of weldments	T- and K-joints may be particularly susceptible to overstressing.
Gravity Mat Foundations	Loss or displacement of ballast Foundation scour	
Anchor Pile Foundations	Integrity and condition of pile–structure connection Scour around piles	
Cathodic Protection	See Section A.14, Cathodic Protection Systems	
Gravity Structure Tower Bases	See Section A.3, Gravity and Retaining Structures	
Open Piled Tower Bases	See Section A.2, Open-Piled Structures	

the potential problems associated with overstressing and scour may require special attention during the inspection.

A.11.2.2 Tubular Welded Steel Frame Structures. Deterioration typical to the material is an obvious concern. Most tower bases would be equipped with a cathodic protection system that should be checked for proper operation. Other causes for concern on these structures include

- bent, broken, or missing members
- signs of overstressing of tubular members, particularly at T- and K-joints
- cracking or pitting of weldments
- flooded members
- loss or displacement of ballast in mat foundations, shifting of pile foundations
- scour at structure base

A.12 MOORINGS AND ANCHORS

A.12.1 General Description

Moorings provide primary, temporary, or contingency berthing for vessels. A mooring generally consists of a floating buoy, anchor chain(s), and anchor(s). Some types of moorings currently in use include the free-swinging mooring, the bow-and-stern mooring, the spread mooring, the Mediterranean-type mooring, and the buoy dolphin mooring. Moorings are classified by their respective holding power. The United States Navy classification includes holding powers ranging from 5,000 to 300,000 lb (22 to 1,340 kN).

The *free-swinging mooring* (also called a single-point mooring) consists of a single buoy to which the ship moors with bow lines or anchor chain, allowing the ship to swing 360° around the buoy. A *riser* free-swinging mooring consists of a hawsepipe or tension bar–type buoy, a riser chain with swivel, ground ring, chain anchor legs, and anchors. Three or four anchor legs connect the anchor to the ground ring, which usually is located about 10 ft above the bottom at high tide. The riser chain connects the ground ring with the buoy. The *nonriser* free-swinging mooring consists of a relatively large buoy held in place by chain anchor legs and anchors. The three to eight anchor legs are attached to the underside of the buoy, and the ship connects its line to a swivel on top of the buoy.

The *bow and stern mooring* is designed for use by a single ship and limits the movement of the ship while moored. The moorings can consist of either riser or nonriser buoy systems. The *spread mooring* is designed for use by one or more vessels and consists of chain legs attached directly to the vessel (without buoys) and anchors. It is commonly used for more permanent ship berthings such as floating dry docks. When more than one vessel ties up to this type of mooring, they are held together by interconnecting lines and separated by floating camels or fenders. The *Mediterranean mooring* was developed to permit the nesting of vessels side by side, perpendicular to the wharf with the stern in. The bow is secured by two or more bowlines that may include mooring buoys. Each mooring line may divide into two anchor legs leading to anchors or stakepiles. The stern is typically moored to the pier. The *buoy dolphin mooring* usually consists of bow or stern buoy dolphins that are used by a ship to maintain its position when breasted to a short pier or wharf.

A.12.2 Typical Underwater Components and Common Problem Areas

Unless a mooring can be completely lifted out of the water for assessment, an underwater inspection usually forms an essential part of a mooring inspection. Given that mooring buoys are typically difficult to access, it may be advisable to inspect the above-water components of the buoy concurrent with the underwater inspection. Table A-12 is a summary of the specific components of the common mooring types that usually need to be inspected while submerged, including the typical above-water buoy components and the most common areas of concern for each component.

TABLE A-12. Checklist for Underwater Inspections: Moorings and Anchors

Type, Component, and Section/Part	What to Look For	Comments
Riser and Nonriser Type Moorings		
Buoy, Upper Portion		
General	Size, freeboard, and physical damage (dents, holes, list); coating condition	
Fenders, Chafing Rails/Strips	General condition	
Top Jewelry	General condition of tension bar, hawsepipe, and manhole covers. as applicable	Check for hardware wear, corrosion, and damage.
Buoy, Lower Portion		
Hull	General condition, physical damage (dents and holes)	Check condition of coating.
Bottom Jewelry	Condition of tension bar, hawsepipe, as applicable; condition of chain padeyes (for nonriser moorings)	Tension bar: Check eye and retaining plate for wear or distortion. Hawsepipe: Check chain for wear or corrosion, rubbing casting for wear.
Riser Chain Subassembly		
Chain Links, Connecting Hardware, Swivel, Ground Ring	Type and general condition, wear or corrosion, distortion	Measure chain links at three locations for each shot of chain, that is, each end and midway between. At each location, take single- and double-link measurements. Check for pitting corrosion.
Anchor Chain Subassembly		
Chain Links, Connecting Hardware, Swivel (if applicable)	Type and general condition, wear and corrosion, distortion; compass bearing of each chain	
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, Cathodic Protection Systems	

Discussion of the 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. Buried portions of the mooring such as anchors and chain anchor legs usually are not uncovered for 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.12.2.1 ***Buoys.*** Different types of buoys used in moorings include the drum buoy, the peg-top buoy, the drum nonriser buoy, and the cylindrical buoy.

The *drum buoy* is shaped like a drum and is available in various sizes. It can be provided with a tension bar that passes through the drum and has padeyes at both ends. The lower padeye is connected to the riser chain, and the vessel mooring line is connected to the upper padeye. Alternatively, the drum buoy can be provided with a hawsepipe, which allows the riser chain to pass through pipe and the drum and be connected to a chain plate at the top of the pipe. The ship's mooring line is then attached directly to the riser chain.

The *peg-top buoy* is cone-shaped, with the top deck area considerably larger than the bottom surface. It is usually used to support a riser-type mooring. *Drum nonriser buoys* are usually larger than those used in riser-type moorings because they have three or more chain anchor legs to support. The anchor legs are attached to padeyes on the buoy hull, and the ship's mooring line is tied to a swivel top. The *cylindrical buoy* is shaped like a cylinder and is designed with either a tension bar or a hawsepipe. It is usually used in smaller classes of moorings. Most cylindrical buoys have fenders attached to the side to protect the buoy from damage in case of contact with a mooring vessel. In addition, chafing rails or strips are added to the top of the buoy to prevent damage from the mooring lines.

The majority of mooring buoys have steel hulls protected with several coats of paint or with fiberglass coating. To protect the coating from damage during the underwater inspection, it may be advisable not to attempt to remove any marine growth from the buoy.

Many mooring buoys are cathodically protected by sacrificial anodes attached to the hull. The condition, dimensions, and connection of the anodes must be checked during an underwater investigation. Electrical potential readings should be taken with an underwater voltmeter at several locations on the buoy bottom.

A.12.2.2 ***Riser Chain Subassembly.*** The riser chain subassembly usually 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.

To determine wear and corrosion of chain, the diameter of the wire is measured at several locations along a shot of chain (15 fathoms or 90 ft). The area likely to exhibit the most severe degree of both wear and corrosion is at link crosses, where the two adjoining links are in contact with each other. At locations where the measurement of individual wire diameter is difficult, the in-place length of the links may provide an indication of deterioration, given that the relationship between link length and wire diameter for a specific chain usually is fixed.

A.12.2.3 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 non-riser moorings) to the anchors. The chain should be checked for wear and corrosion as described above for the riser chain subassembly. The 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.12.2.4 Anchor Subassembly. If an anchor is located, a pop float may be attached to it so that the relative position of the anchor to the mooring buoy can be observed from the surface. If possible, the type and condition of the anchor and the connecting hardware should be checked. Also, the reason for it being uncovered should be investigated.

A.12.2.5 Cathodic Protection System. The cathodic protection system used on moorings consists of sacrificial zinc anodes connected to the buoy or the chain via an electrically sound mechanical connection. 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.

The inspection of the cathodic protection system is detailed in Section A.14.

A.13 TANKS AND STORAGE FACILITIES

A.13.1 General Description

Tanks may be located above ground, at ground level, or below water. They may be constructed of steel, concrete, or timber. They may contain water, wastewater, chemicals, or petroleum. Generally, only tanks that contain raw water, potable water, or some forms of wastewater would be candidates for underwater investigations.

The general procedures described here are primarily intended for potable water tanks, where health safety requirements are most stringent, and may have to be revised or expanded to meet specific site situations. For tanks that contain raw water, the health safety requirements might be relaxed in consideration of future treatment. For tanks that contain wastewater, health safety procedures to protect the diver from the water may be necessary (e.g., full encapsulation to isolate the diver from the water, and cleaning and disinfecting the diver and the suit before the diver removes the diving equipment).

Steel and concrete tanks are most common and are subject to the same kinds of deterioration found on other in-water structures of similar materials.

American Water Works Association (AWWA) Standard D101 requires thorough inspections of water tanks at intervals of not more than 5 years. Because the costs incurred in dewatering, installing and removing scaffolding, and inspecting and decontaminating a tank are so high, the underwater inspection of tanks—with proper precautions—can be cost-effective.

To ensure the safety of the water supply, the inspector should successfully pass a physical examination. The extent of the examination should be determined in consultation with appropriate medical and health safety personnel but generally will include, as a minimum, tests for medical conditions such as amoebic dysentery, typhoid, intestinal parasites, hepatitis, and so forth. A diver suspected of any illness should not be allowed to enter the tank.

All diving equipment used in potable water facilities, including dry suits, should be dedicated for use only in such facilities. All diving and inspection equipment should be composed of an inert, nonabsorbing material that can be properly disinfected.

All equipment except the dry suit should be thoroughly washed to remove foreign objects, and then placed in a covered tank containing 500 mg/l of chlorinated freshwater for a minimum of 30 minutes before inspection. After the diver has donned the suit, the dry suit should be disinfected with a chlorine solution sprayed on all external surfaces.

The opening to the water storage facility should be cleaned, disinfected, and covered with a sterile material before beginning the inspection.

Before inspector enters, the free chlorine residual in the tank should be raised to 1 part per million, and representative water samples should be taken for testing. At the conclusion of the inspection, additional water samples should be taken for testing. The free chlorine residual should be reduced to normal levels 24 hours after the inspection.

A.13.2 Typical Problem Areas

The interior of a steel tank is generally coated with a coating of epoxy or a similar approved product. The greatest source of deterioration for steel structures is corrosion. The freeze–thaw action at the water surface often causes local damage, or holidays, in the coatings that can be the source of concentrated corrosion. Condensation corrosion of the tank section above the internal water level is also a concern.

Reinforced concrete tanks often are found below ground level. Their roofs may be exposed but sometimes are covered with earth fill. Being in the ground, the temperature may remain relatively constant throughout the year, but the top slab and upper portions of the walls (especially in cold climates) are exposed to temperature variations so that expansion and contraction occur. As a result, cracks often occur in the roof slab and in the portions of the walls near the ground surface. The junction between the roof slab and the walls, especially when it is located at the ground line, can be the point of entry for surface runoff if it is not well sealed. The water may seep into the joint, freeze later on, and break off the corner of the wall within the tank.

