NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM
SYNTHESIS OF HIGHWAY PRACTICE **88**

UNDERWATER INSPECTION AND REPAIR OF BRIDGE SUBSTRUCTURES

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TRANSPORTATION RESEARCH BOARD
NATIONAL RESEARCH COUNCIL
WASHINGTON, D.C. DECEMBER 1981

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Systematic, well-designed research provides the most effective approach to the solution of many problems facing highway administrators and engineers. Often, highway problems are of local interest and can best be studied by highway departments individually or in cooperation with their state universities and others. However, the accelerating growth of highway transportation develops increasingly complex problems of wide interest to highway authorities. These problems are best studied through a coordinated program of cooperative research.

In recognition of these needs, the highway administrators of the American Association of State Highway and Transportation Officials initiated in 1962 an objective national highway research program employing modern scientific techniques. This program is supported on a continuing basis by funds from participating member states of the Association and it receives the full cooperation and support of the Federal Highway Administration, United States Department of Transportation.

The Transportation Research Board of the National Research Council was requested by the Association to administer the research program because of the Board's recognized objectivity and understanding of modern research practices. The Board is uniquely suited for this purpose as: it maintains an extensive committee structure from which authorities on any highway transportation subject may be drawn; it possesses avenues of communications and cooperation with federal, state, and local governmental agencies, universities, and industry; its relationship to its parent organization, the National Academy of Sciences, a private, nonprofit institution, is an insurance of objectivity; it maintains a full-time research correlation staff of specialists in highway transportation matters to bring the findings of research directly to those who are in a position to use them.

The program is developed on the basis of research needs identified by chief administrators of the highway and transportation departments and by committees of AASHTO. Each year, specific areas of research needs to be included in the program are proposed to the Academy and the Board by the American Association of State Highway and Transportation Officials. Research projects to fulfill these needs are defined by the Board, and qualified research agencies are selected from those that have submitted proposals. Administration and surveillance of research contracts are the responsibilities of the Academy and its Transportation Research Board.

The needs for highway research are many, and the National Cooperative Highway Research Program can make significant contributions to the solution of highway transportation problems of mutual concern to many responsible groups. The program, however, is intended to complement rather than to substitute for or duplicate other highway research programs.

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PREFACE

There exists a vast storehouse of information relating to nearly every subject of concern to highway administrators and engineers. Much of it resulted from research and much from successful application of the engineering ideas of men faced with problems in their day-to-day work. Because there has been a lack of systematic means for bringing such useful information together and making it available to the entire highway fraternity, the American Association of State Highway and Transportation Officials has, through the mechanism of the National Cooperative Highway Research Program, authorized the Transportation Research Board to undertake a continuing project to search out and synthesize the useful knowledge from all possible sources and to prepare documented reports on current practices in the subject areas of concern.

This synthesis series attempts to report on the various practices, making specific recommendations where appropriate but without the detailed directions usually found in handbooks or design manuals. Nonetheless, these documents can serve similar purposes, for each is a compendium of the best knowledge available on those measures found to be the most successful in resolving specific problems. The extent to which they are utilized in this fashion will quite logically be tempered by the breadth of the user's knowledge in the particular problem area.

FOREWORD

By Staff
Transportation Research Board

This synthesis will be of special interest to bridge maintenance engineers and others concerned with the inspection and repair of bridge elements below the waterline. Problems with substructures are identified, and procedures, equipment, and techniques currently used for underwater inspection are evaluated. The methods and materials used for maintenance and repair of bridge substructures below the waterline are also described.

Administrators, engineers, and researchers are faced continually with many highway problems on which much information already exists either in documented form or in terms of undocumented experience and practice. Unfortunately, this information often is fragmented, scattered and unevaluated. As a consequence, full information on what has been learned about a problem frequently is not assembled in seeking a solution. Costly research findings may go unused, valuable experience may be overlooked, and due consideration may not be given to recommended practices for solving or alleviating the problem. In an effort to correct this situation, a continuing NCHRP project, carried out by the Transportation Research Board as the research agency, has the objective of synthesizing and reporting on common highway problems. Syntheses from this endeavor constitute an NCHRP report series that collects and assembles the various forms of information into single concise documents pertaining to specific highway problems or sets of closely related problems.

Federal and state laws require periodic inspection and appraisal of all bridge elements. A substantial amount of information is available on repair methods for superstructures and substructures above the waterline, but procedures for use below the waterline have received little emphasis and application is complicated by inaccessibility. As a result, deficiencies, including scour and structural distress, damage, and deterioration, are not always detected or are endured until the potential for a major failure becomes apparent.

This report of the Transportation Research Board provides information on procedures, equipment, and techniques for underwater inspection and repair of bridge substructures. A related study, NCHRP Project 10-16, is scheduled for completion in August 1982 and has as its objectives: (a) development of improved methodology for evaluating the effects of underwater deficiencies on the structural capacity of the substructure, and (b) development of solutions to specific deterioration problems that are found in bridge substructures below the water surface and in the splash zone.

To develop this synthesis in a comprehensive manner and to ensure inclusion of significant knowledge, the Board analyzed available information assembled from numerous sources, including a large number of state highway and transportation departments. A topic panel of experts in the subject area was established to guide the researcher in organizing and evaluating the collected data, and to review the final synthesis report.

This synthesis is an immediately useful document that records practices that were acceptable within the limitations of the knowledge available at the time of its preparation. As the processes of advancement continue, new knowledge can be expected to be added to that now at hand.

CONTENTS

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Adrian G. Clary, Engineer of Maintenance, Robert J. Reilly, Projects Engineer, and Lawrence F. Spaine, Engineer of Design, of the Transportation Research Board, assisted the Project 20-5 Staff and the Topic Panel.

Information on current practice was provided by many highway and transportation agencies. Their cooperation and assistance were most helpful.

UNDERWATER INSPECTION AND REPAIR OF BRIDGE SUBSTRUCTURES

SUMMARY

The life of any bridge depends on the preservation of the physical integrity of both the superstructure and substructure; therefore, the implementation of an adequate inspection, maintenance, and repair program for the entire structure is essential. However, because there have been few catastrophic failures of bridges, there has been minimal interest in underwater inspection. Unfortunately, in many cases, the condition of the parts of the substructure located under water is not as easily determined as the condition of those parts located above water.

The quality of inspection under water should be equal to the quality of inspection above water. Inspection of the underwater portions of structures is more difficult; the harsher environment affects the inspector's mobility, visibility, and such functions as cleaning and sampling. However, properly trained, equipped, and supervised personnel can do an effective job.

Each state transportation agency must evaluate its own underwater inspection needs and choose the best method for performing the inspections: contracting with engineering firms and divers for all underwater inspections; using in-house dive teams; or using a combination of in-house and contract divers. The decision by an agency to use either contract or in-house inspectors should be based on the need for a full-time team, the ability to use the team in other assignments, and comparison of the costs of total contract, partial contract, and total agency teams.

The importance of personnel being qualified both as divers and bridge inspectors is recognized by several state agencies. However, there is some disagreement concerning which ability should be primary. Some divers believe that they can be easily trained to be inspectors, whereas some agencies have indicated that young, healthy bridge engineers and inspectors can be better trained as responsible divers. Nonengineer inspectors are being employed with increasing confidence, with the current use of television (including video tape) and photography. The person in charge of the underwater inspection should be well-trained in structural inspection and have a good knowledge of the structure and the capabilities of the inspection team.

A diver is confronted with natural forces and physiological effects not encountered in the normal environment, which impose definite limits and may cause serious accidents. Many potential dangers are usually completely avoidable. It is suggested that employers of diving personnel develop manuals of safe practice for each type of diving operation. Scuba and surface-supplied air diving, using air as the breathing medium, are the two methods of diving operations most applicable to bridge inspections.

The frequency of underwater inspection ranges within agencies from after each major storm to 5 years or only when there is some indication of a problem. Level of inspection ranges from swim-throughs to in-depth detailed inspections.

Cleaning marine growth from the underwater portions of the bridge is almost always necessary in an underwater inspection. The extent of the cleaning depends on the amount of growth present and the type of inspection; indiscriminate cleaning should be avoided. Light cleaning can be done with a diver's knife or with hand tools. Tough jobs on concrete and steel require a high-pressure water blaster.

Visual examination is the primary method of detecting underwater problems.

However, in turbid water, the inspector must use tactile examination to detect flaws, damage, or deterioration. In some cases, ultrasonic thickness gauges, computerized tomography, or television cameras may be required. Samples may be taken to help identify the problem and the extent of damage.

Scour around piers and abutments is one of the problems that can be detected by inspection. Other problems include the deterioration of wood caused by marine-borer infestation; corrosion of steel; cracks, spalls, and cavities in concrete; and structural damage caused by construction, collision, abrasion, or storms. Structural failure resulting from overload, foundation failure, or maintenance failure may also be revealed during underwater inspection.

Transportation agencies develop schedules for maintenance and repair of above-the-water portions of bridges; however, this practice is not as widespread for the underwater elements. A prerequisite of the maintenance or repair of underwater structures is an understanding of the causes of the deterioration or damage.

The recent increase in underwater inspections by transportation agencies has resulted in an increased awareness of the need for underwater repair. However, there are fewer options available for underwater maintenance and repair than for above water, and there is less certainty that the work will be done satisfactorily. Decisions on the various methods of repair entail weighing risks and costs, and require expert engineering knowledge, experience, and judgment.

Determining the most effective solution to a scour problem is difficult. In some cases, certain remedial work could be detrimental to the structure or the channel. Repair of damage caused by scour may be accomplished by replacement of the material, placement of sheet piling, construction of training works, or modification of the structure.

Problems with underwater concrete durability are often related to chemical processes in a marine environment, chemical reaction within the concrete mass, and corrosion of reinforcing steel. Most repairs to concrete substructures involve sealing cracks, patching, filling cavities, and encasing concrete members. Epoxies, epoxy mortar, and quick-setting cements are used for concrete maintenance and repairs. The concrete may be placed with a bucket or a tremie, pumped, or placed in bags.

Metallic and nonmetallic coatings and cathodic protection are used to prevent steel members from corroding; concrete encasement of steel can also be used. Repairs to steel members are made by bolting or welding in new sections.

Protective barriers can prevent damage to wood members by marine borers. Underwater piling and other wooden members can be spliced or even replaced where there is sufficient work space. Cast-in-place concrete jackets are used when 20 percent or more of the wood-pile cross section has been damaged or lost. Fabric socks, oil drums, and glass-reinforced plastics are used as form materials. Precast half-cylinders have also been used to protect or strengthen wood piles.

Once below-the-waterline deficiencies have been detected and repair methods selected, the work should be performed as soon as possible, because defects progress rapidly and delays in repair procedures can increase the cost of repairs.

Agencies should review their experience with underwater structures at different locations under various conditions. Some inspection and repair techniques can be generally employed, but many problems necessitate custom solutions.

Research is needed to develop more corrosion-resistant steels for underwater structures. Problems with adhesion, thickness, workability, durability, compatibility, and strength of coatings require study. Research and development in the use of cathodic protection is recommended, as is research on more effective treatments for protection against marine borers.

CHAPTER ONE

INTRODUCTION

NEED FOR UNDERWATER INSPECTION

Because there have been few catastrophic failures of bridges, there has been minimal interest in underwater inspection. Some substructure components have never been inspected as inspection below the waterline is a difficult procedure. Although it is hoped that future inspections will not identify any serious problems, aging structures, greater loads, and recent unusual weather all contribute to making underwater inspection an essential procedure today. Yesterday's technology enabled the construction of underwater structures; today's technology permits inspection of these structures, correction of construction errors, and performance of maintenance and repair work.

The bridge substructure is the structural element that serves as a link between the superstructure and the supporting material. The top of the substructure provides the bearing surface for the support of the superstructure, whereas the lower part or foundation transmits to the supporting soil all the loads and forces acting on the bridge, including those acting on the substructure itself. The ratio between the construction cost of the substructure and the cost of the superstructure varies according to the physical characteristics of the crossing and the type of bridge. In general, the cost of the substructure is always a substantial percentage of the total construction cost of the facility, and, in many cases, this cost equals or closely approaches the cost of the superstructure.

The life of any bridge depends on the preservation of the physical integrity of both the superstructure and the substructure; therefore, the implementation of an adequate inspection, maintenance, and repair program for the entire structure is essential. Unfortunately, in many cases, the condition of the parts of the substructure located out of sight, below the waterline, is not as easily determined as the condition of those parts of the substructure located above the waterline and that of the superstructure.

Purpose of Synthesis

This report is based on a survey of the practices of each of the state highway agencies, selected railroads, and turnpike and bridge authorities in order to identify the policies, procedures, and techniques currently used to inspect underwater bridge substructures. A summary of the results of the survey is presented in Tables 1 and 2. The purposes of this synthesis are:

- To identify the problems with respect to various materials and types of substructures;
- To synthesize and evaluate current underwater inspection procedures, equipment, and techniques;
- To consider the procedures, techniques, and materials used for maintenance and repair of bridge substructures below the waterline;
- To recommend the best procedures; and
- To suggest areas in need of modification or improvement.