Most steel tanks are protected with a sacrificial or impressed current cathodic protection system. The components of the system can be damaged when water freezes. Some of the typical problem areas that may be associated with storage tanks and that could require underwater inspections are summarized in Table A-13.

A.14 CATHODIC PROTECTION SYSTEMS

A.14.1 General Description

Marine structures constructed with steel or reinforced concrete components are subject to corrosion. To prolong their service life, these structures can be protected with a cathodic protection system. Cathodic protection is simply a means of making a structure the cathode in an external electrochemical cell. It transfers the uncontrolled corrosion of the structure to controlled corrosion of external anodes, which can be replaced.

The two types of cathodic protection systems are the galvanic anode system (also known as the passive or sacrificial system) and the impressed current system (also known as the active system).

A.14.1.1 Galvanic Anode System. Galvanic anode systems consist of sacrificial anodes that are electrically connected to the structure and immersed in an electrolyte (water). The anode contains metal of a higher potential than the steel it is protecting. Because of the potential difference between

TABLE A-13. Checklist for Underwater Inspections: Tanks and Storage Facilities

Type and Component	What to Look For	Comments
Above-Ground Tanks		
Exterior Shell	Deterioration typical for the material in question (steel, concrete, or timber) Signs of leakage	
Interior Shell and Lining	Deterioration Integrity of lining	Epoxy lining may be susceptible to freeze–thaw damage.
In-Ground Tanks		
Exterior Surfaces	Deterioration of accessible surfaces typical to the material in question Signs of leakage (may not be readily visible)	Roof and wall joints of concrete tanks should be checked for spalling and deterioration; road salt attack on concrete could be a concern.
Interior Surfaces and Lining	Same concerns as for above-ground tanks above	
Steel Tanks		
Cathodic Protection	See Section A.14, Cathodic Protection Systems	
Potable Water Tanks		Special precautions and considerations apply to diver health requirements and equipment disinfection for the inspection of potable water tanks.

the anode and the structure cathode, the anode is consumed to produce the required current to maintain the structure in cathodic condition.

The anodes can be attached directly to the underwater structure by attachments that are welded or bolted to the steel component. Metals used for sacrificial anodes usually include zinc and aluminum alloys. Another type of design suspends the anodes from points in the structure above the intertidal zone. This design allows for easy renewal and repair, but the position of the anodes makes them susceptible to damage by wave action, debris, ice, and severe weather.

A.14.1.2 Impressed Current System. In an impressed current cathodic protection system, electrical current from an outside source is used to cathodically protect steel and reinforced concrete structures. This system is designed in such a way that it is capable of delivering and distributing sufficient direct current (DC) to maintain the submerged structure in a polarized condition. The impressed current system usually consists of

- anodes and associated DC positive wiring
- DC power supply and current regulation (rectifier)
- negative return circuit from the protected structure to DC power supply, including electrically bonding the structure
- reference cell and means for measuring structure potential (may be portable) to determine the amount of current required to provide adequate protection for the structure

Materials used for anodes may consist of alloys of lead, high-silicon iron, or graphite. Placement of the anodes depends on the construction of the structure. Typically, the anodes are suspended from the structure or are fastened to underwater sleds. Occasionally, the anodes are inserted in slotted or perforated insulated holders that are attached to the structural components by mounting brackets.

Rectifiers are the most widely used DC source for impressed current cathodic protection systems. A rectifier consists of a step-down transformer with voltage adjustment taps and a rectifier stack to convert the alternating current (AC) power source to DC. The units are mounted in a housing suitable for the marine environment. Although these units are located above water, they should be inspected as part of the underwater inspection.

To provide proper cathodic protection to an entire marine structure, it is necessary that all submerged steel members and components be bonded together metallically to ensure electrical continuity. For instance, at 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 ensured by welding across interlocks. Concrete structures may be provided with bonding of the reinforcing steel, or by supplemental wire connections.

A.14.2 Cathodic Protection System Deterioration

Deterioration of a cathodic protection system can be caused by improper design and by external mechanical and environmental factors.

A.14.2.1 Design Deficiencies. Cathodic protection systems should be designed and manufactured to provide continuous dependable operation for at least 10 years. To accomplish this goal, the type of system (galvanic or impressed), type of construction, types of anodes, monitoring systems, and the maintenance plan are integral parts of the design process. A deficiency in any one area will negatively impact the performance of the protection system and allow corrosion of structural members. This kind of deterioration results in damage to the members similar to that encountered with unprotected steel and concrete structures.

A.14.2.2 Environmental Factors. Several environmental parameters affect the design and functioning of a cathodic protection system. Proper monitoring of these factors and consequent adjustment of the system is required if the system is to perform satisfactorily.

The following factors may affect the adequacy of cathodic protection systems:

- *Resistivity* of the electrolyte is affected by salinity and temperature.
- Because oxygen is the principal depolarizer in seawater, increased *oxygen content* will promote greater depolarization of the cathodic reaction and a corresponding increase in current will be required to maintain polarization.
- Increased *water velocity* around all or some of a structure causes the products of cathodic reaction to be removed faster. The amount of oxygen arriving at the cathodic surface per unit of time will also increase because of increased velocity. This combination of effects causes a rise in current demand for polarization.
- The application of cathodic current to a structure promotes the formation of a *calcareous coating*. After this coating has formed, a much lower current density is required for continued protection.

A.14.3 Typical Components and Common Problem Areas

Some parts of cathodic protection systems may be installed on land. However, verification of the effectiveness of the system and inspection of the more critical components can be performed only by underwater inspection. Table A-14 is a summary of the various components of the cathodic protection systems and the specific areas of concern.

A.14.3.1 Galvanic Cathodic Protection System. Galvanic anode systems are subject to various types of deterioration. The three most common types of damage encountered are consumed anodes, broken connection wires, and coating failure. Impact forces, abrasion, and environmental factors can cause these kinds of damage.

A.14.3.1.1 Anodes. Anodes should be visually inspected for even consumption. No evidence of consumption indicates the system is not effective. Anodes should be covered in white oxidation deposits. Anodes

TABLE A-14. Checklist for Underwater Inspections: Cathodic Protection Systems

Type and Component	What to Look For	Comments
Galvanic System		Verify the effectiveness of the system through potential survey using reference cell and voltmeter.
Anodes	Condition of anodes, physical damage, and remaining material	Check color of anode oxide coating.
Connections	General condition and electrical continuity across structural joints	
Protective Coatings	General condition of paint and other protective coatings	Breaches in protective coatings will increase requirement for protection.
Impressed Current System		Verify effectiveness of system through potential survey using reference cell and voltmeter.
Rectifier	Proper performance, integrity of wiring, and so forth	Accessible above-water, frequent inspection recommended (monthly), improper performance can cause structural damage.
Anodes	Condition of anodes, physical damage, and remaining material	Check color of anode oxide coating.
Connections	General condition and electrical continuity across structural joints	
Protective Coatings	General condition of paint and other protective coatings	Breaches in protective coatings will increase requirement for protection.

should be replaced before they are completely consumed to ensure continued effective functioning of the system.

A.14.3.1.2 Connections. Connections (e.g., welded cross bracing, connection wires, support wires, straps, and conduits) should be examined to ensure they are sound. These components ensure the electrical continuity of the structure, and any breaches can affect the performance of the system. Damage to these components can be caused by wave action, debris, ice, severe weather, or impact.

A.14.3.1.3 Coatings. The protective coating of a structure should be inspected for any breaches. Failure of the coating can increase current requirements, and additional anodes may be required.

A.14.3.1.4 Potential Survey. Verify adequate cathodic protection 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 receiving protection.

A.14.3.2 Impressed Current Cathodic Protection System. As with the galvanic cathodic protections system, the impressed current system should be inspected to ensure proper operation.

Rectifiers are subject to electrical failure and broken wires, which can result in misadjustment of the system, leading to structural damage such as under- or overprotection and the potential for stray current corrosion on adjacent structures. Insufficient current can result in underprotection and corrosion. Excessive current can lead to overprotection, which causes failure of protective coatings and also the potential for both hydrogen embrittlement of high-strength steel prestressing wire and stray current corrosion to adjacent structures.

Anodes, connections, and protective coatings should be examined for damage and deterioration as described above for the galvanic system. Also, a potential survey should be carried out to verify the cathodic protection.

A.14.3.3 Stray Currents. Stray electric currents promote corrosion by accelerating the electrochemical process. These currents can originate from various sources, such as welding activity, cathodic protection systems for neighboring structures or pipelines, transit systems, DC industrial generators, power stations, and substations. This kind of accelerated corrosion and member deterioration also results in damage similar to that encountered in damage to steel and concrete structures.

Appendix B

TYPES AND CAUSES OF DEFECTS AND DETERIORATION

This appendix provides general information on various types and causes of underwater deterioration. It provides general knowledge on the most common deterioration processes for typical marine construction materials.

Because of the diversity of the materials available and the ever-changing technology behind the manufacturing of specific materials, this appendix does not cover all situations. It is meant to provide basic information on the common types and possible causes of deterioration that structure owners and operators may find within their facilities. Additional information on specialized deterioration may be available within the reference material presented in Appendix C.

B.1 CONCRETE STRUCTURES

B.1.1 Concrete Deterioration

In-service deterioration of concrete members can occur as a result of exposure to the hostile marine environment or unusual loading conditions often associated with marine structures. Several factors may affect concrete integrity and lead to deterioration and failure, such as poor design details, construction defects, temperature, chemical reactions, and mechanical damage. Concrete deterioration generally is caused by concrete degradation, corrosion of internal reinforcing steel, overstress, construction deficiencies, or a combination thereof.

If the concrete deterioration is sufficient to require repair, it is essential that the cause of the deterioration be determined before selecting an appropriate repair method. Some types of deterioration occur primarily in the splash zone, others in the water column, and some extend below the mudline. Deterioration below the mudline may make some repair methods inappropriate, because the repair will not continue into this zone.

B.1.1.1 Cracking. Cracking is a linear separation of concrete into two or more parts. The crack may extend partially or completely through the member. In reinforced concrete, cracking usually can be seen by the naked eye; however, a crack gauge is usually required to measure the damage. Concrete components may have structural, nonstructural, and degradation-type cracking.

Structural cracks are caused by dead-load and live-load stresses. Flexural cracks begin at the maximum tension zone and progress toward the compression zone. Shear cracks are diagonal cracks that normally occur in the web of a member, beginning at the side and extending diagonally toward the center.

Nonstructural cracking is generally minor but can provide openings for water and contaminants to enter. Such cracks include 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 mass concrete sections.

Degradation cracking is generally caused by the corrosion of reinforced steel or the volumetric expansion of concrete. Several types of cracking are observed in underwater concrete.

B.1.1.2 Concrete Degradation.

B.1.1.2.1 Corrosion of Internal Reinforcing. Corrosion of internal reinforcing is one of the major causes of concrete deterioration. The effects of corrosion are delamination, cracking along the reinforcing bars, and eventual spalling that exposes the reinforcing steel. 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, and the reaction results in the formation of iron oxide.

The intrusion of chlorides and salts from marine spray, deicing agents, and industrial brine into the concrete initiates corrosion on substructures that are exposed to water. These agents penetrate the concrete through pores, cracks, and holes or by diffusion, allowing oxygen and water to attack the reinforced steel, thus forming iron oxide. Chlorides and salts act to accelerate the electrochemical process, forming corrosion by-products that occupy many times the volume of the original steel that in turn cause internal pressures of up to 5,000 psi to develop. These expansive forces cause the concrete to crack and allow increased access by oxygen, chlorides, and moisture, which intensifies the corrosion and accelerates the loss of steel. Loss of steel threatens the structural integrity of the concrete component.

The structural implications of internal corrosion are more acute in prestressed concrete than in nonprestressed concrete because of the difference in the quantity of steel in the two types of construction; the steel strands used in prestressed construction are considerably smaller than the cross-sectional area of reinforcing steel used in nonprestressed construction. The concrete requires the same amount of corrosion 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 is formed and visible.

The rate of corrosion is very slow in high-quality concrete. Accelerated corrosion will occur if the alkalinity is low, aggressive chemicals are present, or dissimilar metals are introduced into the concrete. Stray electrical currents and concentration cells caused by an uneven chemical environment can also speed corrosion. Additionally, concrete structures can also be vulnerable to reinforcing corrosion caused by the action of sulfate-reducing bacteria found in sediments and discharged production water. This action produces a porous and disintegrating matrix. Mechanical damage can also reduce the layer of concrete over the reinforcing steel, initiating and accelerating internal corrosion.

Corrosion Cracking. A corrosion crack is a split that occurs in concrete due to the expansion of chemical products generated by the corrosion of steel reinforcement. Corrosion cracks occur where aggressive chloride ions penetrate the concrete cover. Chlorides depassivate the steel, causing corrosion. The volume of corrosion products is many times greater that the volume of the original steel, causing internal pressure to develop around the reinforcing steel, primarily along the outside surface, where protection is minimal and corrosion is greatest. Corrosion cracks are formed when the internal stresses produced by the expansion of corrosion products exceed the tensile strength of the concrete. It generally 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.

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 steel. Additional traits of corrosion cracks are variable widths, 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 that often bleed from the crack.

In marine structures, a corrosion crack most commonly starts above the mean higher high water on a pile and extends upward. A large crack may travel down into the tidal zone but will usually stop near the mean lower low water. Substructure members that are subjected to saltwater spray, such as piling in the back rows of concrete wharves, are more susceptible to corrosion cracking due to splash caused by wave action against the retaining structure. In permanently submerged concrete components, this type of crack is not typically encountered; the general rate of corrosion of reinforcing steel is minimal because of the lower concentration of chlorides and the lack of dissolved oxygen in deep water.

Closed Corrosion Spall. As corrosion cracking continues, the cracks generally degrade into closed corrosion spalls. A closed corrosion spall is identified by a slightly raised area of concrete completely or partially surrounded by corrosion cracks. When struck with a hammer or steel rod, the spall gives off a hollow sound, indicating the existence of a fracture plane below the surface. Spalling is the intermediate stage in the process of complete separation of a fragment of concrete cover.

A closed spall does not significantly affect the structural capacity of concrete components. However, it is indicative of a loss of steel in some of the reinforcing, which will eventually reduce the structural capacity of the component. Additionally, a closed spall's surface crack serves to accelerate corrosion.

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 products.

In open spalls, the structural significance of the damage depends on the extent of the steel loss. Open spalls also reduce the durability of concrete components by accelerating the corrosion process.

Delamination. Delamination is a separation of layers of concrete along a plane parallel to and near the surface of the concrete. It is caused by the expansion of corroding steel reinforcement. As the rust layer builds, the expansion forces cause the concrete layer to separate.

Delamination can occur on any concrete surface where reinforcing steel corrosion is possible. It is primarily found on the soffits of pile caps, beams, and decks but also can form on the vertical faces and corners of piles, caps, beams, and retaining structures. Because delamination is the initial stage of spalling, it ultimately impacts the structural capacity of a component due to loss of reinforcing steel.

B.1.1.2.2 Volumetric Expansion. Volumetric expansion occurs when the byproducts of chemical reactions form in the concrete with sufficient volume to cause microcracking. With continued expansion, macrocracking will become visible on the exterior of the concrete. These macrocracks may be continuous or discontinuous and generally extend vertically. Volumetric expansion may cause softness of the affected concrete.

The mechanisms of *alkali–silica reactions* (ASR) and *alkali–aggregate reactions* (AAR) are not completely understood. It is known that certain aggregates (such as reactive forms of silica) react with alkalis (typically potassium and sodium) and calcium hydroxide from the cement and, when sufficient moisture is present, form a gel around the reacting aggregates. As the gel develops, it expands, causing microtension cracks to form around the aggregate. The gel continues to form until the reactive aggregate or alkalis are consumed.

Alkali–carbonate reactions (ACR) can cause underwater cracks on concrete piles in marine environments. The cracks are typically oriented vertically and are usually found in the submerged zone. It is believed that the deterioration takes place underwater because the seawater provides additional alkalis for the reaction and intensifies the reaction.

ACR cracks do not significantly reduce a pile's capacity as long as the cracks remain shallow. Deep ACR cracks have the potential to expose the reinforcing steel to corrosion and thus may seriously affect the integrity of prestressed members.

Chloride contamination is caused by the presence of *cast-in chlorides.* They may be introduced intentionally as an accelerator or occur naturally in some aggregates. Concrete made with beach sand or mixed with seawater will also have cast-in chlorides. Water-soluble chlorides are the most damaging because they readily recrystallize within the concrete. The newly formed salt crystals cause the capillary cavities in the concrete to swell, and the expansive force of the increase in volume can cause the concrete to disintegrate.

Secondary ettringite formation, more commonly known as *delayed ettringite formation* (DEF), is a form of internal sulfate attack that can cause longitudinal cracking and areas of microcracking in the submerged portion of concrete components. This kind of cracking is not typically encountered above the MLLW. Cracking may be continuous or discontinuous along the length of the member. The depth of cracking varies but may extend to the reinforcing.

Another type of secondary ettringite formation results from external sulfate attack. External soluble sulfates, common in mining and chemical operations, paper milling industries, and seawater, react with the cement paste's hydrated lime and hydrated calcium aluminate. The reaction causes volumetric expansion, which causes microcracking and disintegrates the cement paste, resulting in scaling. The concrete then becomes soft and brittle.

B.1.1.2.3 Carbonation. Carbonation is the reaction between acidic gasses in the atmosphere and the products of cement hydration. It can occur in industrial areas where the level of carbon dioxide in the air is generally high. The carbon dioxide enters the pores of the concrete by diffusion and reacts with the calcium hydroxide dissolved in the pore water. The alkalinity of the concrete is reduced, resulting in lost material, reduced strength, and softening. Consequently, the concrete protection of the reinforcing steel is reduced, thereby initiating the onset of corrosion if oxygen and moisture are present. The carbonation process requires continuous wet–dry cycles. In the marine environment, seawater normally contains very small amounts of carbon dioxide. However, concentrations increase in the presence of decaying organic matter, and carbonation can occur. Carbonation also can take place in concrete that is exposed to water emanating from underground. It does not occur when concrete is continuously submerged.

B.1.1.2.4 Scale. Scaling is the gradual and constant loss of surface mortar and aggregates from an area of concrete. It is sometimes found at the waterline and near the channel bottom.

Scaling is caused by the freeze–thaw cycle in cold climates. Water penetrates the pores and minor surface defects in the concrete. When the water freezes, it expands by approximately 9%, causing the surface of the concrete to crack and disintegrate. Uniform scaling can also occur on substructures located in polluted water. Scaling can lead to cracking, spalling, and the eventual depletion of the concrete cover.

B.1.1.2.5 Freeze–Thaw Deterioration. Freeze–thaw damage takes place when freezing and thawing cycles act on porous concrete that has absorbed water. Water in the pores expands as it freezes, creating expansion forces that break the surrounding concrete. 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 spray and in cold climates.

B.1.1.3 Honeycombs. Honeycombs are voids or hollows in the concrete, construction deficiencies caused by inadequate consolidation of the concrete. The lack of vibration segregates the coarse aggregates from the fine aggregates and the cement paste. 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 of the area affected. These areas will have high permeability and will be more susceptible to chemical attack. Surface honeycombing has the additional potential of allowing the penetration of corrosion agents into the reinforcing steel and eventual cracking and spalling.

B.1.1.4 Pop-Outs. Pop-outs are shallow, cone-shaped holes in the surface of the concrete 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 would still be attached to the small end of the cone that popped out.

Pop-outs are caused by the presence of reactive aggregates and high alkali cement. They also can occur when aggregates that expand with moisture, such as shale, are in the makeup of the cement or when the ends of internal reinforcing steel corrode, developing localized expansive forces.

B.1.2 Mechanical Damage

B.1.2.1 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.

Overload damage is caused when loads are applied to the structures in excess of their capacity. When loads cause stresses in excess of the tensile stress capacity of the concrete or the yield stress of the reinforcing steel, damage occurs. As with impact damage, the extent of the damage can range from superficial damage to fracture or failure of the member.

Impact or overload may cause localized overstressing of concrete members and can cause severe cracking with potential for additional damage from corrosion and contamination. Overstressing is caused by external loads, which cause high internal stresses that exceed the strength of the concrete member. The result is an overstress crack, which is characterized by its sharp edges and small wedges of missing concrete along the length of the crack.

Overstressing damage does not necessarily occur at the point of maximum applied load but at locations where the stress meets or exceeds the concrete's structural capacity. Generally, the consequences of impact are localized structural problems 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 reducing the concrete cover.

B.1.2.2 Abrasion or Erosion. Abrasion of the surface of concrete structures is the result of external forces acting on the concrete. There are four major agents of abrasion.

Waterborne Solids. Sand, small rocks, and debris carried in wave or current action cause abrasion damage at the water line or in the tidal zone. Ice floes can abrade at this elevation. Abrasion also can occur at the mudline, caused by the action of abrasive material carried in the swift current of some rivers.

Friction. The proximity of marine traffic and the continuous friction from attached mooring lines and anchor chains is a source of abrasion.

Propeller Wash. The wash from vessels starting and reversing their propellers repeatedly and quickly (e.g., ferries), can act as a sandblaster on underwater components. Tugboats maneuvering close to bridge piers can have the same effect.