INSPECTION PERSONNEL

Bridge inspections must be carried out by experienced inspectors and engineers. The qualifications of inspection personnel are clearly defined by the American Association of State Highway and Transportation Officials (AASHTO) (*1*) and the Federal Highway Administration (FHWA) (*2*). Underwater inspections require a professional level of effort; the "out-of-sight, out of mind" point of view can no longer be accepted. Many state agencies have recognized that competent engineering inspections of underwater structural elements (Figure 1) are essential and have assumed the responsibility for such underwater inspections.

Inspection of the underwater portions of structures is different from that of the visible parts; the harsher environment affects the inspector's mobility, visibility, and such functions as cleaning and sampling. However, properly trained, equipped, and supervised personnel can do an effective job. The individual performing underwater bridge inspection must have considerable knowledge of the proper use and care of diving equipment, safety requirements, communication techniques, and diving operations. The inspector must (a) be capable of working under adverse conditions, such as deep, cold water and poor visibility; (b) have comprehensive knowledge of the design and construction features of bridge substructures; (c) properly interpret and report what is observed; (d) be able to recognize any structural deficiency and assess its seriousness; and (e) identify incipient problems so that preventive action can be taken.

The inspection checklist for piers and bents used in Louisiana (Figure 2) outlines the responsibilities of inspectors.

In-House and Contract Employees

Underwater inspection of bridges and other structures is performed by either agency or contract personnel. When the inspectors (dive team) are agency employees, the required education and experience and the physical requirements are

TABLE 1
INSPECTION OF UNDERWATER BRIDGE SUBSTRUCTURES: PRACTICES OF STATE TRANSPORTATION AGENCIES (1980)

	① Does your agency routinely inspect existing bridge substructures below the waterline?	② If so, is this in conjunction with the above-the-waterline inspection of the substructure and superstructure?	③ If underwater inspections are conducted, what is the frequency of inspection? (A) One year (B) Two years (C) Other	④ What are the required personnel qualifications for underwater inspections? Professional: (A) Licensed engineer (B) Engineer (C) Diver supervised by licensed engineer (D) Other Diving: (A) Scuba certifications (B) Professional diver (C) Other	⑤ What degree of detail is required in routine inspection? (A) Spot check (B) Spot clean and check (C) Complete detailed inspection (D) Complete cleaning and detailed inspections (E) Other	⑥ What equipment is employed in routine inspections? Dive: (A) Scuba (B) Surface supply (C) Other Tools: (A) Scrapers (B) Hammers (C) Probes (D) Photographic (E) Closed circuit TV (F) Other	⑦ What techniques and equipment are employed when inspection is conducted in turbid water where visibility is poor or nil? (A) Utilization of clear water mask and artificial light (B) Tactile inspection (C) Wait for better visual conditions (D) Other	⑧ Are depth soundings taken during routine inspections? (A) Lead line (B) Echo sounder (C) Other (D) None	⑨ Are any non-destructive testing (NDT) techniques employed in either routine or condition inspection? (A) Ultrasonic (B) Vibrational analysis (C) Acoustic emission analysis (D) Radiography (E) Magnetic particle (F) Corrosion potential (G) Core samples (H) Petrography (I) Other (J) No NDT	⑩ Are any underwater monitoring devices employed to determine the extent of crack progression? Please describe.
ALABAMA	Yes	No	C(5 years)	Pro: C Div: B	C	Div: A,B Tls: A,B,C,D	B	B	F,G	No
ALASKA	No	—	—	Pro: A Div: A	—	—	—	—	—	—
ARIZONA	No	—	N/A	N/A	N/A	N/A	C	N/A	N/A	N/A
ARKANSAS	No	No	—	Pro: C Div: B	C	Div: A Tls: A,B,C	B,C	B	J	No
CALIFORNIA	No	N/A	C(Very infrequently)	Pro: C Div: A,B	A	Div: B Tls: B,C	N/A	A,B	J	No
COLORADO	No	—	C(Very infrequently)	—	—	—	—	—	—	—
CONNECTICUT	Yes	Yes	B,C(Movables annually)	Pro: C Div: A,B,C(Ex-navy divers)	B,C	Div: A,B Tls: A,B,C	A,B,C	A,B	J	No
DELAWARE	Only if evidence of foundation problems	No	C(As needed)	Pro: C Div: A,B	—	Div: B Tls: C,F(Sounding rod and lines)	B	A,C(Probing)	J	No
FLORIDA	Yes	Yes	B,C(As needed)	Pro: C,D(Diver must be certified bridge inspector) Div: A	B,C,D	Div: A,B Tls: A,B,C,D,E	A,B,C	A	A,F,G	—
GEORGIA	Yes	No	C(5 years)	Pro: C Div: A	B	Div: A,B Tls: A,B,C,D	B,D(Artificial light)	A	G	No
HAWAII	No	—	—	Pro: — Div: A	—	Div: A,B Tls: A,B,C	—	—	J	—
IDAHO	During low river flows	Yes	B	Pro: C Div: A	C	Div: A Tls: A,C,E	C	A	J	Yes, cathodic protection
ILLINOIS	No	N/A	C(As needed)	Pro: A Div: A	E(Visual check for scour or conc. detr.)	Div: A Tls: A,B,C	B,C	B	J	No
INDIANA	No	—	—	None	—	—	—	—	—	—
IOWA	No	N/A	N/A	N/A	N/A	N/A	N/A	B	J	No
KANSAS	Only when water level drops	Yes	—	Pro: A Div: —	A	Div: — Tls: A,B,C	C	D	J	No
KENTUCKY	Only if evidence of foundation problems	—	—	Pro: C Div: B	—	Div: A Tls: —	—	A	A,C,E,F,G	No
LOUISIANA	Only if evidence of foundation problems	No	C(As needed)	Pro: C Div: B	E(Depends on need)	Div: B Tls: A,B,C,D,E,F(Air comp., sand blaster, water blaster air tools)	—	A,B,C(Rod, tape)	F,G	No
MAINE	Yes	Yes	C(As needed)	Pro: D(Diver must be supervised by qualified bridge insp.) Div: B	C	Div: A Tls: A,C,E	C	A	J	No
MARYLAND	Yes	Yes	C(4 to 6 years)	Pro: C Div: B	B,D	Div: A Tls: A,B,C,D,E	A,B	A,B	A,D,I(Dye penetrant, eddy current)	No
MASSACHUSETTS	Yes	No	B	Pro: B Div: A,B	C	Div: A Tls: A,B,C,D	A,B	No	G	Yes, meas., photos, sketch
MICHIGAN	No	N/A	C(As needed)	Pro: C Div: A	C	Div: A Tls: C	B	B	J	No
MINNESOTA	Yes	Yes	C(After unusually high water)	Pro: C Div: B	B	Div: A,B Tls: A,B,C,D	B	B	E,F,G	No
MISSISSIPPI	No	—	—	—	—	—	—	—	—	—
MISSOURI	No	—	—	—	—	—	—	B	J	No
MONTANA	No	No	—	—	—	—	—	No	J	No
NEBRASKA	No	—	—	—	—	—	—	—	—	—
NEVADA	Yes	Yes	B	Pro: B Div: —	A	Div: — Tls: C	C	—	J	No
NEW HAMPSHIRE	Yes	No	C(As needed)	Pro: C,D(Chief bridge insp.) Div: B	C	Div: A Tls: A,B,C,D	A,B	C(Occasionally)	J	No
NEW JERSEY	Yes	Yes	C(2 to 3 years)	Pro: C Div. B	C	Div: B Tls: A,B,C,F(Voice comm.)	C	B	J	No
NEW MEXICO	No	N/A	N/A	—	—	—	—	—	—	—
NEW YORK	No	No	C(Very infrequently)	Pro: A,C Div: B	B	Div: B Tls: A,B	B	A	J	No
NO. CAROLINA	Yes	Yes	C(Depends on personnel)	—	B,C	Div: A Tls: A,B,C,D	B,C,D(Artificial light)	A,B	A	No
NO. DAKOTA	No	—	C(As needed)	Pro. A Div: —	A	Div: A Tls: —	A	D	J	No
OHIO	No	—	—	—	—	—	—	A	J	No
OKLAHOMA	No	No	—	Pro. A Div: B	D	Div: B Tls: —	—	—	—	—
OREGON	Yes	No	C(As needed)	Pro: D(Diving coordinator is a structural engineer) Div: A	C	Div. A Tls. A,B,C,D(Measuring rods)	B	A,B,C(Depth gauge)	A,G	No
PENNSYLVANIA	As needed	—	C(After major floods)	Pro: C,D(Consulting eng.) Div: B,C (Approved underwater insp. firms)	E(As specified in proposal)	N/A	Inpections conducted by specialized firms	—	—	—
PUERTO RICO	—	—	—	—	—	—	—	—	—	—
RHODE ISLAND	Yes	No	B	Pro: C Div: B	B	Div: B Tls: A,B,C,D	C	D	J	Probing
SO. CAROLINA	Partial inspection, usually soundings	Yes	B	Pro: D(Bridge inspector) Div: A	C	Div: A Tls: A,B,C	C	A	J	No
SO. DAKOTA	No	No	C(5 to 6 years)	Pro: C Div: A	C	Div: A Tls: A,B,C	C	A,B	J	No
TENNESSEE	No	N/A	N/A	N/A	N/A	N/A	N/A	B,C(Probe with rod)	J	No
TEXAS	As needed	Usually	C(As needed)	Pro: C Div: B	C	Div: A Tls. A,B,C,D,E	A,B,C	A	J	No
UTAH	No	—	—	—	—	—	—	—	—	No
VERMONT	Yes	Yes	C(5 years)	Pro: A Div: A	C	Div: A Tls: B,C,F(Lights)	A	C(Rod readings)	J	No
VIRGINIA	Yes	No	C(5 years)	—	C	Div: A,B Tls: A,B,C	B	D	J	No
WASHINGTON	No	—	—	Pro: A,C Div: B	N/A	N/A	A,B	B	A,G	No
WASHINGTON D.C.	No	—	C(5 to 10 years)	Pro: A Div: B	C	Div: B Tls: F(Two way communication)	A	D	A	—
W. VIRGINIA	No	—	—	—	C	Div: A Tls: A,D	A,B,C	A	J	No
WISCONSIN	No	No	—	Pro: C Div: A,B	C	—	B	A,B	J	No
WYOMING	—	—	—	—	—	—	—	—	—	—