Cavitation. Damage can occur in areas of high water velocity. It is manifested as localized areas of erosion and may be encountered in intakes and spillways. Such damage is similar to scale damage and is mainly cosmetic, although it does reduce the thickness of the member and decreases the cover to steel with its consequential long-term effects. Cavitation damage can be identified in the form of cracks, gouges, and cavities.

B.1.3 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, decrease gas permeability, and consequently reduce carbonation and the availability of oxygen that would promote corrosion.

In saltwater, 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 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 concrete.

B.1.4 Contamination

Certain chemical solutions will attack marine structure components. Various acids, organic acids, alkaline solutions, and salt solutions are all 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 that are leached away. When limestone or dolomite aggregates are used, the acid may dissolve them.

B.2 STEEL STRUCTURES

B.2.1 Steel Deterioration

Typically, the deterioration of steel structures in the marine environment is caused by corrosion, fatigue cracking, and impact or overload damage. Often, two or more of these destructive agents work together to cause the destruction of steel structures.

B.2.1.1 Corrosion. Steel corrosion 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 common in the splash and intertidal zones but also may be found in the submerged zone of the member, particularly near the mudline.

B.2.1.1.1 Progression of Corrosion. The rate and progression of corrosion is determined by numerous factors, including environmental conditions, the type of steel, surface protection, and other parameters.

Environmental conditions include temperature, humidity, and the exposure of the metal. Warm water and air temperatures increase the rate of corrosion, as does high humidity. Exposure to the drying effects of wind and sun decrease corrosion rates, and sheltered areas retain moisture and promote corrosion. 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, increasing the supply of oxygen to the metal. Water movement also can facilitate the removal of the prime layer of corrosion, which normally provides some amount of protection in helping to reduce the rate and progression of corrosion.

In addition, the presence of abrading elements in moving water can remove the prime corrosion and increase the rate of deterioration. Excessive repeated cleaning to facilitate inspection of the same steel member or component can also increase corrosion rates at these sites.

Other factors affecting corrosion include atmospheric pollutants, animal deposits, stray electric currents, galvanic action, and surface growth. Atmospheric pollutants can act similar to salt in water, and acids formed from atmospheric gasses can attack steel directly. Bacteria often destroy the protective film or coating on metals, forming deposits, and occasionally attack the steel itself. Bird droppings retain moisture and form deposits, which chemically attack the steel. Stray electric currents from adjacent sources may promote corrosion by speeding the rate of the electrochemical process. Galvanic action occurs when other metals come in contact with steel and cause corrosion similar to rust. Marine growth on steel located in saltwater can occasionally deter corrosion, but it also can hide areas of damage.

B.2.1.1.2 Characteristics of Corrosion. Types of corrosion are classified according to the manner in which the corrosion attacks the metal.

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 rust is identified by uniform rust or section loss over the entire surface. Rust is made up of many small pits joined together. The corrosion product reduces the corrosion rate by forming a barrier between the metal and the environment.

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 also are often trapped in crevices. Crevice corrosion is typically found within gaps between mating surfaces or between back-to-back members.

Pitting is localized corrosion attack that causes the formation of deep, narrow penetrations into steel surfaces. It is caused by chemical or physical differences, such as imperfections in the steel or debris under the paint. Pitting can increase stress and cause failure by cracking.

Galvanic corrosion occurs when two different metals are in contact in the presence of an electrolyte. The difference in their corrosive potentials produces an electron flow, with one metal becoming the cathode and the other the anode. This effect results in an area of thinning and perforation of the steel. Galvanic corrosion can occur in a single piece of steel because of differing potentials within the material.

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 initiates discontinuities in the metal that act as stress risers, leading to section loss and possible cracks.

Erosion corrosion is the attack on a metal caused by the flow of liquid over the metal surface with sufficient velocity to remove adhering surface corrosion products. It is caused by particle erosion, whereby particles in water abrade the metal surface, wearing away the surface coating of corrosion protection products. Such erosion allows corrosion to attack bare metal continuously and consequently speeds the rate of deterioration. This kind of corrosion is found in areas where river currents, tidal flow, or propeller wash carry particulate matter such as silt and sand. It is usually identified as damage at a particular elevation or band of deterioration on the member.

B.2.1.1.3 Effects of Corrosion. Steel components used in underwater construction that are subject to corrosion are predominantly H-piles, pipe piles, sheet piling, and bracing. Additionally, underwater connections (e.g., bolt, rivets, and welds) also are susceptible to galvanic 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. This type of deterioration is typically characterized by thinning, knife edging, areas of missing sections, and localized buckles.

- 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 buildup in constricted areas can generate pressure that bends or moves components with damaging effects.

B.2.1.2 Fatigue Cracking. Corrosion fatigue is fatigue-type cracking of metal caused by repeated or fluctuating stresses applied in a corrosive environment. Factors determining the development of fatigue cracking are the frequency of traffic, age of the structure, load history, magnitude of stress range, type of connection details, quality of fabricated detail, material fracture toughness, and quality of welds. Cracks may develop at reentrant corners or coped sections, abrupt and large changes in plate width or thickness, concentrations of heavy welds, and insufficient bearing areas for a support. This type of cracking is often difficult to identify because of marine fouling buildup.

B.2.1.3 Impact or Overload Damage. Loads that exceed the capacity of a member or structure may cause deformation or failure. Impact or overload 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, that is, double-bow buckling where the component under compression is fixed at the center point. Deformation of flexural members can also be identified by buckling and elongation as well as by locations of concentrated corrosion in areas of high stress.

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 when a portion has been severed or is missing. The member may be functional but has 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.2.1.4 Biological Deterioration. *Microbiologically induced corrosion* (MIC) is caused by the presence of microbes whose metabolism produces acids and sulfides. These agents can either participate directly in the electrochemical reaction in a corrosion cell or provide alternate routes for such a reaction. Microbiological involvement in corrosion provides additional means by which aggressive ions can be formed and accelerates the corrosion process.

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 is uncommon in underwater marine structures. MIC can be controlled by adjusting pH in certain situations and by cathodic protection in others. An effective prevention and maintenance program for MIC must combine expertise in microbiology and corrosion science.

B.2.1.5 Coating and Wrap Deterioration. Several different types of coatings and wrap materials have been used to protect 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 factory-applied and heat-shrink applications of plastics, concrete, and other materials, are also available.

B.2.1.5.1 Coatings. The most critical aspect of coating application is the preparation of the material surface. Frequently, the breakdown of the coating can be traced back to poor surface preparation. Shop-applied coatings provide greater control over conditions such as cleaning and moisture. However, damage to the coating can occur during transport or installation.

Abrasive blast cleaning is typically preferred because it removes mill scale and provides an anchor pattern as well as cleaning. Structural steel shapes are prone to coating problems because of the 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. Therefore, hand application of the coating with a brush is specified for these areas.

Operational causes of coating deterioration often result from impact damage or a buildup of marine fouling that can breach the coating and allow corrosion of the steel. A poorly adjusted cathodic protection system results in blistering of the coating caused by electroosmosis or hydrogen gas evolution.

B.2.1.5.2 Wraps. Several wrap materials are also available for either shop application or field installation. These products are generally composed of plastic, polyvinyl chloride (PVC) sheet material, or mastic-coated tapes that are installed over field-prepared members. As with coatings, these products are used as a preventative maintenance technique to isolate the steel and prevent the process of oxidation and corrosion.

Deterioration of wrap material may be caused by various factors, including impact damage, ultraviolet radiation, and puncture by marine growth.

B.3 WOODEN STRUCTURES

B.3.1 Wood Deterioration

Deterioration of wooden structures in the marine environment can be caused by biological factors, mechanical means, or chemical agents. Several factors can affect the rate of deterioration.

B.3.1.1 Biological Damage.

B.3.1.1.1 Marine Borers. The two types of marine borers responsible for the majority of the damage to structures in the saltwater environment are crustacean borers and molluscan borers. The *Limnoria* is a crustacean borer. *Teredo, Bankia,* and Pholads are molluscan borers.

Limnoria is a waterborne, surface-boring crustacean. It is also known as the wood louse or gribble. Adults reach a length of ⅛ in. to ¼ in. It is the only marine borer that is free-swimming and can move from member to member. *Limnoria* bores into wood, preferably untreated, as soon as it hatches.

Limnoria bore a tunnel to a depth of ¼ 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 the 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 wooden 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, that typically gives an hourglass shape to piling in the tidal zone. Damage can extend to the mudline. Infestation also can occur through construction damage caused by overdriving, open bolt holes, 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 difficult to locate and assess.

Teredo and *Bankia* are both molluscan borers and members of the Teredinideae family of internal marine borers. They are also known commonly as "shipworms." These clam-like mollusks burrow by rasping with a pair of finely serrated shells on the head of a wormlike body.

The shipworm begins its life cycle as a free-swimming larva that attaches to wood, preferably untreated, and starts boring. It can spread from one member to another only when it is in this free-swimming larval stage. After the wood is bored into, the larvae are imprisoned. A small opening is maintained at the surface of the wood to provide fresh water for respiration and to obtain potential nourishment from seawater. The larvae undergo metamorphosis, 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 attain access to a member through areas where the protective layer is defective or damaged, such as open bolt holes, untreated field cuts, and splits or cracks sustained during construction or during their service life at breaches in the preservative caused by mechanical impact or abrasion. 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. Only a few animals can completely destroy a pile in as little as 6–9 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 wooden member, areas of damage are difficult to visually identify.

Living, actively boring shipworms may only be visible as 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 shipworm infestation 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.

B.3.1.1.2 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. Pholads bore into the surface of the wood making a pear-shaped burrow that enlarges as they grow. *Martesia striata* is the species most commonly associated with wood attack. Adults range in size from 2 in. to 2½ in. long and up to 1 in. in diameter.

As Pholads grow, they enlarge the entrance hole to ¼ in., making it more readily detectable than shipworms. Pholad attack is most severe in the tropical waters of Hawaii and Mexico, but they also have been sighted along the western coast of the United States.

B.3.1.1.3 Fungi. Fungal decay is primarily a problem in the above-water portions of waterfront and bridge structures. However, it can be of concern from a below-water perspective when a structure is situated on a lake or river with regularly fluctuating water levels. In this situation, fungal decay may take hold in an area that is above the waterline when the water level is low. This area may subsequently be underwater when the water level is high.

Fungi require four conditions to grow:

- oxygen (in atmospheric air)
- 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)
- adequate food supply (wood)
- adequate supply of moisture (20% to 50%)

Decay is usually found in areas that have consistent wet–dry cycles. Moisture is often retained at member interfaces and in the vicinity of steel fasteners, spikes, bolts, or drift pins, which provide optimal conditions for fungal attack when temperatures are favorable.

Three groups of fungi can be found growing on wood.