TABLE 1 *continued*

	(11) Is the evaluation of conditions, damages, and need for repair determined by: (A) Inspector (B) Bridge designer (C) Inspector and bridge designer (D) Other	(12) Has your agency performed any underwater maintenance or repair of substructures? Was this work inspected after completion?	(13) Are construction or maintenance personnel pre-qualified to perform specific tasks underwater?	(14) Have you developed any specific or standard procedures for doing underwater repair on any of the following? (A) Concrete for piers (footings/base/shaft) (cracked, spalled, disintegrated, scoured) (B) Exposed reinforcing steel (C) Concrete piles (cracked, spalled, deteriorated) (D) Steel piles (E) Timber piles (F) Other	(15) Have you employed any type of permanent protection (forms, jackets, etc.) on new underwater construction? If "Yes", describe. Results?	(16) What materials, products, or systems have been used for making underwater repairs?	(17) Would you provide copies of any specifications, job instructions, pre-qualifications, etc., you have for underwater work?
ALABAMA	D(Maint. engineer)	Yes.Yes	—	No	No	Epoxy, concrete, hydraulic cements, cutting, non-structural welding & underwater pile splices	Yes
ALASKA	—	—	—	—	—	—	—
ARIZONA	N/A	No	N/A	N/A	No	N/A	N/A
ARKANSAS	B,C	Yes.—	No	No	No	N/A	N/A
CALIFORNIA	—	Yes.Yes	No	A,C,E	No	Rock, tremie concrete	—
COLORADO	—	No	No	No	No	—	—
CONNECTICUT	C	Yes.Yes	No		No	Bag concrete, pressure grouting	Yes
DELAWARE	C(bridge engineer)	Only in tidal zone.Yes	No	C(Jacket filled with concrete)	Yes. Steel sheeting left in place	Splash zone coating on armor plate Fabriform pile jacket, grouted	Yes
FLORIDA	C	Yes.Yes	No	B,C,D	No	Cathodic protection, concrete jackets, structural steel reinforcing	Yes
GEORGIA	C	Yes.Yes	No	No	No	Sand blasting, forms, rip-rap, cathodes for protective systems, submarine cable, assist in core drilling, coat steel H-pile w/ epoxy	N/A
HAWAII	C	Yes.Yes	No	—	No	Concrete	OSHA
IDAHO	C	Yes.Yes	No	No	No	None	Yes
ILLINOIS	C	No	No	F (scour problems)	No	Fiberglass form with aggregate and epoxy injection used at waterline	N/A
INDIANA	—	—	—	—	No	—	—
IOWA	D (Maintenance bridge engineer)	No	No	No	No	—	—
KANSAS	A,B	No	No	No	No	None	N/A
KENTUCKY	C	—	—	No	No	—	—
LOUISIANA	C,D(Bridge maint.)	Yes.No	No	D	No	Epoxies, dense concrete, mortars, steel pipe, vinyl forms, fiberglass forms, timber forms, Symons system, Sea Coatings system, Fox system, Gator Fabricator system	Yes
MAINE	C	No	No	No	No	—	—
MARYLAND	C	Yes.Yes	No	A,B,C,D,E	—	Concrete struts as sacrificial protection to the piles at the waterline limits	Yes
MASSACHUSETTS	C	Yes.Yes	Yes	A,D,E	Yes. Steel sheeting around foundation, concrete protection around pile	Pumped concrete to fill scour hole beneath footing, steel plates used to span deteriorated steel 'H' piles	Yes
MICHIGAN	A	Yes.Yes	No	No	No	—	—
MINNESOTA	C	Yes Yes	No	No	Yes Concrete jackets on piles and piers at waterline	Sand/cement grout to repair scouring. Steel piles underpinning the foundations	Yes
MISSISSIPPI	—	No	—	—	—	—	—
MISSOURI	—	—	—	C	No	—	N/A
MONTANA	—	No	—	No	No	—	—
NEBRASKA	—	—	—	—	—	—	—
NEVADA	C	No	No	—	No	None	—
NEW HAMPSHIRE	C(Bridge engineer)	Yes.Yes	No	D	Yes Wrought iron jackets filled with concrete. Numerous jackets have developed cracks	Plates welded on steel piles, encase with conc. filled metal jackets	N/A
NEW JERSEY	C	Yes Yes	No	No standard techniques, each job is unique	Yes. Granite facing 2' to 3' above & below H B L WL, wrought iron plates on old bridges; very good results	Quick setting cementitious patch material, fiberglass forms filled with conc. for pile repair, concrete filled bags for scour at footings	Specs very general
NEW MEXICO	—	No	—	—	—	—	N/A
NEW YORK	A	Yes.Yes	No	No	Yes We use a variety of fendering sys ranging from rubbing strips to energy absorbing sys.; no results yet	Grout, concrete	—
NO. CAROLINA	C	Yes.Yes	Yes	No	No	Fiberglass forms filled with grout for steel piles' protection	Yes
NO. DAKOTA	B	No	No	No	No	None	—
OHIO	D(District bridge engineer)	No	No	No	No	—	—
OKLAHOMA	C	Yes.Yes	No	—	No	—	N/A
OREGON	D(Diving coordinator)	Yes.Yes	Yes	A,B,C,D,E	No	Epoxy injection & grouting for conc. piers, cathodic protection for steel piles, concrete encasement, PVC wrap protection for timber piles	N/A
PENNSYLVANIA	D(Bridge engineer)	Not known	No	No	No	N/A	Yes
PUERTO RICO	—	—	—	—	—	—	—
RHODE ISLAND	C	Yes.Yes	No	A,E	Yes. Wrought iron jackets used in salt water tidal zone	Clean with high pressure water, chip deteriorated areas & forms. Pump special mix conc.	N/A
SO. CAROLINA	D(Inspector & bridge maintenance engineer)	Yes.Yes	Yes	No	No	Jackets, epoxy coatings and special repairs to footings where scour has exposed untreated timber piling	Yes
SO. DAKOTA	D(Inspector & bridge maintenance engineer)	Yes.—	Yes	No	Yes. Jackets, with satisfactory results	—	N/A
TENNESSEE	N/A	No	No	N/A	No	N/A	N/A
TEXAS	C	Yes.Yes	No	A,C,D,E	No	Concrete filled fiberglass jackets, concrete enclosed footings	Yes
UTAH	C	No	—	No	No	None	—
VERMONT	C	No	No	No	No	—	N/A
VIRGINIA	B	Yes.No	Yes	A,B,C	No	Jackets using timber, steel or nylon bags. Footing repairs using metal forms and tremie concrete	Yes
WASHINGTON	A	Yes.Yes	No	No	No	Tremie concrete	Yes
WASHINGTON D.C.	B	No	No	No	No	—	N/A
W. VIRGINIA	—	Yes Yes	No	No	No	Various epoxy materials. Grout-bag bulkhead around undercut void, pumped grout in void	N/A
WISCONSIN	A	No	No	No	No	—	—
WYOMING	—	—	—	—	—	—	—

TABLE 2 INSPECTION OF UNDERWATER BRIDGE SUBSTRUCTURES: PRACTICES OF RAILROADS AND TOLL AUTHORITIES (1980)

	① Does your agency routinely inspect existing bridge substructures below the waterline?	② If so, is this in conjunction with the above-the-waterline inspection of the substructure and superstructure?	③ If underwater inspections are conducted, what is the frequency of inspection? (A) One year (B) Two years (C) Other	④ What are the required personnel qualifications for underwater inspections? Professional: (A) Licensed engineer (B) Engineer (C) Diver supervised by licensed engineer (D) Other. Diving: (A) Scuba certifications (B) Professional diver (C) Other	⑤ What degree of detail is required in routine inspection? (A) Spot check (B) Spot clean and check (C) Complete detailed inspection (D) Complete cleaning and detailed inspection (E) Other	⑥ What equipment is employed in routine inspections? Dive: (A) Scuba (B) Surface supply (C) Other. Tools: (A) Scrapers (B) Hammers (C) Probes (D) Photographic (E) Closed circuit TV (F) Other	⑦ What techniques and equipment are employed when inspection is conducted in turbid water where visibility is poor or nil? (A) Utilization of clear water mask and artificial light (B) Tactile inspection (C) Wait for better visual conditions (D) Other	⑧ Are depth soundings taken during routine inspections? (A) Lead line (B) Echo sounder (C) Other (D) None	⑨ Are any non-destructive testing (NDT) techniques employed in either routine or condition inspection? (A) Ultrasonic (B) Vibrational analysis (C) Acoustic emission analysis (D) Radiography (E) Magnetic particle (F) Corrosion potential (G) Core samples (H) Petrography (I) Other (J) No NDT	⑩ Are any underwater monitoring devices employed to determine the extent of crack progression? Please describe
RAILROADS										
LOUISVILLE & NASHVILLE RR.	No	Yes	—	Pro: — Div: —	C	Div: A Tls: B	—	D	J	—
CHICAGO & NORTH WESTERN TRANS. CO.	Only bridges over major waterways	No	C(4 to 6 years)	Pro: A Div: B	B	Div. A Tls: A,B,C	A	D	J	No
SOUTHERN PACIFIC TRANSPORTATION CO.	As needed	No	C (As needed)	Pro: B Div: A or B	C	Div: A or B Tls: A,B,C,D	A,B	A or B	J	No
KANSAS CITY SOUTHERN RAILWAYS	Yes	—	C(5 to 10 years)	Pro: C Div: A	B	Div: A Tls: A,B,C	A	A	J	—
CHESSIE SYSTEM	Yes	Yes	C (As needed)	Pro: C Div: B	E(Check for voids, cracks and scours)	Div: B Tls: C,D,E	B	A	J	No
SEABOARD COAST LINE RAILROAD	Yes	No	A	Pro: C Div: B	C	Div: A,B Tls: A,B,C	A,C	A	G	No
LEE TURZILLO CONTRACTING COMPANY	Yes	No	C(Varies)	Pro: C Div: A,B	B,D	Div: A,B Tls: A,B,C,D,E	A	A,B	A,B,G	Yes
TURNPIKE, TOLL AND BRIDGE AUTHORITIES										
RHODE ISLAND TURNPIKE & BRIDGE AUTHORITY	Yes	No	B	Pro: B Div: B	C	Div: B Tls: A,B,C,D	C	B	J	No
NEW YORK STATE THRUWAY AUTHORITY	As needed	No	C(5 years)	Pro: — Div: B	B	Div: B Tls: A,B,C,E	A,B	B	J	No
THE DELAWARE RIVER AND BAY AUTHORITY	Only as dictated by previous history of structure insp.	Sometimes	C(5 years)	Pro: C Div: B	C	Div: B Tls: A,B,C	B	A,B	J	No
MASSACHUSETTS TURNPIKE AUTHORITY	Yes	Yes	B	Pro: B Div: A	C	Div: A Tls: C	C	A	J	No
OHIO TURNPIKE COMM.	Yes	Yes	B	Pro: A Div: —	A	Div: Tls: C,D(Fathometer)	N/A	B	A,G,H	No
THE PORT AUTH. OF NEW YORK AND NEW JERSEY	No	No	—	Pro: A Div: B	C	Div: A Tls: A,B,C,E	A,B	A	A	—
TRIBOROUGH BRIDGE AND TUNNEL AUTH.	Yes	No	C(6 to 10 years)	Pro: C Div: B	C	Div: B Tls: E	A	D	J	No
MACKINAC BRIDGE AUTHORITY	Yes	Yes	B	Pro: B,C Div: A	C	Div: A Tls: B,C	C	A,B	J	No

	⑪ Is the evaluation of conditions, damages, and need for repair determined by: (A) Inspector (B) Bridge designer (C) Inspector and bridge designer (D) Other	⑫ Has your agency performed any underwater maintenance or repair of substructures? Was this work inspected after completion?	⑬ Are construction or maintenance personnel pre-qualified to perform specific tasks underwater?	⑭ Have you developed any specific or standard procedures for doing underwater repair on any of the following? (A) Concrete for piers (footings/base/shaft) (cracked, spalled, disintegrated, scoured) (B) Exposed reinforcing steel (C) Concrete piles (cracked, spalled, deteriorated) (D) Steel piles (E) Timber piles (F) Other	⑮ Have you employed any type of permanent protection (forms, jackets, etc.) on new underwater construction? If "Yes," describe. Results?	⑯ What materials, products, or systems have been used for making underwater repairs?	⑰ Would you provide copies of any specifications, job instructions, pre-qualifications, etc., you have for underwater work?
RAILROADS							
LOUISVILLE & NASHVILLE RR	C	Yes,Yes	No	No	No	Reinforced concrete	—
CHICAGO & NORTH WESTERN TRANS. CO.	A	No	No	No	No	Grout bags	N/A
SOUTHERN PACIFIC TRANSPORTATION CO.	D(Bridge eng)	Yes,Yes	No	No	No	Pre-fab forms for concrete jackets	N/A
KANSAS CITY SOUTHERN RAILWAYS	C	No	—	—	No	—	—
CHESSIE SYSTEM	D(Bridge eng.)	No	N/A	A,B,C,D	No	Epoxies, fiberglass shields, grout bags, cement grout	N/A
SEABOARD COAST LINE RAILROAD	C	Yes,Yes	Yes	No	No	Concrete and plastic wrap	Yes
LEE TURZILLO CONTRACTING COMPANY	A,B,C	Yes,Yes	Yes	A,C	Yes	Bagpipes, Flexform	Yes
TURNPIKE, TOLL AND BRIDGE AUTHORITIES							
RHODE ISLAND TURNPIKE & BRIDGE AUTHORITY	B	Only at water line Yes	No	No	Yes On drilled in caisson pier legs, steel jacketing was left on, jackets are filled with concrete & reinf cages	None	N/A
NEW YORK STATE THRUWAY AUTHORITY	C,D(Maint engineer)	Yes,Yes	No	B,E	Yes. Greenheart timber for timber icebreaker piles and granite for steel sheathing on conc. icebreaker	Greenheart timber, granite	Yes
THE DELAWARE RIVER AND BAY AUTHORITY	C	Yes,Yes	Yes	No	Underwater protective coatings, grout bag stabilization of dock area bulkheads, granite facings	Structural timber and steel, protective coatings	Yes
MASSACHUSETTS TURNPIKE AUTHORITY	B	No	No	No	Yes Piers faced with granite blocks: excellent protection, steel sheathing at ftgs: excellent for scour	—	—
OHIO TURNPIKE COMM.	D(Licensed engineer)	No	No	No	N/A	N/A	N/A
THE PORT AUTH. OF NEW YORK AND NEW JERSEY	B	No	No	No	No	—	—
TRIBOROUGH BRIDGE AND TUNNEL AUTH.	B	Yes,Yes	No	No	Yes. Use of wrought iron plates in tidal zone on concrete piers. Still serviciable since 1936	Remain in place preformed concrete forms for tremie concrete.	N/A
MACKINAC BRIDGE AUTHORITY	B	Yes,Yes	No	A	No	Epoxy sealers on concrete tested in limited area	Yes

FIGURE 1 Inspecting underwater structural elements.

clearly defined (see Appendix A). However, when the competence of the underwater inspection crew is the responsibility of a contractor, the required qualifications of the inspectors are not always specifically defined. (An annual contract proposal for underwater inspection is shown in Appendix B.) With proper education, training, experience, equipment, and agency support, both agency and contract dive teams should be capable of performing the inspection task. Only nine agencies require professional engineers who are also certified scuba or professional divers. The majority of agencies use commercial divers supervised by professional engineers.

The decision to use either contract or in-house personnel is based on the need for a full-time team, the ability to use the team in other assignments, and the comparative costs of the use of total contract, partial contract, and total agency teams. Another consideration is determination of responsibility for engineering inspection. If the agency delegates this responsibility to others, this may affect the decision to use either contract or in-house employees.

In Oregon, in-house employees inspect all timber structures at least once a year. The North Carolina dive team monitors the channel at problem structures, and performs construction and maintenance inspections. The inspectors also help to coordinate and check the work of contract consultants performing maintenance inspections. Florida and Massachusetts also use in-house dive teams, and several other agencies either have limited capability or are considering using in-house inspectors. In-house inspectors can also perform above-water inspections.

Training and Certification

The state agencies generally use their own inspection manuals, which are based on the FHWA *Bridge Inspector's Training Manual,* or use the FHWA manual along with checklists and supplements. Inspectors in every state have been trained by the FHWA bridge inspector's training course, administered by the National Highway Institute since the early 1970's. However, underwater inspection is treated somewhat superficially in this course.

The agencies using in-house inspectors are involved with the training, certification, and physical examination of divers. It is common practice to require that contract divers be certified; however, the person who actually certifies that a diver is qualified is rarely indicated. Organizations that certify divers include the National YMCA Center for Under-

PREPARATION	TOOLS AND EQUIPMENT	INSPECTION PROCEDURE	DOCUMENTATION
A. Review bridge reports for: 1. Identification of type and members in the system 2. Types of material to be encountered 3. Work or repairs accomplished since the last inspection 4. Results of latest underwater investigation 5. Accident or damage reports 6. Location and type of navigation lights, dolphins and fenders, and signing, if applicable B. Organize inspection routine - determine best sequence for inspection C. Make arrangements to ensure availability of: 1. Special tools and equipment 2. Specialist personnel, if required D. Make sketches, as necessary, for documentation of inspection items/defects E. Determine best time for inspection considering: 1. Available daylight 2. Traffic flow and density 3. Tide, if applicable	A. Boat with oars, motor and life preservers, if required B. Cameras and film C. Inspection documents, paper, clipboard and pencil D. Concrete, timber or steel tool kit depending upon type of materials contained in piers and/or bents E. Ladder, "Snooper" scaffolding, platform truck, as required F. Underwater investigation equipment and personnel, if required G. Sounding equipment and marking crayon, if required to determine scour H. Safety equipment	A. Access: 1. Boat 2. Walking and climbing 3. Platform truck, ladder, snooper, scaffolding B. Observe in general for: 1. Alignment 2. Missing or broken piles/columns and bracing 3. Fire or impact damage a. Observe for accumulations of flammable material 4. Condition of incrustation buildup, if applicable 5. Determine scour, if required 6. Conduct underwater investigation, if required to determine: a. Deterioration of construction material b. Loss of protective stone facing c. Indication of movement d. Buildup on piling C. Measure amount of pier or bent movement: 1. Determine out of alignment with engineering, mason's or carpenter's level 2. Determine type of movement NOTE: • Measure piers and bents out of alignment with sophisticated survey equipment when available. Obtain measurements using plumb bob and tape rule or folding rule to compute amount of movement when more sophisticated instruments are not available. • Determine if unusual movement occurs in any bent members during passage of heavy loads. D. Scrape off incrustations with scraper, as necessary for inspection E. Determine: 1. Need to replace protective treatment 2. Type and extent of deterioration/distress/damage 3. Condition of navigation lights, if applicable for operation, glass, wiring conduits 4. Condition of signing, if applicable F. Sound by tapping with hammer for: 1. Deteriorated timber or hollow zones in concrete G. Check any architectural treatment for: 1. Missing material 2. Mortar cracks H. Check stone masonry for: 1. Mortar cracks 2. Vegetation 3. Water seepage through cracks 4. Loose or missing stones 5. Weathering 6. Spalled or split blocks I. Measure size, length and determine type, location and direction of cracks 1. Observe for rust stains, exudation and efflorescence in concrete J. Probe, pick and/or bore timber, especially in areas that are alternately wet and dry, with knife, ice pick, prying tool and/or increment borer, if necessary, for signs of deterioration such as: 1. Fungus decay 2. Vermin attack 3. Weathering 4. Wear NOTE: Replace all test borings with creosoted plugs. K. Check cathodic protection system, if installed L. Measure with a rule and caliper, and compute loss of section, recognizing that some areas are more critical than others: 1. Area between two feet below low water and two feet above high water for: a. Eroded concrete b. Corroded steel. Also, check closely at the face of exposure where steel pile is encased in concrete c. Vermin-attacked timber 2. Impact-damaged areas 3. Spalled-concrete areas M. Pry and probe around pile/column and bracing connections to determine: 1. Tightness, adequacy and soundness 2. Deterioration between surfaces, especially where cap bears and where earth or other extraneous material may have accumulated, for decay 3. Missing or broken rivets, bolts and nuts NOTE: When sounding connections for loose nuts, bolts, or rivets, tap with care where paint on and around rivets or bolts is in good condition, and there is no sign of movement.	A. Photograph all defects reported 1. Ensure pictures of alignment problems show condition with respect to an aligned element 2. Annotate picture with measurement data, if applicable B. Sketch and annotate 1. Cross reference to pictures and vice versa C. Identify abutment by number and name D. Narrate (Tape recorder or script): 1. Type of deterioration/distress/damage 2. Location 3. Dimensions, if applicable 4. Loss of material or section, as applicable 5. Cause, if known 6. Rating: ( ) Good ( ) Fair ( ) Poor ( ) Critical 7. Recommendations: a. Replace decayed timber b. Grout bearing plate c. Correct alignment d. Remove flammable accumulations e. Replace stone and patch crack in mortar 8. References: a. Refer to other documentation such as: • Erosion of approach embankment • Transverse cracks - approach pavement • Scour report, if applicable

FIGURE 2 Inspection checklist for piers and bents (Louisiana).

water Activities, the United Brotherhood of Carpenters, and the American Diving Contractors Association.

The Occupational Safety and Health Administration (OSHA) standards for commercial diving operations are followed by both agency and contract inspectors (*3*). Although some general dissatisfaction with the OSHA standards was expressed by the agencies, all indicated compliance with the established standards.

FREQUENCY AND LEVEL OF INSPECTION

The frequency of underwater inspection varies among the state transportation agencies. Fifteen state transportation agencies routinely inspect existing bridge substructures below the waterline; 9 of the 15 agencies perform these inspections in conjunction with above-the-waterline inspections of the substructure and superstructure. Several agencies schedule inspections of specific structures. Connecticut, Florida, Massachusetts, Rhode Island, and South Carolina conduct underwater inspections every 2 yr; bridges in Florida are inspected after each major storm; and in Georgia, Maryland, Vermont, and Virginia, inspections are scheduled every 5 yr. In Oregon, all bridge piling in coastal estuaries is inspected annually; 1500 to 2000 piles per year are inspected for collision or marine borer damage (*4*).

TABLE 3
INSPECTION NEEDS FOR STEEL STRUCTURES (*5*)

	Inspection Needs \ Physical Properties	General Structural Integrity	Structural Deformation	Joint Separation	Joint Cracking	Corrosion Protection System Integrity	Corrosion Potential Measurements	Corrosion Thickness Measurement	Fouling	Scour	Nature and Location of Debris	Vibration	Tilt
GENERAL PERIODIC INSPECTION	**Above Water**												
	Existence of Corrosion					X		X					
	General Deterioration and Cracking		X	X	X			X					X
	Structural Distress	X	X	X	X								X
	Splash Zone												
	Corrosion					X	X	X					
	General Deterioration		X	X	X		X	X	X				
	Structural Deformation	X	X	X	X							X	
	Thickness Gauging							X					
	Weld Zones in Detail		X		X			X					
	Excessive Fouling								X				
	Submerged Zone												
	Member Missing	X										X	
	Structural Deformation	X	X	X	X							X	
	Excessive Scour									X	X		
	Corrosion-Protection System					X	X	X					
	Thickness Gauging							X					
	Weld Zones in Detail		X		X			X					
	Excessive Fouling								X				
	Presence of Debris										X		
	Repairs and Modifications		X	X	X	X	X	X					
EVENT-ORIENTED INSPECTION*	**Above Water**												
	General Structural Integrity	X	X	X	X	X							X
	Splash Zone												
	General Structural Integrity	X	X	X	X	X	X						
	Submerged Zone												
	General and Local Structural Integrity	X	X	X	X	X	X	X		X	X		X
	Corrosion Inspection Where Suspected						X	X					

*Requirements are the same for event-determined and periodic inspections.

Other agencies have their bridges inspected infrequently, or only for specific problems or when there are indications of underwater problems (Tables 1 and 2). In some cases, a swim-through is scheduled immediately after each major storm where structural problems are anticipated.

Condition inspections are those made routinely; no specific problems are anticipated, and a superstructure, or above-water, inspection has not indicated that a foundation or substructure problem would be discovered under water. The condition inspection should reveal all existing defects and also identify potential problem areas. This type of inspection can also be classified as a preventive maintenance inspection. The routine inspections scheduled every 2 yr by transportation agencies generally are condition inspections.

Detailed inspections supplement condition inspections or are required when specific underwater substructure problems have been identified. Sampling may be one of the tasks performed during this inspection. Detailed inspections are used to provide information, develop plans, select types of repairs, and determine construction procedures. Table 3 lists inspection needs for offshore drill platforms (5).

It is best to schedule underwater inspections during that period of the year when conditions are most favorable, such as during periods of low water and low pollution levels, minimum ice, or good underwater visibility. Also, a good time to schedule an inspection is immediately after exposure to conditions that can cause scour. The procedure for these inspections should be organized and systematic. Checklist techniques are helpful to ensure that no important items are overlooked.

CHAPTER TWO

IDENTIFICATION OF UNDERWATER PROBLEMS

SCOUR

Scour is the removal of stream bed, backfill, slopes, or other supporting material by stream, tidal action, dredging, propeller backwash, etc. The degree of damage depends on such factors as the character of the stream bed, the volume of water, and the shape and elevation of the structure. Bridge engineers are well-acquainted with this destructive problem (*6*). All piers and abutments erected in water should be designed to be protected from scour and erosion; however, both stream and structure conditions may change during the life of the structure.

Piers and abutments are obstructions in a stream that reduce the channel cross section and increase the velocity, thus causing a disturbance of the flow (Figure 3) (*6*). To avert failures caused by currents, the bridge engineer incorporates in the bridge design the following preventive measures:

- Provision for an adequate channel to keep flow velocity low,
- Training structures,
- Armor protection (concrete, rip rap, etc.),
- Bottom of footing designed to be well below maximum scour elevation,
- Extra length piles, and
- Streamlining and alignment of piers.

The variable mood of a swift river or a strong tide demands constant vigilance. Unusual rainfall and storms, boat movement, and dredging of a channel can result in scour around the foundation of piers and abutments. Structures with foundations that are subject to scour should be inspected immediately after storms that result in flooding and strong currents. A 1980 report by the FHWA (*7*) contains an excellent bibliography on scour.

DETERIORATION

This problem involves the degradation of structural members or materials through natural processes.

Wood

Wood members deteriorate through various fungal processes (rot) and can be destroyed (consumed) by marine organisms. Deterioration of submerged timbers within the design life of a pile is associated with marine borers (see Figures 4 and 5). The principal marine borers encountered in U.S. waters are the *Limnoria* and the *Teredo*. The marine borer *Limnoria* is a crustacean whose tunneling is limited to the exposed outer shell of wood; thus it is a "surface" borer. The marine borer *Teredo* (or shipworm) is a mollusk whose larvae begin tunneling on the outside surface of the wood but rapidly grow and cross into the internal structure of the member; thus it is referred to as an "internal" borer. These two borers are responsible for most of the biologically caused deterioration of submerged marine timber structures (Figure 6).

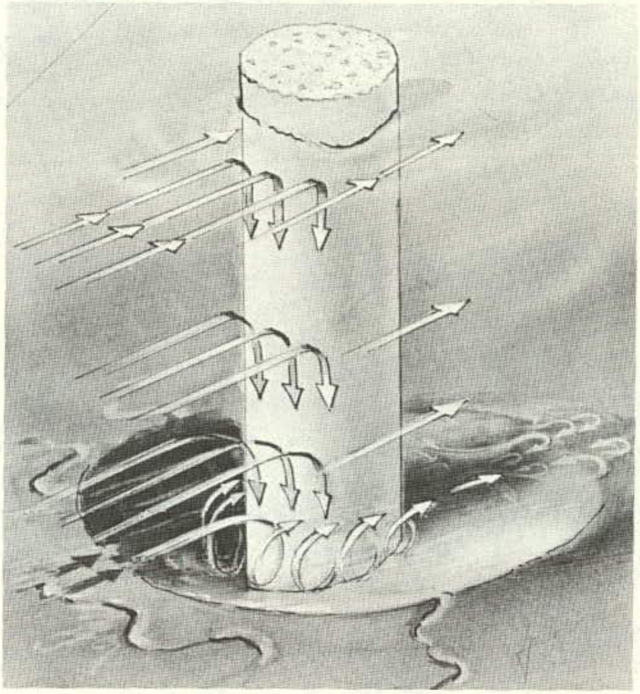

FIGURE 3 Scour at circular shaft (*6*).

Limnoria activity can easily be identified because of its surface-boring habits. The smallest colony on the surface of a pile is readily identified—not necessarily by observing the actual animals but by the lack of fouling organisms attached to that area of the pile surface and the observation of tunnels. The initial attack is generally small, not limited to a specific elevation, and difficult to detect. Once the infestation is entrenched and the population increases, mechanical erosion of the tunnels occurs and the pile section is reduced, making both visual and tactile detection of the borers more likely.