- Wood-destroying fungi: *Brown rot,* common in softwoods, significantly reduces wood strength. The wood becomes brittle, is brown, and displays distinct cross-grain checks. *White rot* attacks hardwoods and causes less loss of strength than brown rot. 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.
- Soft rot: Occurring at high moisture levels, *soft rot* causes the gradual softening and degradation of the wood surface and significantly reduces strength properties.
- Wood stains and molds: *Stains* are spots, streaks, or patches of varying colors that penetrate the sapwood. They are a superficial phenomenon. *Molds* are powdery circular growths of varying colors. They can be brushed off when the wood is dry and do not cause decay. Neither molds nor stains cause decay, but they do indicate conditions favorable to fungal growth.

B.3.1.1.4 Insects. Insect damage occurs primarily to the above-water sections of wooden structures. In some facilities, the water level may shift such that certain members that are generally exposed (dry) may be submerged for periods of time. Should an inspection occur during a high-water period, the inspector should have a basic knowledge of the various wood-destroying insects such as termites, carpenter ants, and buprestid beetles. Like their marine borer counterparts, these insects can cause significant loss of cross-sectional and structural integrity to affected members.

The caddis fly is an insect that can damage wooden piles. It is typically found in freshwater but also can tolerate brackish water. It 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 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 and 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 pile, combined with bacterial and fungal decay as well as the abrasive action of river or tidal currents, can reduce the cross-section of the member and its structural strength.

B.3.1.1.5 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. Presently, little is known about their destructive process. The continuing study of wood-inhabiting microbes may further define the role of bacteria in the breakdown of wood.

B.3.1.2 Mechanical Damage.

B.3.1.2.1 Impact. Wooden components will shear off 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 wooden surface. This damage can compromise the protective coating and expose untreated wood to attack by wood-destroying organisms.

B.3.1.2.2 Abrasion. Abrasion of the surface of wooden members can be caused by floating debris, marine traffic, floating docks, anchoring systems, and waterborne materials such as ice and sand. Areas of wood damaged by abrasion appear worn and smooth. Abrasion damage typically occurs at the waterline and the mudline. The effects of abrasion damage are twofold: gradual reduction in the diameter of the member and damage to the protective coating (which exposes untreated wood to attack by wood-destroying organisms).

B.3.1.2.3 Construction Damage. Wooden members can be damaged during construction. Splits or cracks caused by improper handling and 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.

B.3.1.3 Chemical Damage. Chemicals commonly encountered in a marine environment such as chlorides and sulfates typically do not cause wood degradation. 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 promote fungal decay.

B.4 MASONRY STRUCTURES

Stone masonry is not currently common in marine structure or bridge construction except as ornamentation. However, many older masonry structures are still in use. Granite, limestone, and sandstone are the most common types of stone found in masonry construction.

B.4.1 Masonry Deterioration

Masonry structures in aquatic or marine environments are, like their more modern counterparts, susceptible to various destructive processes that can affect the rock or the mortar and can lead to significant structural damage or destruction.

B.4.1.1 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.

B.4.1.2 Splitting. Splitting of the rock used in masonry occurs when cracks open up in the rocks, eventually breaking the rock into small pieces. It can be caused by volume changes such as seasonal expansion, contractions of the rock, and freeze–thaw cycles. Plant growth also can 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.4.1.3 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 caused by waterborne materials such as sand, debris, and ice. This type of deterioration also can be caused by chemicals (gases and solids) dissolved in the water. Oxidation and hydration of some compounds found in the rocks also can cause damage. Additionally, lichens and ivy can chemically attack the surface of stone, degrading the rock surface.

B.4.1.4 Degradation of Mortar. The mortar used in masonry construction is subject to deterioration. 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. It is not uncommon to find the mortar essentially absent from this area. Abrasion and chemical damage are also agents of mortar deterioration.

B.4.1.5 Marine Borers. Marine borers can attack stone. Rock-burrowing clams called Pholads use chemical secretions to bore into the rock. They make a pear-shaped burrow that enlarges as they grow, up to 2½ in. long and 1 in. deep. This burrowing results in loss of cross-section in the rock under attack.

B.5 COMPOSITE STRUCTURAL COMPONENTS

The use of composite materials for marine and waterfront construction is a relatively new development compared with conventional materials. Consequently, few composite structures are made of composites that can provide long-term information about performance and durability of the various materials and member types.

Fiber-reinforced polymer composites and recycled plastics represent alternative construction materials that typically are 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 because of their low strength. The use of aramid fibers is usually limited to specialty applications of high stress and vibration because of 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 relatively 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 piling is currently available in many proprietary configurations, including

- recycled plastic with steel reinforcement
- recycled plastic with FRP reinforcement
- hollow steel core with a recycled plastic shell (the core may be filled with concrete or sand)
- hollow FRP core with a recycled shell (the core may be filled with concrete or sand)

B.5.1 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.

B.5.2 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.

B.5.3 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.5.4 Overstress Damage

Composite materials often allow significant deflection as a result of heavy loads. Large deflections can result in cracking of the outer shell, potentially compromising the members' 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. Permanent deflections can also result from the hysteresis effect of repeated large deflections. These deflections can render the component ineffective and may lead to damage of adjacent members. Long-term deflection caused by creep also can be a concern with composite materials.

B.6 UNDERMINING AND SCOUR

Scour is the movement of riverbed or seabed material by the action of moving water as a result of current and propeller wash. This movement may result in degradation (erosion) as well as 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.

B.6.1 Types of Scour

Three forms of scour can affect the safety of marine structures and bridges.

- *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* involves the removal of material from the bed and banks across all or the majority of the width of a channel. The scour is caused by increased velocities and results in increased bed shear stresses and subsequent loss of material.
- *Local scour* is the removal of material from an area and is restricted to a minor proportion of the width of the channel or seabed. The main mechanism of local scour is the formation of vortices at the base of piers, piles, or other substructure elements as a result of propeller wash, pipelines, localized currents, or other factors.

Appendix C
BIBLIOGRAPHY

Allen, R.T., ed. *Concrete in Coastal Structures.* London: Thomas Telford, 1998.

American Association of State Highway and Transportation Officials. *Manual for Condition Evaluation of Bridges.* Washington, DC: AASHTO, 1994.

———. *Manual for Maintenance Inspection of Bridges.* Washington, DC: AASHTO, 1983.

American Concrete Institute. *Concrete in Marine Environment.* SP-109. Proceedings, Second International Conference, St. Andrews by the Sea, Canada. Farmington Hills, MI: ACI, 1988.

———. *Concrete Repair Guide.* ACI 546R-96. Farmington Hills, MI: ACI, 1997.

———. *Guide for Evaluation of Concrete Structures Prior to Rehabilitation.* ACI 364.1R-94. Farmington Hills, MI: ACI, 1994.

———. *Guide for Making a Condition Survey of Concrete in Service.* Rev. ed. ACI 201.1R-92. Farmington Hills, MI: ACI, 1998.

———. *Guide for Repair of Concrete Bridge Superstructures.* Rev. ed. ACI 546.1R-80. Farmington Hills, MI: ACI, 1988.

———. *Guide to Underwater Repair of Concrete.* ACI 546.2R-98. Farmington Hills, MI: ACI, 1998.

American Water Works Association. *Disinfection of Water-Storage Facilities.* Rev. ed. Denver: AWWA, 1993.

———. *Inspecting and Repairing Steel Water Tanks, Standpipes, Reservoirs, and Elevated Tanks for Water Storage.* Denver: AWWA, 1986.

California State Lands Commission, Marine Facilities Division. *Marine Terminal Audit Manual.* Rev. ed. California State Lands Commission, 1997.

Code of Federal Regulations. 23 Highways Part 650, Subpart C—National Bridge Inspection Standards.

Collins Engineers, Inc. *Underwater Inspection of Piles.* Washington, DC: United States Department of Commerce. 1989.

Department of Energy (Britain). *Typical Blemishes Visible on the Surface of Concrete Underwater, A Supplementary Classification and Identification.* Offshore Technology Report OTH 87 261. McAlpine Sea Services for DOE, Her Majesty's Stationery Office.

Dismuke, T.D., Coburn, S.K., Hirsch, C.M., eds. *Handbook of Corrosion Protection for Steel Pile Structures in Marine Environments.* Washington, DC: American Iron and Steel Institute, 1981.

Edwards, G.R., et al. *International Workshop on Advanced Materials for Marine Construction.* American Bureau of Shipping. 1997.

Emmons, P.H. *Concrete Repair and Maintenance, Illustrated.* Kingston, MA: R.S. Means Co., 1994.

Federal Highway Administration. *Bridge Inspector's Training Manual/90.* Rev. ed. Washington, DC: United States Department of Transportation, 1995.

———. *Recording and Coding Guide for the Structure Inventory and Appraisal of the Nation's Bridges.* Washington, DC: United States Department of Transportation, 1995.

———. *Underwater Inspection of Bridges.* Washington, DC: United States Department of Transportation, 1989.

Gaythwaite, J.W. *Design of Marine Facilities for the Berthing, Mooring, and Repair of Vessels.* New York: van Nostrand Reinhold, 1990, pp. 432–438.

Han-Padron Associates, LLP. *Program Manual—Waterfront Facilities Inspection and Maintenance Program.* Rev. ed. 1999.

———. *Repair Manual—Waterfront Facilities Inspection and Maintenance Program.* Rev. ed. 1999.

———. *Turbid Underwater Inspection Manual.* 1997.

Heffron, R.E., Goldstick, J. *Inspection Guidelines Manual for New York City Economic Development Corporation Waterfront Facility Inspection Program.* 1999.

Heffron, R.E., Lindner, J. *A New Automated Information System for the Inspection and Repair of Marine Structures.* Proceedings, California State Lands Commission, Prevention First '96 Symposium, 1996.

Highley, T.L., Scheffer, T. *Controlling Decay in Waterfront Structures.* Madison, WI:. US Department of Agriculture, Forest Products Laboratory, 1989.

Holtzhausen, A.H. *Effective Use of Concrete for Breakwater Armour Units.* PIANC Bulletin 90. March 1996.

Japan International Cooperation Agency. *Maintenance of Port and Harbour Facilities.* Japan: Japan International Cooperation Company, 1995.

Kay, T. *Assessment and Renovation of Concrete Structures.* London: Longman Group, 1992.

Malhotra, V.M., Carino, N. *Handbook on Non-Destructive Testing of Concrete.* Boca Raton, FL: CRC Press, 1991.

McLeish, A., ed. *Underwater Concreting and Repair.* London: Edward Arnold, 1994.

Nanni, A., Lista, W.L. Concrete Cracking in Coastal Areas: Problems and Solutions. American Concrete Institute, Compilation 25, *Concrete Durability: Corrosion Protection.*

Naval Facilities Engineering Command. *Conventional Underwater Construction and Repair Techniques.* Report P-990. NAVFAC, 1995.

———. *Harbour and Coastal Facilities Design Manual* Report DM-26. NAVFAC,

———. *Maintenance of Waterfront Facilities.* Report MO-104. NAVFAC, 1978.