Identification of *Teredo* activity is not as simple. *Teredo* larvae enter the surface of the wood and begin boring and growing within the internal structure of the wood while the tails (siphons) remain at the surface. If the inspector is familiar with the physical appearance of these siphons and is

FIGURE 4 Typical damage to untreated timber piling by the marine borer *Limnoria*.

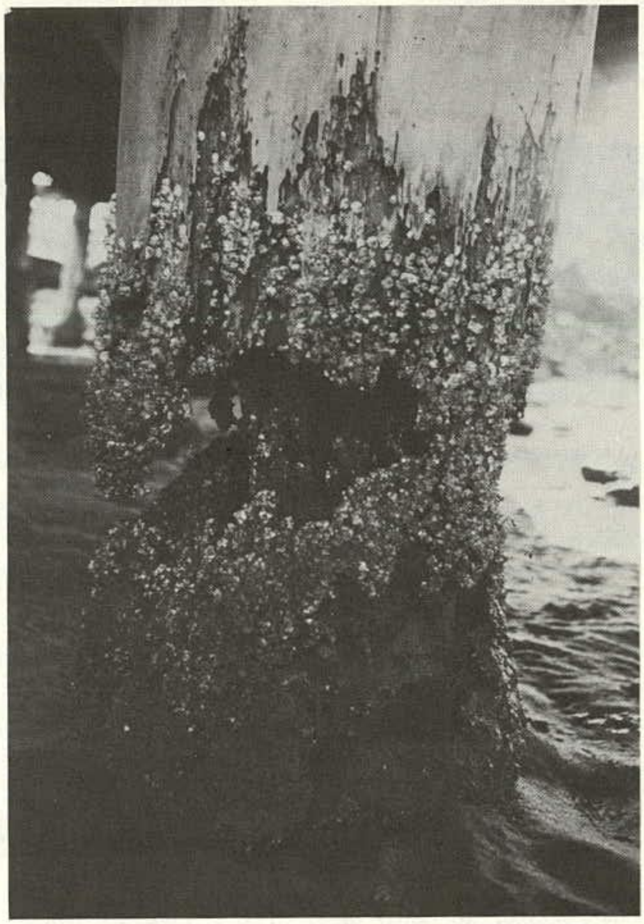

FIGURE 5 Timber piling completely destroyed by a combination of marine borers.

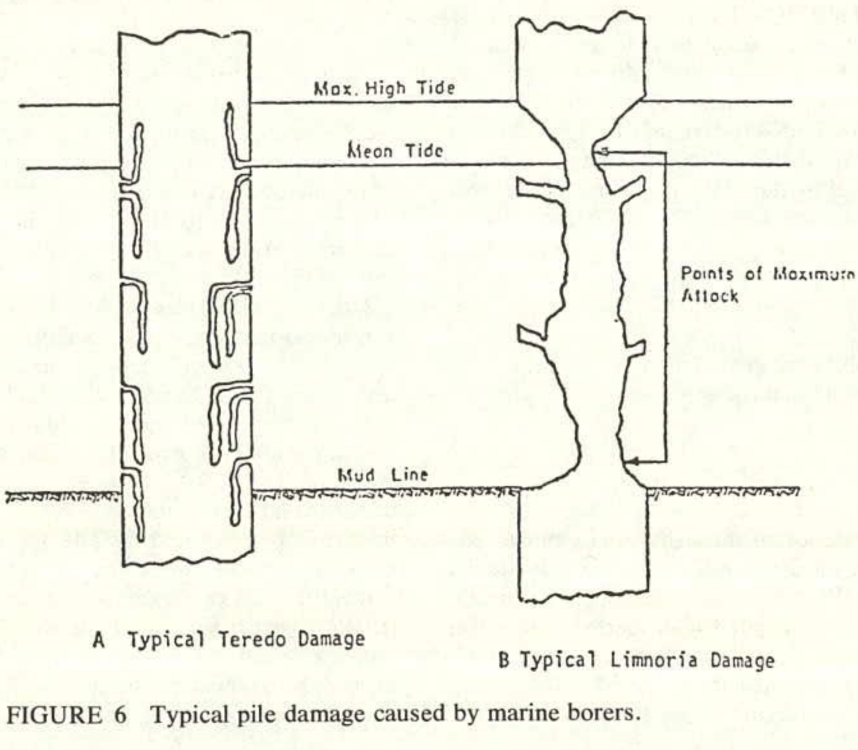

FIGURE 6 Typical pile damage caused by marine borers.

extremely cautious, it is possible to observe them protruding from the surface of the pile. When *Teredo* and *Limnoria* are found together, the surface borers usually have eroded sufficient wood to uncover the calcareous-lined tube of the internal borers, thus making visual confirmation possible. Nondestructive techniques for testing for the marine borer *Teredo* are available (*8,9*). Destructive testing, which involves retrieval of a portion of the structure for analysis, can also determine the presence of *Teredo*.

No wood is immune to marine-borer attack, and no commercially important wood in the United States has sufficient marine-borer resistance to justify the use of untreated wood for structures in areas where borers are active. The heartwood of several foreign species (including turpentine, greenheart, jarrah, azobe, teak, totara, manbarklak) has shown resistance to marine-borer attack. Service records on these woods, however, do not always show uniform results and are affected by local conditions.

Many new wood preservatives are developed each year. Creosote is the most widely used wood preservative and is highly effective against virtually all borers except the species *Limnoria tripunctata,* which is creosote-resistant. Research conducted by the U.S. Navy Civil Engineering Laboratory (NCEL) on improved preservatives for marine piles indicates that an effective preservative system consists of a combination treatment. One component of the treatment should be toxic to *Limnoria* and the other toxic to *Teredo*. Roe (*10*) evaluated various timber piles impregnated with (a) creosote containing two toxic additives, (b) a selected single treatment with a solution containing two toxic compounds, or (c) a dual treatment (*10*). A dual treatment is recommended by the American Wood-Preservers' Association.

The use of the dual treatment in fender systems is questionable because there is evidence that treatment with water-borne salts embrittles wood and decreases its energy-absorbing capacity. In some fender systems the piles are extensively damaged from impact before attack by marine borers can affect the installation.

Steel

Steel members of bridge substructures are subjected to corrosion (rust) (see Figure 7). Corrosion is the conversion of the metallic iron, through chemical or electrochemical reactions, into compound form. This compound flakes off easily from the parent metal, and the area of the section is reduced. Corrosion can be classified as atmospheric, underwater, soil, chemical, and electrolysis (caused by electric currents) (*10*).

In atmospheric corrosion, such as in that part of a steel member located above the splash zone, the predominant corrosion factor is moisture because there is an excess of avail-

FIGURE 7 Corrosion of steel bridge substructure.

able oxygen. In that part of a steel member located above the waterline but within the splash zone, corrosion is accelerated by salt water and the effects of the wetting and drying cycles. The predominant cause of corrosion in the submerged part of a steel member is the concentration of dissolved oxygen. Chemical corrosion results from chemical compounds making contact with the steel surface. In that part of a steel member located below the mud line (buried in the soil), the predominant causes of corrosion are electrical conductivity, total acidity, water content, and dissimilar metals. Stray electric currents may cause severe corrosion by electrolysis.

Corrosion is readily identified by its typical reddish-brown, rust-colored appearance and its pitted, oxidized surface, usually showing loose flakes of oxide. The presence of limited growth of barnacles in marine piling tends to increase the amount of pitting. However, heavy growth tends to check corrosion; thus, unless absolutely necessary, marine growth should not be removed from steel piles. The higher the velocity or turbidity of the water, the higher the rate of corrosion because more oxygen is brought into contact with the metal.

Concrete

Concrete is used in pier footings, abutment walls, piles, and seals. Below-the-waterline deterioration of concrete is readily identified by the presence of cracks, spalls, and cavities (Figure 8); however, determination of the cause of deterioration is a complex problem.

Concrete members, in some instances, deteriorate because of chemical processes that occur in a marine environment. Magnesium ions in seawater salts attack concrete by reacting with the calcium. Sulfate solutions react with tricalcium aluminate hydrate, which is a normal constituent of concrete, forming calcium sulfoaluminate hydrate. This reaction is accompanied by a substantial expansion and causes cracking and spalling. Cement contains tricalcium aluminate, which reacts with chloride ions in salt water. Acid generated by bacteria also attacks concrete. Sometimes deterioration is produced by chemical reaction within the concrete mass, such as the reaction of high-alkali cement with minerals in certain aggregates. Also air and moisture that penetrate the concrete cover cause the reinforcing bars to corrode; the swelling of the corrosion products can cause the surrounding concrete to crack and spall. Several types of marine rock borers (e.g., *Pholas*) bore into concrete. However, this damage occurs infrequently in tropical or semitropical waters and appears to take place only in low-quality concrete (*11*).

DAMAGE (STRUCTURAL)

Structural damage to the parts of a bridge substructure below the waterline, which can compromise the structural integrity of the facility, can be classified as follows:

- Construction Damage or Error
- Collision
- Storm
- Abrasion (Erosion)
- Deferred Maintenance (Neglect)

Construction Damage or Error

Construction damage can result from improper procedures or accidents during the construction phase.

Concrete

- Often pieces of steel are left protruding from the finished concrete surface, including hardware used to secure the reinforcing steel and formwork in place or lifting rings not removed from precast concrete piles. With time, the corrosion of these metals will cause cracks and spalls in the adjacent concrete area.
- During setting of the concrete, cracks will appear in the structure if the formwork moves or as a result of vibrations caused by pile driving, blasting, poor workmanship, etc.
- The concrete in the substructure, if not properly placed, is subject to cracking caused by differential settlement of the concrete suspension and by initial and drying shrinkage.
- Stresses resulting from changes in the atmospheric temperature or in the internal temperature of the concrete mass can cause cracking.
- If the shoring system or framework is prematurely removed, the concrete may crack severely.
- When the reinforcing steel is placed with insufficient cover, corrosion may occur.

Timber

- Timber piles can be damaged before installation by incorrect preservation techniques and improper or rough handling.
- During construction, overdriving may cause splits, checks, and shakes of piles, which are visually identifiable under water.
- Improper preservative treatment and hardware placement in piles can cause areas of piles to be inadequately protected against attack by marine borers. Bolt-holes that provide a point of entry for borers may be hidden by fouling organisms and therefore difficult to detect. Gouges and tears on the surface of piles, resulting from rough or improper handling techniques, which can be used by borers to enter the pile, are visually identifiable.

Piles

Overdriving causes all piles to buckle. Rough or improper handling and overdriving cause cracking on precast concrete piles.

Inspection

Even though the possibility of construction-related damage exists on any job, the underwater structural members of bridges are not routinely inspected by state agencies during or immediately after construction. With the passage of time, the discovery of such damage (cracks, spalls, honeycomb

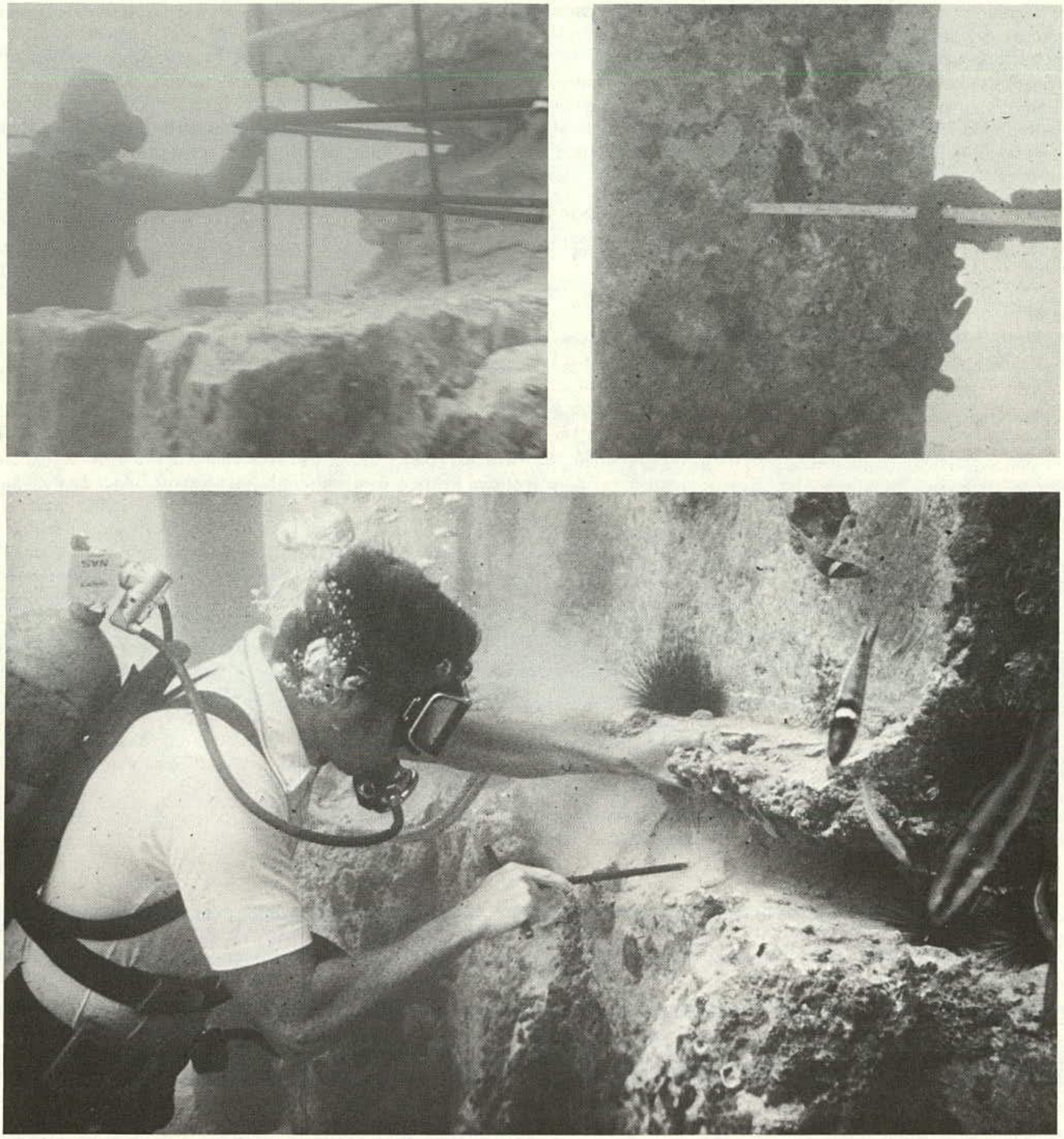

FIGURE 8 Concrete deterioration.

areas, splits, deformed or crippled areas, etc.) becomes more difficult and expensive as a result of the amount of cleaning required before close visual inspection is possible.