———. *Rapid Condition Assessment Manual.* Report 55-95 (24). NAVFAC, 1995.

———. *Specialized Underwater Waterfront Facilities Inspections.* Report MO-104.2. NAVFAC, 1987.

———. *Inspection of Elevated Water Tanks.* Report MO-210.9. NAVFAC, 1990.

———. *Underwater Facilities Inspections and Assessments: Guidelines for Preparation of Reports on Underwater Inspection of Waterfront Facilities.* NAVFAC, 1998.

New Mexico State University. *Comprehensive Bridge Inspection Training Course.* New Mexico State University, Civil Engineering Department, 1991.

Parsons Brinkerhoff. *Bridge Inspection and Rehabilitation.* Silano, L.G., ed. Canada: Wiley, 1993.

PIANC. *Life Cycle Management of Port Structures General Principles.* Belgium: PIANC, 1998.

Port Authority of New York and New Jersey. *Standards for Structural Integrity Inspection of Piers, Wharves and Bulkheads.* New York: Engineering Quality Assurance Division, 1984.

Society for Protective Coatings. *The Inspection of Coatings and Linings: A Handbook of Basic Practice for Inspectors, Owners, and Specifiers.* Pittsburgh: Society for Protective Coatings, 1997.

Strategic Highway Research Program, National Research Council. *Alkali–Silica Reactivity: An Overview of Research.* 1993.

———. *Eliminating or Minimizing Alkali–Silica Reactivity.* 1993.

———. *Handbook for the Identification of Alkali–Silica Reactivity in Highway Structures.* 1991.

Transportation Research Board, National Research Council. *Instrumentation for Measuring Scour at Bridge Piers and Abutments.* Washington, DC: National Academy Press, 1981.

———. *Underwater Bridge Maintenance and Repair.* Washington, DC: National Academy Press, 1994.

———. *Underwater Inspection and Repair of Bridge Substructures.* Washington, DC: National Academy Press, 1981.

United States Army Corps of Engineers. *A Rating System for the Concrete in Navigation Lock Monitors.* REMR-OM-4. Washington, DC: USACE, 1989.

———. *Maintenance and Repair of Steel Pile Structures.* REMR-OM-9. Washington, DC: USACE, 1990.

———. *REMR Management Systems—Coastal/Shore Protection Structures: Condition Rating Procedures for Rubble Breakwaters and Jetties Initial Report.* REMR-OM-11. Washington, DC: USACE, 1991.

———. *User's Manual: Inspection and Rating of Steel Sheet Pile Structures.* REMR-OM-3. Washington, DC: USACE, 1989.

United States Army Engineer Waterways Experiment Station. *Shore Protection Manual.* Vicksburg, MS: Coastal Engineering Research Center, 1984.

United States Department of Commerce. *Repair, Evaluation, Maintenance, and Rehabilitation Research Program. Inspection of the Engineering Condition of Underwater Concrete Structures.* Springfield, VA: National Technical Information Services, 1989.

United States Department of the Interior et al. *International Workshop on Advanced Materials for Marine Construction.* Proceedings, February 4–7, 1997.

Vegsund, E.B., Sommerfeld S.D. *Canadian Department of National Defense Marine Structures Inspection Training Manual.* 1991.

White, K.R., et al. *Bridge Maintenance Inspection and Evaluation.* New York: Marcel Dekker, 1981.

Wolter, S. *Ettringite: Cancer of Concrete.* St. Paul, MN: Burgess Publishing, 1997.

This page intentionally left blank

Appendix D
GLOSSARY

AASHTO: American Association of State Highway and Transportation Officials
Abrasion: wearing away of surfaces by friction
Abutment: foundation or retaining structure at the approach and departure ends of a bridge
ACA Preservative: ammoniacal copper arsenite
ACC Preservative: acid copper chromate preservative
ACZA Preservative: ammoniacal copper zinc arsenite preservative
Aluminum: structural lightweight metal used in ship and dock construction and in sheathing; may be used as a sacrificial anode in cathodic protection against corrosion
Amphipod: smaller division (order) of the larger group (class) of invertebrates known as Crustacea (*Chelura* belong to this order)
Anode: positive electrode of an electrolytic cell
ASR: alkali–silica reaction of aggregate and cement in concrete
ASTM: American Society for Testing and Materials
Atmospheric Pressure: normal pressure of air at sea level (14.7 pounds per square inch)
AWPA: American Wood Preservers Association
Bankia: genus of molluscan marine borers
Bark: outside layer of a tree, composed of living, inner bark (phloem) and an outer bark of dead tissue
Barnacle: encrusting fouling organism belonging to the large general group (class) Crustacea
Batter Pile: 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. or more thick and 8 in. or more wide, graded with respect to its strength when loaded on the narrow face
Bearing Piles: piles in a structure that support the load
Bench Capping: method of replacing damaged piles at higher elevations when more than one pile in line is to be repaired
Bent: transverse pile framing in the structure of a pier

Biological Deterioration: deterioration or damage caused by living organisms
Bitumastic: coating made from materials with high boiling points found in tar
Bleeding: 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 attach to wood in the submerged portions of structures placed in saltwater or brackish water. Two generally recognized groups of borers are crustacean and molluscan.
Boring: 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 saltwater and partly freshwater
Branding: permanent marking on a treated wood product to identify the supplier and date of treatment as well as other information when so specified
Breakwater: structure used to eliminate or reduce the magnitude of wave impinging on the shoreline or vessels behind it
Brown Rot: deterioration caused by a group of fungi producing a brown residue or powder
Bulkhead: structure used in waterfront construction to retain earth fill
Burrow: tunnel or excavation made by marine borers
Caliper: compass or divider with curved legs for measuring diameter of piles
Camel: floating device acting as a fender and used to separate a moored vessel from a pier, wharf, quay, or other vessels
Cap Log: wooden member connecting and protecting the heads of piles; generally not a structural member
Cathode: negative electrode of an electrolytic cell
CCA: chromated copper arsenate; a preservative (see *Greensalt*)
Chafing: abrasion caused by material rubbing against the structure
Check: separation along the grain of the wood that occurs across the annual rings
***Chelura*:** genus of crustacean borers
Chemical Damage: failure of structural members that results from chemical reactions
Chock: piece of wood fitted between two piles to prevent the piles from rolling on impact
Clamped: method of fastening whereby one member is sandwiched between two other members
Clear Water Box: transparent container filled with clean water to provide a transparent path for viewing or photographing objects submerged in dark or dirty water
Cleat: wooden or metal fitting, usually with two projecting horns around which a rope may be fastened; 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: bodies of saltwater bordering the continents and adjacent waters that are subject to tidal flow
Coatings: protective covers to prevent corrosion
Composite: structural member or members made up of disparate materials

Concrete Forms: usually temporary wood or steel structures constructed to retain wet concrete until the concrete sets

Conditioning: 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 wooden joint

Coping: 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: toxic chemical preservative that is particularly effective against insects and destructive fungi

Core: cylinder of wood removed by means of an increment borer from which may be determined sapwood thickness and preservative penetration (by linear measurement) and preservative retention and distribution (by assay)

Corrosion: destruction of a metal by a chemical or electrochemical reaction with its environment

CP: corrosion protection

Crack: split or separation of material

Creosote, Coal Tar: 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. It 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%–50% coal tar.

Creosote, Marine-Grade: 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 wood, concrete, or steel filled with ballast

Crustacea: large group (class) of invertebrate animals. Barnacles, *Limnoria*, *Sphaeroma*, and *Chelura* are examples.

Decay: disintegration of wood substance caused by the action of wood-destroying fungi

Delayed Ettringite Formation (DEF): calcium sulfoaluminate formed when gypsum and hydrated aluminate are combined in concrete

Depassivate: to remove steel's ability to resist corrosion

DGPS: differential geodetic positioning system

Dimension Stock: squares of flat wood, usually in pieces smaller than the minimum sizes admitted by standard lumber grades, that are rough, dressed, green, or dry and cut to the approximate dimension required for the various products of woodworking factories

Dip Treatment: total submergence of a structural member in preservative

Discharge Structure: outfalls at the ends of pipes, where material flowing from pipes enters an ocean or lake; usually concrete or masonry, but can be steel or wood

Dolphins: marine structures for mooring vessels

Dote: like *doze* and *rot*, 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"

Dry Rot: term loosely applied to many types of decay but especially to that which, at an advanced stage, permits the wood to be crushed easily to a dry powder. 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 dry 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 a flood; falling tide

Electrolyte: 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*

Empty Cell Process: method of pressure treating wood without use of a preliminary vacuum

Estuary: area connecting a harbor or open sea and a freshwater river

Evaluate: to determine or set the value of something on the basis of given observations

Fender: device or framed system placed against the edge of a pier or dock to absorb the impact from berthing or berthed vessels

Fir: 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

Flood: rising tide

Flow: direction of movement

Flukes: barb-shaped part of an anchor that digs into the bottom

Fouling: organisms growing on the surfaces of submerged materials

Full Cell Process: method of pressure treating wood using initial vacuum

Fungus: primitive plant in the group that includes molds and mushrooms

Gabion: wire container filled with stones, used for retaining structures

Galvanic: of or relating to a direct current of electricity

Galvanic Corrosion: corrosion known as couple action

Girder: 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 or grade based on the presence or absence of defects such as knots, checks, and decay

Grain: direction, size, arrangement, appearance, or quality of the fibers in wood

Grain, Close: wood with narrow and inconspicuous annual rings. This term is sometimes used to designate wood with small and closely spaced pores, but in this sense, the term *fine-textured* is used more often.

Grain, Coarse: wood with wide and conspicuous annual rings in which there is considerable difference between springwood and summerwood. This 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 called *plain-sawn*

Grain, Interlocking: wood in which the fibers are inclined in one direction in a number of rings of annual growth, 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 hardwood

Grain, Quarter-Sawn: another term for *edge grain,* used generally in hardwood

Grain, Spiral: 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: tropical wood used in marine construction, resistant to marine borer attack

Greensalt: chromated copper arsenate (see *CCA*)

Gribble: common name for the crustacean borer *Limnoria*

Grout: cement–sand mortar of plastic consistency that can be poured easily

Hardwoods: botanical group of trees that are broadleaved. The term has no reference to the actual hardness of the wood.

Heartwood: inner core of a woody stem that extends from the center to the sapwood, usually of a dark 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

Hydrology: study of the constituents of water

Imbed: (see *embed*)

Increment Borer: auger-like instrument with a hollow bit used to extract cores of wood from piling

Infilling: relatively 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): scrutinization and supervision of the purchasing, acquiring, manufacturing, treating, and handling of material for compliance with specification requirements

Inspection (of Structures): 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

Intertidal: 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: electrically charged atom or group of atoms

Isopod: smaller division (order) of the larger group (class) of invertebrates known as Crustacea that includes *Limnoria* and *Sphaeroma*

Jetty: dock or breakwater that projects into the water

Jewelry: hardware fittings on a buoy to which the mooring lines or 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.*

Key: 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 layer floating on concrete during tremie pours; often found in layers at the face of concrete piers or abutments

Laminate: single layer of wood or plastic in an assembly of layers

Leaching: 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 found in older structures

***Limnoria*:** commonly known as gribble, a genus of Crustacea borers causing serious destruction to marine structures

Locks: enclosed chamber in a canal or dam with gates at each end, for raising or lowering vessels from one level to another by admitting or releasing water

Magnesium: 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: structure built with stones or bricks, usually held together with mortar

MHW: mean high water

Mill Scale: heavy oxide layer resulting from hot fabrication or heat treatment of metals

MLW: mean low water

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 (phyla) used in animal classification that includes several of the destructive marine borers

Mudline: point of intersection of the seawater and the bottom soil

Mushroomed: head of a pile that has been subjected to excessive axial load or deterioration such that the wooden fibers have separated, causing the pile head to flatten and resulting in reduced load capacity

Mussels: molluscan fouling organisms

Nacerda: beetle that can cause damage to the superstructure of wharves

Nail, Dating: nail with a date or symbol on its head that is driven into wood to indicate the year of treatment or date of installation

Nearshore: area of the water next to the shoreline

Neat Cement: cement mortar without added sand

NGVD: national geodetic vertical datum; references mean sea level elevation measured in 1929

Nominal Dimension: 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: pile that is not connected to a pile cap such that the pile is not carrying any axial load

NDT: nondestructive testing

Oak: species of hardwood used in waterfront structures

Ogee Washer: special cast washer used in waterfront construction to distribute the load from a bolt and nut to a wooden 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: instrument used to measure the thickness of an object or material; also a magnetic device used to measure the concrete cover over reinforcement or to locate rebar

PCBs: polychlorinated biphenyls; toxic chemicals often found in sediments where waste products from industry have been released into the water. A PCB count is now required before all dredging operations.

PCF: pounds per cubic foot

PDT: partially destructive testing

Penetration: depth to which preservative enters the wood

Penta Preservative: wood-preserving solution made of pentachlorophenol (C_6CL_5OH) dissolved in hydrocarbon solvent. Frequently, an auxiliary solvent is added to increase the solubility of the "penta."

Pentachlorophenol: toxic chemical preservative particularly effective against destructive fungi

Petrographic Analysis: for concrete, used to determine the quality of the aggregate, concrete paste, bonding, and so forth

Pfisteria: disease of the skin and nervous system that may be passed to human beings by infected fish. Symptoms in fish are massive fish kills and ulcerated lesions.

Pholad: molluscan marine borer

Pier: wharf projecting perpendicular to the shoreline

Pile Adrift: old or structurally inadequate pile that has been abandoned for load-carrying capacity and generally is not connected to other members in the structure

Pile Bent: (see *Bent*)

Pile Cap: beam member connecting pile heads and through which deck loads are transmitted to the piles

Pile, Marine: pile that is partly embedded in bottom soil and partly exposed to salty seawater

Pile Top Cap: any cover fastened over the cut surface of a pile to prevent exposure to the atmosphere

Pitting: form of corrosion

Plug, Tie: wood plug (usually treated with preservative) used for filling an old spike hole

Pointing: filling joints or defects in the face of a masonry structure

Polyethylene: plastic material used for sheathing

Polyvinyl Chloride: PVC; plastic material used for sheathing

Posting: method of replacing damaged sections of piles at higher elevations

Posts and Timbers: lumber of square or approximately square cross section, 5 in. × 5 in. and larger, graded primarily for use as posts or columns carrying axial load

Preservative: chemical compound that creates a protective mechanism against destructive organisms

Preservative, Oil-Borne: 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: wood preservative that is introduced into wood in the form of a solution in water

Preservative, Water-Repellent: 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: includes such chemicals or combinations thereof that will protect wood against deterioration from any one or combination of 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: removal of water from the wood before treatment to ensure that the preservative enters and is retained in the wood

Probing: penetrating through the surface with a probe to detect deterioration

psi: pounds per square inch

psia: pounds per square inch absolute; pressure measured with respect to zero pressure

psig: pounds per square inch gauge; pressure measured with respect to the atmosphere

Pulse Velocity/Pulse Echo Testing: use of ultrasonic signals for measuring distance and thickness

Punk: area of decay in a wooden member exhibiting a soft spongy appearance and loss of integrity

Punt: small, flat-bottomed boat with square ends

Rebar: reinforcing steel used in concrete such that the concrete and reinforcement act together in resisting force

Relieved Edges: exposed edges of a wooden plank cut on angle (i.e., chamfered) to reduce edge splintering

Repairs: restoring or replacing to a sound, or good, condition after damage

Resilient: capable of withstanding shock without permanent damage

Retaining Wall: wall for sustaining the pressure of earth or filling deposited behind it

Retention: per unit volume, the quantity of preservative in the wood

Riprap (Rip Rap): rough stone of various sizes placed compactly or irregularly to prevent scour by water

Rubble: fieldstone or rough stone as it comes from the quarry; when large or massive in size, called *block rubble*

Salinity: total salt content in proportion to a unit volume of water

Sapwood: outer, light-colored wood of the tree stem

Scab: a wood member used in posting to provide a positive connection between the post and pile and pile cap

Schmidt Hammer: mechanical device that uses a standard hammer for testing the condition of a concrete surface

Scour: condition whereby bottom material has been washed away from a pile or structure that penetrates the bottom

Seasoning: evaporation or extraction of moisture from green or partially dried wood

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

Shake: separation along the grain of the wood that occurs between the annual rings

Sheathing: exposed face material used in bulkhead construction

Sheeting: lining of planks or boards for supporting an embankment, usually placed vertically and supported by walers, braces, and piles

Shim: 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

Silver/Silver Chloride: reference cell for electrolyte potential measurements in seawater

Skiff: a small rowboat

Soft Rot: deterioration of wood components by certain molds and other fungi that are outside of the common wood-destroying group, often without visual distortion or apparent damage to the wood. The affected wood is likely to be extremely brittle and break without splinters.

Softwoods: botanical group of trees with needlelike or scalelike leaves, often referred to as conifers. The term has no reference to the softness of the wood.

Sonar and Side-Scan Sonar: ultrahigh-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 sonar* transmits signals at an angle less than 90 degrees.

Sonar, Multibeam: sonar transmitted in a 180-degree pattern to record bottom topography, scour, and depth over a wide swath in a single pass

Sounding: method used to determine interior deterioration in wood and concrete; method used to determine the depth of the bottom below water

Spalling: chipping or fragmentation of a 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: replacement of the damaged portion of a pile

Split: 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: discoloration of wood indicating the presence of fungus

Steel Sheetpile Wall: bulkhead composed of driven vertical or near-vertical steel sheet sections interlocked to form a continuous wall; sometimes tied back to anchors

Stringer: horizontal wooden member spanning between pile caps used to support decking

Structural Deterioration: 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.

Subdecking: area beneath the surface decking

Surf Condition: site that is usually adjacent to a well-established beach condition and facing more or less open sea

Surface Treatment: application of a preservative on the surface by means of a brush, swab, or spray gun

Synthetic Resin: chemical sometimes used for impregnating piles

Tar: generic term applied to nonaqueous liquids obtained as residue in the destructive distillation of organic materials such as coal, lignite, petroleum, and wood

Tar, Coal: nonaqueous portion of the liquid distillate obtained during the carbonization of bituminous coal

Tender: individual responsible for the diver's welfare during an inspection; also a small boat

***Teredo*:** genus of molluscan marine borers, commonly called shipworm

Teredo Tube: tubular residue left by *Teredo* borers

Tidal: of, relating to, caused by, or having tides

Tide: periodic rising and falling of the surface of the ocean and other water bodies

Tie Back or Tie Rod: generally, a tension rod with anchorage used to restrain a wall from movement or displacement

Timber: broad term including standing trees and certain products cut from them, including lumber 5 in. or larger in least nominal dimension

Topography: 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, for example, 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: treatment in which air imprisoned in the wood is used 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: 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 by gravity or by pumping concrete underwater where the concrete does not fall directly through the water but rather through a pipe or hose

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 varieties cause rashes on divers

Ultrasonic Thickness Measurement: measurement made from one side of a material using ultrasonic wave transmission and return to determine thickness

Wale or Waler: 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: preservative that is soluble in water

White Rot: deterioration caused by a group of fungi that cause "bleaching" of the wood

Windsor Probe: device used to determine the strength of concrete by shooting a standardized probe into the concrete and measuring the depth of embedment

Wolman Salts: Fluor Chrome Arsenate Phenol Type A

Wood: broad term including standing trees and certain products cut from them, including lumber 5 in. or larger in least nominal dimension

Wood Preservation: art of protecting wood against the action of destructive agents; usually refers to the treatment of wood with chemical substances (preservatives) that reduce its susceptibility to deterioration by fungi, insects, and marine borers

***Xylophaga*:** genus of wood-boring pholads

Zinc: metal used for pile caps; also may be used as a sacrificial anode in cathodic protection against corrosion

This page intentionally left blank

INDEX

The use of 'n' following the page number indicates the information will be found in a note.

above-water inspections 3
abrasion damage 105, 114, 115. *See also* defects and deterioration
abutments. *See* bridges
action choices
  guidelines 22
  guidelines by type (figure 2-2) 24
  recommendations (table 2-6) 23
administration
  agreements 49
  insurance 50–52
  personnel qualifications 15, 18–19
alkali-carbonate reactions (ACR) 103. *See also* defects and deterioration
anchors 87–91. *See also* floating structures; marinas
  inspection checklist (table A-12) 89
architectural plans 30–31
assessment ratings 11

baseline inspections 30–31
  action guidelines (figure 2-2) 24
  action recommendations 29
  described 5, 6
  documentation 30–31
  levels of effort 26–27, 31
  methods 30–31
  objectives 30
  purpose and frequency 9
  purpose and frequency (table 2-1) 8
  scope of work 9
biological deterioration 105, 110, 111–114, 116. *See also* defects and deterioration
bracing. *See* open-piled structures
breakwaters 83–86
  inspection checklist (table A-10) 85
bridges 53–58
  inspection checklist (table A-1) 55
bulkheads. *See* retaining structures
buoys. *See* moorings
buttress walls. *See* gravity structures

carbonation 103–104. *See also* defects and deterioration
cathodic protection systems 34, 91, 93–98
  inspection checklist (table A-13) 94
cavitation 105. *See also* defects and deterioration
cellular degradation 114. *See also* defects and deterioration
certification requirements. *See* personnel requirements
channel bottom inspections 38
chemical damage 114. *See also* defects and deterioration
coating protection systems 34, 110. *See also* defects and deterioration
composite structural components
  defects and deterioration 116–117
  inspection intervals (table 2-2) 10
  inspection levels (table 3-1) 28
  inspection methods 37
  materials 116