Underwater inspections should be conducted during and at the end of the construction phase (after pile driving, underwater concrete placement, etc.) before acceptance of the bridge. The recognized capability of an agency to perform underwater inspection may prove beneficial in securing top-quality underwater construction. Underwater inspection after completion of the structure provides data for a valid determination of compliance with the contract specifications and details, and also provides an inspection base line for future underwater inspections.

Collision

Structural damage to underwater portions of bridge substructures can either be collision-related or the direct result of a collision. Collision impact can damage the immediate area as well as adjacent or even distant structural components, depending on the structural frame and connection system used. The degree of damage can range from superficial, affecting only the appearance of a structure, to complete destruction or failure of all or part of the structural system. Examples of the types of damage that can occur are:

- Timber piles with a severely abraded, splintered surface, or piles that appear to be displaced only slightly but are completely severed below the mud line.
- Crippled flanges on short, steel batter piles, or similar damage on long, vertical steel piles.
- Severe spalling on mass concrete footings.
- Full-depth cracks in a concrete column or beam.

The inspection of collision damage should be done immediately or within a few days at the most, so that all physical evidence will be in optimal condition for discovery, identification, analysis, and recording. Agency policies usually specify the organizations that are to be notified immediately after a collision has been reported. The identity of the vessel involved must be determined if damages are to be collected. (However, it is possible that the owner of the structure may not be notified or may not be aware of the collision.) Regularly scheduled inspections are the only sure way to learn of minor or major unreported collisions.

In areas where serious collisions may occur, structure owners should consider maintaining a file on qualified engineer-divers, rental rates and fee schedules, contract forms, safety and procedure regulations, and any other pertinent information. Several agencies use in-house dive teams to make immediate inspections if there is a possibility that a structure has been damaged by collision. In other agencies, a continuing or annual contract with a diving organization is standard practice.

Storms

Storms can have a detrimental effect on bridge substructures. The velocity and depth of the water and the debris carried increase in relation to the intensity and duration of the storm. The power of the current to pick up and transport granular materials from the bottom of the river increases with increased velocity, which magnifies the erosive power of the current during a storm. Floating debris carried downstream by the water flow may exert horizontal forces against the bridge substructure. Debris accumulation at bridges also increases the potential for scour by concentrating the flow. Waves, generated by wind, induce hydrodynamic pressures on substructure components and piles.

Underwater investigations should be conducted after a major storm or flood in order to determine if the bridge substructure has been damaged. The diver should look for any evidence of storm damage to the substructure structural components, fenders, and any other underwater installation, such as submarine cables and cathodic protection for steel piles.

Abrasion (Erosion)

Deterioration of substructures by abrasion is caused by wave action, the velocity of the currents, and the action of suspended particles of sand and silt in moving waters. Any one or a combination of these agents can reduce the section with passage of time. Another cause of abrasive deterioration of bridge piers is floating ice.

Deterioration of sections because of abrasion can be identified by the worn, smooth appearance of the surface. When the abrasive agent is no longer active, the existing abrasion is not as obvious but usually can be detected by a general depression of the area.

Deferred Maintenance

Many problems are associated with lack of maintenance of the parts of bridge substructures located under water. If cracks, spalls, and voids in the concrete are not repaired on time, distress or even failure may occur. Scour at foundations of piers and abutments should be minimized; timber piles should be kept protected from attack by marine borers; and accumulation of debris should be removed. Fender systems, navigation aids, warning devices, and clearances must be maintained in order to protect bridges from damage by boats, ships, and barges.

To implement and assure a proper maintenance program for below-the-water portions of bridge substructures, it is essential to conduct periodic underwater inspections by qualified personnel. Underwater inspections after unusual high waters or storms should also be performed. All deficiencies must be reported and evaluated, and remedial action taken for immediate repair.

STRUCTURAL FAILURE

Structural failure refers to the reduction of the capability of the bridge substructure or component to such a degree that it cannot safely serve its intended purpose. The factors that may cause or lead to structural failure include:

- Absence of proper soil investigation or incorrect interpretation of the results of an investigation;
- Inadequate design of the structure;
- Poor workmanship and construction materials;
- Insufficient provisions in design for exceptional phenomena, such as thermal and biological conditions, rainfall, ice loads, and floods;
- Settlement due to overloading;
- Deterioration of foundation concrete caused by concrete sulfates;
- Scour of the substructure support;
- Actual loads heavier than design loads; and
- Deferred maintenance.

The underwater investigation of structural failure may be part of a comprehensive disaster-preparedness plan, or it may be an independent investigation conducted when a failure occurs.

FOUNDATION DISTRESS

Foundation distress refers to an impairment of the strength or load response of the substructure that may limit its intended use. Foundation distress can be caused by scour, slides, rotation of piers, or collapse of subterranean caverns. Usually evidence of a problem is visible in alignment or grade changes of the deck or roadway surface. This type of information is collected from above-water inspections or testing to estimate the extent and severity of the problem.

CHAPTER THREE

UNDERWATER INSPECTION OF BRIDGE SUBSTRUCTURES

INSPECTION TEAM

Each agency should evaluate its underwater inspection requirements and then select a method for performing the inspections. The three methods currently in practice are:

1. Contract for all underwater inspection.
2. Use in-house staff for underwater inspection.
3. Use combination of in-house and contract divers.

The level of inspection and the staffing for underwater inspection differ among the state transportation agencies. The number of structures with major underwater substructure components is a factor in an agency's decision to use in-house or contract inspection. Some of the coastal-area states have staffed and trained their own underwater teams for both routine and emergency work. Other coastal-area states depend on contract inspection for all underwater work. In general, the interior states have not developed underwater inspection capability and have not expressed any immediate desire to do so.

In Massachusetts, North Carolina, Florida, and Oregon, underwater inspection efforts have been developed on a professional level.[1] The underwater inspection teams in these states agencies consist of an experienced, commercially certified diver supervisor/coordinator and certified divers. Engineers or inspectors are trained to be divers; they must be safety-oriented (CPR-trained) and must maintain excellent physical condition. Equipment is maintained in good condition.

The advantages of contracting for all underwater inspections include (a) elimination of the need to recruit, train, and maintain a diving team(s); (b) reduced chance of equipment being idle when the team is not actively involved in diving operations; (c) ability to specify a range of work, qualifications, equipment, etc., in each contract; and (d) elimination of problems associated with assignment of divers to other work. Disadvantages include: (a) slow response time to emergency situations; (b) problems associated with bidding for engineering services; (c) possibility of new contracts each year; and (d) assignment of final responsibility for the engineering report of the inspection.

Among the advantages of using an in-house dive team for all inspections are: (a) total control of the inspection effort; (b) ability to train inspectors in specific problems of design, construction, and materials; (c) use of dive team for construction inspection; and (d) accumulation of experience and knowledge obtained from repeat dives during scheduled inspections. Disadvantages include: (a) capability of dive team may be exceeded in some cases; and (b) need for alternate work assignments if dive team is not multiqualified.

Perhaps the best situation exists when an agency has limited dive capability for routine, construction, and emergency inspections with a backup contract for additional diving. In some cases, agency divers can work with or direct contract divers.

When requesting bids on contract diving, the qualifications of the divers (diving, bridge inspection), the size and amount of special equipment, and the rates (hourly, daily, weekly) must be considered. If the inspection report is to be signed by an engineer other than an agency engineer, this should be stated.

The use of television (including video tape), photography, etc., has permitted agencies to employ nonengineer divers with increased confidence; however, most structural and bridge engineers believe that the engineer or diver performing or the person in charge of the underwater inspection should be well-trained in structural inspection. The engineer supervising underwater inspection must have a comprehensive knowledge of structures and their capabilities.

[1] State agencies interested in developing underwater inspection capability should visit with agencies that have experience in this area. The Massachusetts agency has offered to provide limited personnel support to other agencies during the winter months in exchange for transportation, lodging, and meals for personnel during the training period.

PREPARATION

The underwater inspection team should be familiar with the construction of the bridge and the site conditions before starting the inspection. Proper planning and preparation will save much time in the field and result in a more accurate inspection. Just as in planning for an above-water inspection, the underwater inspection team should consider the following items:

- Inspection schedule (priority, frequency).
- Type of inspection (swim-through, in-depth, for specific problem).
- Requirements for manpower, equipment, materials, and special instruments. A typical four-man team (more than one team may be required) includes two divers, one safety diver, and one boat operator (usually also a diver).
- Examination of all pertinent available information on the structure, such as design plans, previous inspections, and previous repairs.
- Type of reporting system to be used (notebooks, standard forms, photographs, video tape, etc.).
- Inspection procedure (see Appendix C).

CLEANING

Cleaning marine growth from the underwater portions of the bridge substructure to facilitate inspection and detection of deficiencies is almost always required. The extent of the cleaning will depend on the amount of growth present and the type of inspection being made. Routine inspections, when there are no known defects, generally require only light cleaning in select areas, whereas detailed inspections may require complete cleaning of certain structural elements. In either case, indiscriminate cleaning should be avoided. Cleaning is not only arduous but can also consume a great amount of time. Another reason to avoid unnecessary cleaning of marine growth is that the growth can afford some protection against deterioration.

A wide variety of tools are available for cleaning marine growth under water. Light cleaning is usually performed with a diver's knife or hand tools such as chipping hammers or scrapers. The cleaning of thick, hard growth from large areas is best accomplished with power tools such as pneumatic or hydraulic-powered chippers, grinders, and brushes. Sand or water blasters can also be used under water.

For tough cleaning jobs, a high-pressure water blaster is effective for steel and concrete surfaces. Water blasters with discharge pressures up to 14,500 psi (100 MPa) are available. The system consists of a surface pump, a high-pressure hose, and a gun. The gun nozzles vary in orifice size and type; a lance nozzle can be used to remove fouling organisms on steel, whereas a fan jet nozzle can be used on concrete. The gun control is a pistol grip, and the gun flow is divided into a primary flow for cleaning and a secondary flow to counterbalance the jet. These high-pressure models are capable of cutting through sound concrete; thus care must be taken not to damage the structure. The water blaster is cumbersome and potentially dangerous; the diver must be careful to keep the nozzle end pointed away from himself and others as it removes bone and muscle more easily than fouling organisms. It should, therefore, be used with great care only by an experienced operator, and should not be used on timber structures.

The hydraulic-power brush systems used to clean ship hulls can also be used to clean large concrete surfaces under water. These systems are not as rapid as water blasters but are satisfactory for some cleaning tasks. Hull scrubbers are similar in operation to floor buffers. The centrifugal action of the brush causes it to adhere to the surface being cleaned. By lifting one edge or the other, the brush can be made to move in any direction; the diver simply hangs on and goes for a ride. These brush systems are available in various sizes; brush sizes up to 16 in. (400 mm) in diameter are suitable for bridge cleaning and can be operated out of small [18 to 20 ft (5.5 to 6.1 m) long] dive boats.

DETECTION

Visual

Visual examination is the primary method used to inspect the underwater portions of a bridge. The most obvious limitation to visual inspection is water clarity. In many cases, bridges are built in generally turbid water in which the degree of visibility varies from poor to zero. When turbidity is high, underwater visibility can be nonexistent, even if the diver carries artificial lights, as direct light is reflected by the turbidity and visibility is reduced. Visibility may be improved if a clear-water mask is attached to the face plate of diving gear. Small plastic bags [0.5 ft^3 (0.01 m^3)] can be used as a clear-water lens to inspect H piles and other irregular shapes.

Tools for probing, scraping, measuring, and recording underwater findings are necessary for a visual inspection; hammers, picks, pry bars, probing rods, and similar devices should be available. For measuring, graduated rods, carpenter's rules, measuring tapes, sounding lines, and in some cases, calipers are needed. Diver's lights with spare batteries and still-camera equipment should also be available. A diver's slate is useful for making notes and sketches under water.

Tactile

As the substructures of many bridges are in turbid water that severely limits visibility, the diver must touch and feel to detect flaws, damage, or deterioration. Divers are capable of conducting inspection using only tactile methods in zero visibility, but it is difficult, if not impossible, to qualitatively assess this technique. The task is even more difficult in cold water, when there is a strong current, or if the structure is coated with marine deposits.

Planning for tactile inspections requires greater preparation than when working in clear water. Attention should be given to the following items:

- In-depth study of plans;
- Good communications between diver and surface;
- Blind practice in a pool to help assess capability;
- Use of nondestructive testing and other techniques not dependent on sight or touch;
- Increased use of sounding equipment to detect scour, debris buildup, etc.;

- Recorder to document voice transmissions; and
- Determination of position and depth of diver.

Other Methods

In some cases, more sophisticated instruments, including echo sounders, ultrasonic thickness gauges, and closed-circuit underwater television are required (see Table 4).

Echo sounders (specifically fathometers) are effective in checking scour in the stream bed adjacent to a bridge. However, fathometers are not effective when used very close to the structure, as erroneous returns from the substructural elements or from accumulated debris are likely to occur. Undermining of piers or abutments cannot be adequately detected with an echo sounder; when undercutting or undermining is suspected, there is no substitute for visual inspection.

Ultrasonic (nondestructive testing) methods can be employed under water to detect and locate discontinuities or flaws and to measure thickness in steel, concrete, and wood structures (or in any material that will transmit vibrational energy) (*9, 12, 13*). Ultrasonics require a clean, bare surface for accurate results. Ultrasonic thickness measurements can be made accurately under water over a range of 0.125 to 10 in. (3 to 250 mm), depending on the type of material, conditions, and the probe selected. In operation, an electric pulse is generated in the test instrument and transmitted to a transducer that converts the electric pulse into mechanical vibrations. The vibrations are transmitted into the object being tested, and are scattered, attenuated, reflected, or resonated. A portion of this energy is returned to the transducer where it is reconverted to electrical energy, and then transmitted to the test instrument where it is amplified and displayed, either digitally or on a cathode-ray tube. All materials have a characteristic sound velocity that must be known for purposes of interpretation. Calibration blocks containing various-sized holes can be employed to calibrate the test instrument. The sound frequency emitted by the transducer for metals testing is high, generally in the range of 3.5 to 5 MHz. For concrete and wood testing, the sound frequency is lower, ranging from 20 kHz to 250 kHz. Some problems have been encountered with this type of equipment, including difficulty with operation under water.

Computerized tomography (CT), now widely used in hospitals, is a recent addition to underwater equipment (Figure 9). With this method, voids can be located, steel location can be pinpointed, and sections can be indicated accurately (Figure 10). Although the equipment and software are available, CT is not currently being used for underwater inspection (*8*). The U.S. Navy is investigating the feasibility of this technique for underwater use.

Documentation of observations on video tape is standard practice in some underwater inspections. The types and capabilities of commercially available underwater television cameras are numerous. Cameras are designed to be handheld or mounted on the diver's headgear. As a documentation tool, television offers no particular advantage over still or cine photography; it is common practice to supplement television with still photographs. Television does offer the

TABLE 4
SENSORS THAT CAN BE USED TO COLLECT DATA REQUIRED FOR INSPECTION OF STEEL STRUCTURES (*5*)

Applicable Sensors	General Structural Integrity	Structural Deformation	Joint Separation	Joint Cracking	Corrosion Protection System Integrity	Corrosion Potential Measurements	Corrosion Thickness Measurement	Fouling	Scour	Nature and Location of Debris	Vibration Signature	Tilt
Eye	X	X	X	X	X		X	X	X	X		X
Television	X	X	X	X	X		X	X	X	X		
Film Camera	X	X	X	X	X		X	X	X	X		
Optical Scan	X	X	X		X			X	X	X		
Acoustic Scan	X	X							X	X		
Ultrasonic Thickness							X					
Radiographic				X								
Magnetic Particle				X								
Corrosion Potential					X	X						
Profile Gauge		X					X					
Straight Edge		X					X					
Accelerometers											X	
Ultrasonic Flaw Detection		X	X									
Platform Tilt and Level Gauge												X
Eddy Current				X								
NOTE: Cleaning is required for certain measurements:												
(a) Brush			X	X			X	X				
(b) Chipper			X	X			X	X				
(c) Water Jet			X	X			X	X				

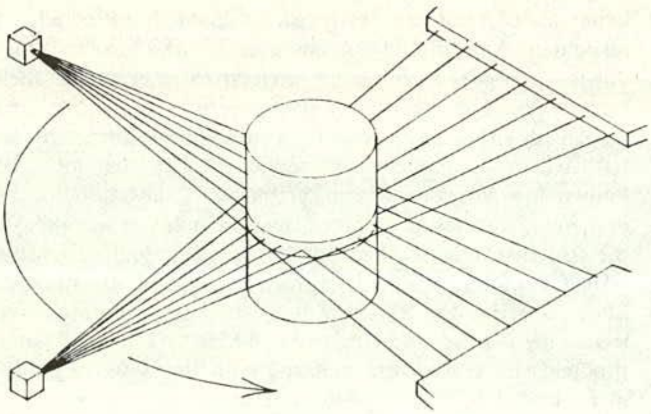

FIGURE 9 Scanning procedure for computerized tomography. A gamma ray source is collimated to form a flat fan of rays that are attenuated as they pass through the object to a set of detectors. Either the object or the source-detector apparatus is rotated to give a series of such projections, all through the same cross section (8).

advantage of real-time display to the surface and real-time quality control of the video image. The underwater television field is advancing rapidly; it appears likely that there will be improved resolution and color transmission in the near future.

SAMPLING

In some cases, visual inspections, even when supplemented with nondestructive testing techniques, do not entirely indicate the condition of a structure. Then it may be necessary to collect samples from the structure. There are a variety of methods by which the materials of bridge substructures may be sampled under water.

Cores can be drilled from wood, concrete, and steel structures. Cores from timber structures are easy to obtain because usually only small-diameter samples are needed. These can be drilled with specially designed, commercially available hand core drills. Timber sections can also be sawed under water with hydraulic or pneumatic power saws.

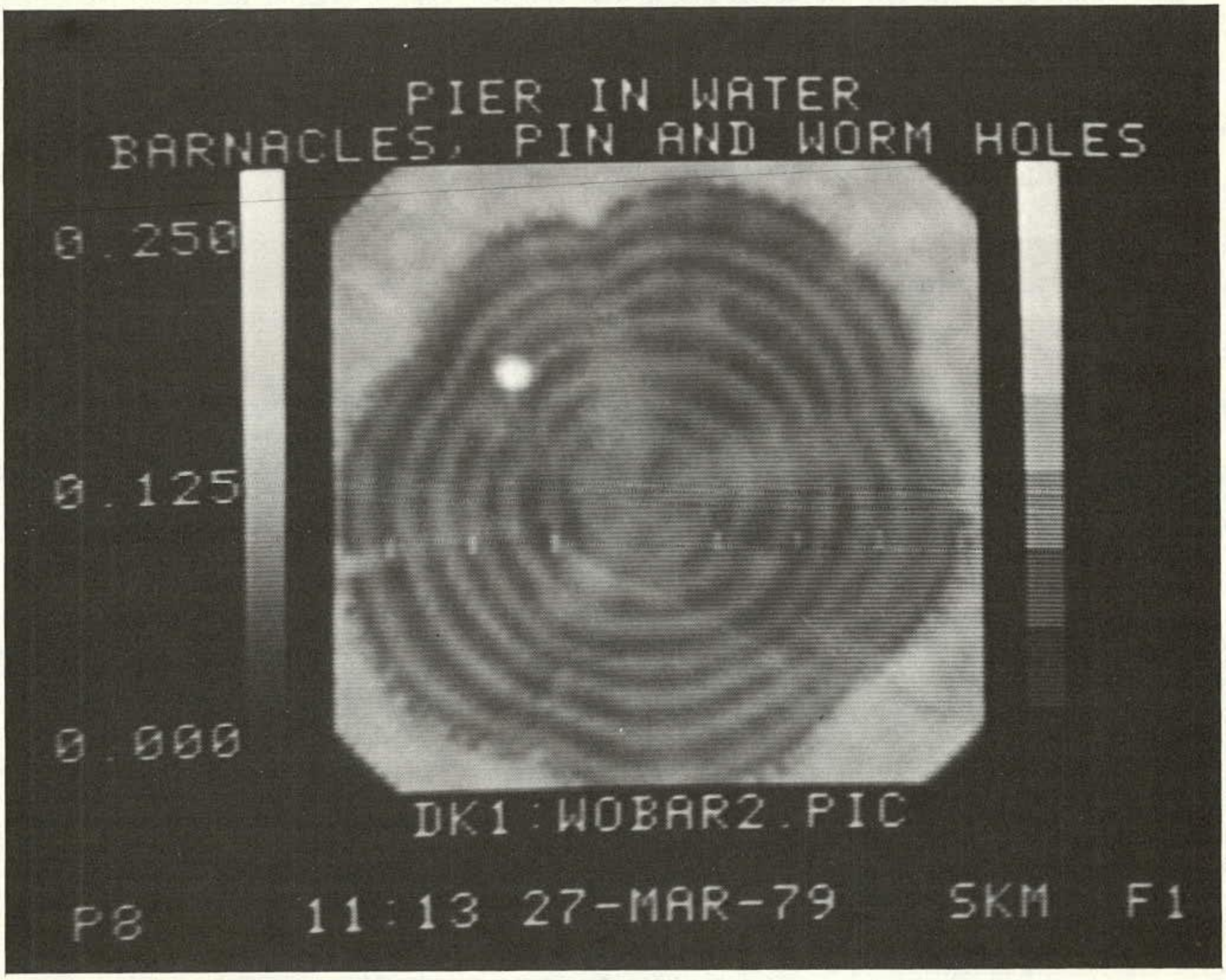

FIGURE 10 CT section of underwater pier.

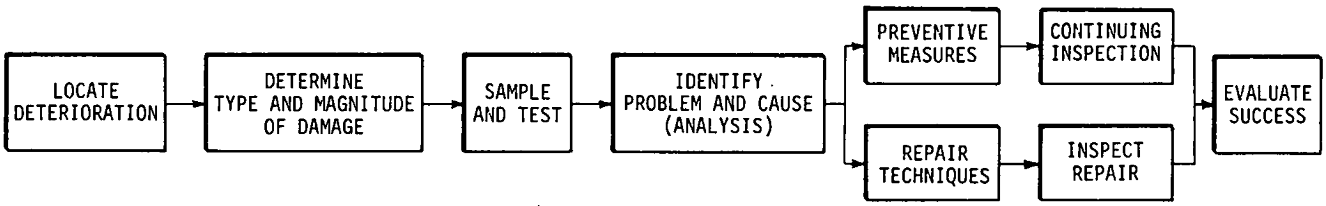

FIGURE 11 Analysis and selection of repair procedure for underwater deterioration.

It is more difficult to sample concrete. Commercially available core drilling equipment is not readily usable for underwater inspection. However, standard core drill frames can be modified for diver operation: electric-powered drills are replaced with pneumatic or hydraulic power drills; and base plates must be bolted to the structure, particularly when drilling in the horizontal position. It is often necessary to incorporate a pressure-regulated pneumatic or hydraulic ram to provide the thrust to the bit. A diver-operated concrete core drilling apparatus was recently assembled for a comprehensive bridge investigation in Florida. Powered by hydraulics, this apparatus is capable of coring either horizontally or vertically to a depth of 4 ft (12 m). Core drills up to 6 in. (150 mm) in diameter can be used. The entire system is light enough to be operated from an 18-ft (5.5-m) boat. Samples can also be sawed or chipped from concrete structures using either pneumatic- or hydraulic power tools.

Steel coupons may be removed by coring or with a cutting torch. Generally, if a large amount of coring is required, it is better to build the diver-operated core drill from scratch. Samples from steel sections, although rarely taken from the underwater portions of bridge substructures, can be obtained by drilling or cutting with a welding torch.

TESTING

Wood

The most common method for testing wood involves boring into the surface with drills or removing samples by means of core drilling. Ease of penetration may indicate low density or voids caused by fungal, bacterial, or borer action.

Test boards are used to detect borer attack. Blocks of wood are immersed in the water and retrieved periodically. The blocks are then wrapped in plastic bags to prevent evaporation and sent to the laboratory for study and identification of borers.

Steel

Chemical tests, microscopy, electron microscopy, and X-ray tests are used to determine flaws detrimental to performance, such as cracks, flaws, and occlusions.

Concrete

To test concrete, compressive strength tests of cores are conducted. Microscopic examination for air content in samples and moisture content tests are performed. Petrographic studies may also be performed using chemical, microscopic, and X-ray techniques.

Nondestructive Testing

Much interest has been expressed by transportation agencies concerning the application of nondestructive testing (NDT). Owners of offshore drill platforms have developed underwater inspection and testing procedures using NDT techniques. Tables 5–7 give the advantages and disadvantages of several techniques currently used. The development capability is given in Table 6. The advantages and disadvantages of the acoustic emission and vibration analysis systems are presented in Table 7.