composite structural components—*continued*
sampling, size and methods (table 3-2) 33
concrete structures
defects and deterioration 35–36, 99–106
inspection intervals (table 2-2) 10
inspection levels (table 3-1) 28
inspection methods 35–36
sampling, size and methods (table 3-2) 32
condition assessment ratings 20
conduits 72–74
inspection checklist (table A-6) 74
construction damage 114. *See also* defects and deterioration
construction drawings 30–31
construction (new) inspections 27–30
action recommendations 29, 31
described 5, 6
documentation 29
methods 29
objectives 27
personnel qualifications 18–19
purpose and frequency 7, 9
purpose and frequency (table 2-1) 8
scope of work 9
construction (repair) inspections
action recommendations 42
costs 3
described 6
documentation 42
methods 42
objectives 41–42
personnel qualifications 18–19
purpose and frequency 13–14
purpose and frequency (table 2-1) 8
scope of work 14
contamination 106. *See also* defects and deterioration
contracts. *See* administration, agreements
corrosion 100–102, 107–109. *See also* defects and deterioration
corrosion damage 117. *See also* defects and deterioration
costs
reducing 3, 4
repair (construction) 3
cracking 100, 109. *See also* defects and deterioration
crib structures. *See* gravity structures

damage
abrasion 105, 114, 115
chemical 114
construction 114
corrosion 117
erosion 105
impact 105, 109, 114
insect 113–114
mechanical 105–106, 114–115
overload 105, 109
overstress 117
dams. *See* hydraulic structures
decay, fungal 112–113. *See also* defects and deterioration
decks, open-piled structures. *See* open-piled structures
defects and deterioration
cathodic protection systems 95–96
composite structural components 116–117
concrete structures 35–36, 99–106
environment conducive to 2–3
inspection intervals (table 2-2) 10
masonry structures 115–116
scour 117–118
special inspections 12–13
steel structures 34, 106–111
underminining 117–118
wooden structures 36–37, 111–115
design drawings 30–31
design repair inspections
action guidelines (figure 2-2) 24
action options (table 2-6) 23
action recommendations 40
described 6
documentation 39–40
methods 39–40
objectives 38–39
purpose and frequency 11–12
purpose and frequency (table 2-1) 8
scope of work 12

deterioration. *See* defects and deterioration
disasters. *See* post-event inspections
docks (dry) 74–78
documentation 45, 47–48
  baseline inspections 30–31
  construction (new) inspections 29
  for construction payments 13–14
  contractor claims 13–14
  inspection report (routine) 45–47
  post-event inspections 14, 44
  repair (construction) inspections 42
  repair (design) 6
  repair design inspections 39–40
  routine inspections 6, 32–34, 45–48
  special inspections 41
dry docks 74–78
  inspection checklist (table A-7) 74

encasements 35, 36
engineering evaluations
  action options (table 2-6) 23
  routine inspections 11
environment types 10n
erosion damage 105. *See also* defects and deterioration
evaluations, engineering
  action options (table 2-6) 23
  routine inspections 11

fender systems. *See* bridges
floating structures 80–83. *See also* marinas
  inspection checklist (table A-9) 82
freeze-thaw deterioration 104. *See also* defects and deterioration
fungal decay 112–113. *See also* defects and deterioration

galvanic anode systems. *See* cathodic protection systems
gates and locks 78–80
  inspection checklist (table A-8) 74
glossary 123–134
gravity structures 60–65. *See also* tower bases
  inspection checklist (table A-3) 63
gridirons. *See* dry docks

health safety requirements 92
honeycombs 104. *See also* defects and deterioration
hydraulic structures 69–72
  inspection checklist (table A-5) 71

impact damage 105, 109, 114. *See also* defects and deterioration
impressed current systems. *See* cathodic protection systems
insect damage 113–114. *See also* defects and deterioration
inspections
  above-water 3
  action guidelines 22–24
  action guidelines by type (figure 2-2) 24
  action options (table 2-6) 23
  activities flowchart (figure 2-1) 7
  baseline 5, 6, 9, 30–31
  baseline-action guidelines (figure 2-2) 24
  channel bottom 38
  construction (new) 5, 6, 7–9, 27–30
  excavation in 3
  frequency 7–15
  frequency (table 2-1) 8
  importance of 2–3
  levels of effort 26–27
  levels of effort summary (table 3-1) 28
  limits of 3–4, 25–26
  mudline 38
  objectives and types matched (table 2-3) 16–17
  organization 4
  personnel qualifications 15, 18–19
  post-event 7, 14–15, 19, 20, 42–44
  post-event-action guidelines (figure 2-2) 24
  post-event assessment principles (table 2-4) 21–22
  purpose 1
  purpose (table 2-1) 8
  ratings and prioritization 19–22
  repair (construction) 6, 13–14, 41–42
  repair (design) 6, 11–12, 38–40
  repair (design)-action guidelines (figure 2-2) 24

inspections—*continued*
  repair (design)-action options (table 2-6) 23
  routine 5, 6, 9–11, 19, 31–38
  routine-action guidelines (figure 2-2) 24
  routine interval maximums (table 2-2) 10
  sampling, size and methods (table 3-2) 32–33
  slope protection 37
  sonar 37, 38
  sonar techniques 37, 38
  special 6, 12–13, 17n, 40–41
  special-action guidelines (figure 2-2) 24
  special-action options (table 2-6) 23
  structural boundaries 25–26
  techniques 13
  types and action guidelines (figure 2-2) 24
  types and objectives matched (table 2-3) 16–17
  types of 5–7
  types of (table 2-1) 8
insurance 50–52
intakes. *See* hydraulic structures

Limnoria 111–112. *See also* defects and deterioration
locks and gates 78–80
  inspection checklist (table A-8) 74

maintenance 2, 6
management. *See* administration
marinas 65–68
  inspection checklist (table A-4) 66–67
masonry structures 115–116
  defects and deterioration 115–116
  inspection methods 37
material incompatibility 117. *See also* defects and deterioration
mechanical damage 105–106, 114–115. *See also* defects and deterioration
moorings 87–91
  inspection checklist (table A-12) 89
mortar degradation 115–116. *See also* defects and deterioration
mudline inspections 38

open-piled structures 58–60. *See also* tower bases
  inspection checklist (table A-2) 59
outfalls. *See* hydraulic structures; marinas
overload damage 105, 109. *See also* defects and deterioration
overstress damage 117. *See also* defects and deterioration

penstocks. *See* hydraulic structures
personnel qualifications 15, 18–19
Pholads (clams) 112, 116. *See also* defects and deterioration
piers. *See* bridges
pile bents. *See* bridges
pile caps. *See* open-piled structures
piles. *See* open-piled structures
pipelines 72–74
  inspection checklist (table A-6) 74
plans, architectural 30–31
pontoons. *See* floating structures
pop-outs 104–105. *See also* defects and deterioration
post-event inspections
  action guidelines (figure 2-2) 24
  action recommendations 44
  condition ratings 20
  condition ratings (table 2-4) 21–22
  described 6, 7
  documentation 44
  methods 43
  objectives 42–43
  purpose and frequency 14
  purpose and frequency (table 2-1) 8
  rating (assessment) system 19
  ratings and prioritization 44
  scope of work 14–15
powerhouses. *See* hydraulic structures
propeller wash 105. *See also* defects and deterioration
protection systems (cathodic) 93–98
public protection and safety 2, 3

quality control 3, 6

railways. *See* dry docks
rating systems 20
repair (construction) inspections
  action recommendations 42
  costs 3
  described 6
  documentation 42
  methods 42
  objectives 41–42
  personnel qualifications 18–19
  purpose and frequency 13–14
  purpose and frequency (table 2-1) 8
  scope of work 14
repair (design) inspections
  action guidelines (figure 2-2) 24
  action options (table 2-6) 23
  action recommendations 40
  described 6
  documentation 39–40
  methods 39–40
  objectives 38–39
  purpose and frequency 11–12
  purpose and frequency (table 2-1) 8
  scope of work 12
reports. *See* documentation
retaining structures 60–65
  inspection checklist (table A-3) 63
revetments. *See* retaining structures
routine inspections
  action guidelines (figure 2-2) 24
  action recommendations 38
  channel bottom 38
  composite components 37
  concrete components 35–36
  described 5–6
  documentation 32–34, 45–48
  evaluation and rating 38
  interval maximums (table 2-2) 10
  levels of effort 26–27, 32
  masonry components 37
  methods 32–34
  mudline 38
  objectives 31–32
  purpose and frequency 9–11
  purpose and frequency (table 2-1) 8
  rating (assessment) system 19
routine inspections—*continued*
  sampling, size and methods (table 3-2) 32–33
  scope of work 11
  slope protection 37
  steel components 34–35
  visual/tactile (level I) 11
  wood components 36–37

safety, public 2, 3, 92
scale 104. *See also* defects and deterioration
Schmidt Hammer testing 31
scope of work
  baseline inspections 9
  construction (new) inspections 9
  post-event inspections 14–15
  repair (construction) inspections 14
  repair design inspections 12
  routine inspections 11
  special inspections 13, 17n
scour
  bottom 57–58
  channel bottom inspections 38
  defects and deterioration 117–118
  inspection intervals (table 2-2) 10
seawalls. *See* gravity structures
sheet pile cell structures. *See* gravity structures
slope protection inspection 37
sonar inspection 37, 38
spalling 115. *See also* defects and deterioration
special inspections
  action guidelines (figure 2-2) 24
  action options (table 2-6) 23
  action recommendations 41
  defects and deterioration 12–13
  described 6
  documentation 41
  methods 41
  objectives 40–41
  purpose and frequency 12
  purpose and frequency (table 2-1) 8
  scope of work 13, 17n
splitting 115. *See also* defects and deterioration
spud piles. *See* floating structures

steel structures
  defects and deterioration 34, 106–111
  inspection intervals (table 2-2) 10
  inspection levels (table 3-1) 28
  inspection methods 34–35
  sampling, size and methods (table 3-2) 32
storage facilities 91–92

tanks 91–93
tension lines. *See* floating structures
testing 13, 31
tower bases 86–87
  inspection checklist (table A-11) 87
training requirements 2, 19
tunnels. *See* hydraulic structures

ultraviolet deterioration 117. *See also* defects and deterioration
undermining 117–118
utilities. *See* marinas

vertical lifts. *See* dry docks
volumetric expansion 102–103. *See also* defects and deterioration

waterfront structures. *See* individual structures, e.g. docks
wave attenuators. *See* marinas
Windsor Probe testing 31
wooden structures
  defects and deterioration 36–37, 111–115
  inspection intervals (table 2-2) 10
  inspection levels (table 3-1) 28
  inspection methods 36–37
  sampling, size and methods (table 3-2) 33
wrap protection systems 34–37, 110–111. *See also* defects and deterioration