ANALYSIS

As soon as deterioration or distress of a bridge substructure has been detected, it is essential that the basic cause of the problem be determined. It is not possible to evaluate the need for repair or to select a satisfactory repair procedure until the basic cause of the deterioration or distress is ascertained. Failure to determine the cause or to understand the main pattern of a deterioration process may lead to the selection of a repair procedure that can cause additional damage (Figure 11).

Determination of the cause of deterioration in steel or timber structural members is fairly straightforward because the relation between symptoms and cause is usually quite clear. However, determination of the cause of deterioration in a concrete structure poses a more subtle problem. There are often several agents and processes at work simultaneously, and all possible causes of the observed condition must be assessed.

Once the cause of the deterioration has been determined, emergency or temporary repairs should be considered. Alternative action may include a reduction of loadings or partial or total closing of the structure. A decision must be made whether (a) to permit deterioration to continue, (b) to implement repairs that will preserve the structure in its present condition, (c) to implement repairs that will strengthen the structure, or (d) to replace the structure in case of advanced deterioration. This decision should be based on considerations of safety, economics, and practicality.

TABLE 5
CURRENT UNDERWATER NDT TECHNIQUES: ADVANTAGES AND LIMITATIONS (*13*)

Method	Material	Defects	Advantages	Limitations	Remarks
Visual	All materials	Surface cracks/pitting, Impact Damage, Surface Corrosion, Marine Fouling, Debris, Scouring, Concrete spalling/crumbling	Results easy to interpret. Can be conducted with a variety of techniques.	Limited to surface defects. Surface must be cleaned for detailed observation.	
Magnetic Particle	Magnetic materials only	Surface cracks, laps, seams, pits and some near-surface flaws.	Easy to interpret.	Thorough cleaning required. Weather dependent in splash zone. Limited to surface and near surface defects. Does not measure depth of defect. Interpretation done only <u>in situ</u>. Present equipment limited to diver use. Magnetic materials only. No permanent record. Cumbersome to perform underwater.	Surface Support required.
Magneto-graphic Method	Magnetic materials only	Surface cracks, laps, seams, pits and some near surface flaws.	Simple to perform. Permanent record. Signal enhancement possible. Defect depth can be obtained. Interpretation conducted on surface. No diver NDT qualifications required.	Thorough cleaning required. Limited to surface and near-surface defects. Geometry of structure can be prohibitive. Magnetic materials only. Equipment limited to diver use.	Potential for application by mechanical manipulators.
Fe Depth Meter	Reinforced concrete	Depth of steel reinforcement in concrete.	Easy to perform. Results immediate. Can be preformed by mechanical manipulation.	Thorough cleaning required. Bar size must be known for greatest accuracy. No data recording feature.	
Ultrasonics	Metals, Concrete, Plastics, Creamics, Glass, Rubber Graphite	Cracks, Inclusions Porosity, Laminations, Bursts, Grain size, Lack of bond, Lack of weld penetration and fusion, Thickness variations.	High sensitivity. Fast Penetrates up to 10mm of steel. Accurate flaw location. Access to only one side needed.	Thorough cleaning required. Operator skill is required. Usually no permanent record. Comparative standards only Surface roughness can affect test. Difficulty with complex shapes. Present equipment limited to diver use.	
Acoustic Holography	Same as above	Same as above.	Provides three-dimensional view of internal defects which can be precisely measured and located.	Thorough cleaning required. No field experience underwater. Present equipment limited to diver use.	
Radiography	All materials	Internal defects such as inclusions, porosity, shrinks, corrosion, lack of penetration and fusion in welds. Thickness measurements.	Provides permanent record Standards established. Accepted by codes and and industry. Portable.	Thorough cleaning required. Potential health hazard. Defect must be at least 2% of total section thickness. Difficulty with complex geometry. Water must be displaced between source and subject. Requires access to both sides. Present equipment limited to diver use.	
Corrosion Potential	Metals	Tests cathodic protection system by measuring interface potential between structure and seawater.	Simple to perform. Rapid measurements. Easy to interpret. Can be performed by mechanical manipulation.	Thorough cleaning required. Measures external potential only.	

TABLE 6
NDT DEPLOYMENT CAPABILITIES: PERFORMANCE AND POTENTIAL (*13*)

Test/Examination	Diver	RCV	Sub	ADS[1]	ADS[2]
Cleaning	A	N	N	P	P
Visual	H	H (exterior only)	A (exterior only)	H (exterior only)	H
Magnetic Particle	H	N	N	P	P
Magnetographic	H	N	N	P	P
Fe-depth	H	P	P	P	P
Ultrasonic					
Thickness	H	P	P	P	P
Flaw	H	N	N	P	P
Acoustic Holography	H	P	P	P	P
Radiography	H	N	N	P	P
Corrosion Potential	H	H	H	P	P

H = High performance
A = Adequate performance
P = Potential performance
N = No foreseeable potential with present facilities
ADS[1] = JIM-Type
ADS[2] = WASP-Type

TABLE 7
SUMMARY OF PERFORMANCE OF MONITORING SYSTEMS (*13*)

	Advantages	Disadvantages
Acoustic Emission	No diver required to conduct tests. Can detect a crack. Can ascertain relative rate of crack growth Can determine crack location.	Long-term reliability not yet verified. Components in water subject to environmental stresses. Cannot determine crack size. Cannot determine nature or significance of the crack. No standards of calibration from system-to-system. Expensive installation (i.e., diver) costs on existing platforms.
Vibration Analysis	No diver required to conduct tests. All components above water. Quick set-up time. Can detect broken load-carrying members.	Limited operational experience. Cannot assess significance of break. Cannot detect cracks unless they are significant in magnitude. Cannot locate cracks or break. Cannot monitor crack growth. No standards of calibration from system-to-system.

CHAPTER FOUR

DIVING EQUIPMENT

A wide variety of individual capabilities, equipment, and techniques are employed in diving operations. In general, there are three types of diving operations in practice (see Figure 12 and Appendix D):

1. Scuba (self-contained underwater breathing apparatus).
2. Surface-supplied / tended air or mixed-gas diving (lightweight diving).
3. Nonsaturation and saturation diving employing diving bell (deep-sea diving).

Scuba and surface-supplied air diving, using air as the breathing medium, are the two methods of diving operations most applicable to bridge inspection work. Mixed gas and diving-bell operations, which are routinely used by the offshore oil industry for deep diving, are seldom required for bridge inspection and will not be discussed here.

SCUBA DIVING

In scuba diving, the diver is provided with a portable air supply and has freedom of movement because he is not connected to the surface or an umbilical cable. This method of diving is especially suited for making inspections when mobility is a prime consideration or many dives of short duration at different locations are required instead of one sustained dive. The disadvantages of scuba diving are depth limitation, limited air supply, and difficulty in communicating with the surface. Generally, the maximum sustained working depth in scuba diving is about 60 ft (18 m). For short periods of time, depths to 120 ft (37 m) normally do not present any special problems to the experienced diver. With a single tank (72 ft^3—2m^3), a scuba diver can usually work at a depth of 30 ft (9 m) for about 1 hr. Air consumption varies for each individual. As the water depth or level of exertion increases, the "bottom time" will decrease.

SURFACE-SUPPLIED/TENDED AIR DIVING

In surface-supplied / tended air diving, air is supplied from the surface to the diver by a flexible hose. In addition to the air hose, a communication cable, a lifeline, and a pneumofathometer are usually attached to the diver. A diver may use either heavyweight (hard-hat) equipment with a dry suit or lightweight (face sealing mask) equipment with a wet, dry, or hot-water suit. A disadvantage of surface-supplied / tended air diving is the size of the operation necessary to support the diver. The extra weight of the air compressor, hoses, and lines, the frequent need for a larger vessel to support the diver, and problems with mobility and transportation are significant disadvantages. The advantages of surface-supplied air diving include: (a) voice communication, and (b) maximal surface control of the diver in mild currents.

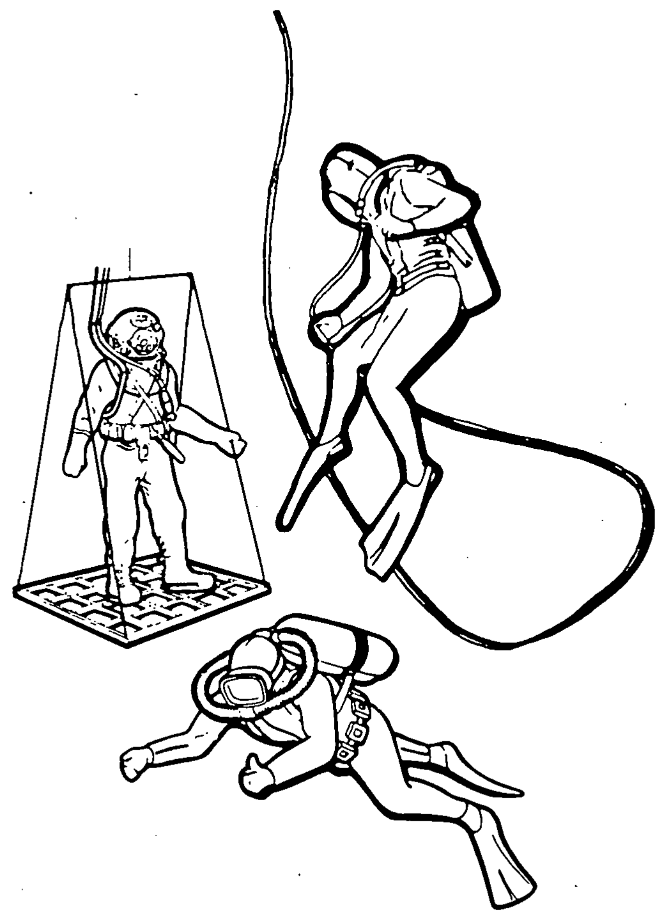

FIGURE 12 The diver may choose from three diving techniques: open-circuit scuba, lightweight, and deep-sea (*14*).

COMPARISON OF EQUIPMENT REQUIREMENTS

For a routine inspection performed by scuba diving, the following equipment is typically used:

- Van, truck, or other vehicle to transport gear;
- Boat, motor, and trailer;
- Anchors, mooring line, and life vests;
- Scuba tanks and other dive gear such as wet suit, fins, weights, masks, regulator, safety vest, etc.;

- Dive flag;
- Chipping hammers, picks, pry bars, probing rods, and scraping tools;
- Underwater lights;
- Writing boards, drafting equipment, and underwater slates for recording data;
- Underwater camera; and
- Yardstick, tapes, calipers, or other measuring devices.

For the same routine inspection performed by surface-supplied/tended air diving, the following equipment is required in addition to the items listed above:

- Larger vehicle to transport equipment;
- Larger boat to support diving operation;
- Diving compressor and receiver tank;
- Diver umbilical with air hose, communication cable, lifeline, and pneumofathometer;
- Surface-supply headgear; and
- Diver's radio.

SAFETY

A diver is confronted with natural forces and physiological effects not encountered in the normal environment, which impose definite limits and may cause serious accidents. The diver's safety depends on knowledge of these factors and ability to recognize and handle them. The diver must be capable of making evaluations of the environment, specific diving equipment, and his or her own condition in relation to the task or diving operation being performed. Many potential dangers are usually completely avoidable.

The various hazards and accidents to which a diver is vulnerable include (not listed in the order of the most common occurrence): respiratory accidents, oxygen poisoning, nitrogen narcosis, bleeding, overexertion and exhaustion, fainting, hypothermia, and other medical conditions and physical injury; squeeze, gas expansion, blowup, loss of communication, fouling, polluted water, noxious air, tides and currents, marine traffic, marine life, floating debris, and other environmental hazards. A detailed explanation of the causes, effects, and treatments of these hazards and accidents is provided in the *U.S. Navy Diving Manual (14)*.

Each type of diving operation and equipment requires safety precautions. General safety precautions that apply to all diving operations include:

- Make sure that each diving operation is thoroughly planned in advance and properly supervised.
- All diving personnel must be thoroughly trained in the equipment being used and physically fit for the diving operation.
- Equipment must be first quality, specially designed for diving, and thoroughly tested and inspected before use.
- Follow all safety precautions during the diving operation.

Employers of diving personnel should develop manuals of safe practices to have available at dive locations. For each type of diving operation, the safety manual should include: (a) safety procedures and checklists for diving operations; (b) assignments and responsibilities of dive team members; (c) equipment procedures and checklists; and (d) emergency procedures for equipment failures, adverse environmental conditions, and diver illness or injury. Diving safety manuals should also contain the current rules and regulations established for commercial diving operations by the Occupational Safety and Health Administration (OSHA) (*2*).

CHAPTER FIVE

MAINTENANCE AND REPAIR OF UNDERWATER BRIDGE SUBSTRUCTURES

INTRODUCTION

It is common practice for state transportation agencies to develop schedules for the maintenance and repair requirements of those portions of bridges above the water line. This practice has not been as widespread for the underwater elements of bridge structures. In part this is because of inadequate detection of the deficiencies caused by construction errors, impact damage, or deterioration of materials in a hostile environment.

The recent increase in underwater inspections by state agencies has resulted in increased awareness of the need for underwater repairs. In-depth problem analysis is advisable when considering repair to underwater structural elements. The fact that repair is required is adequate evidence that the original design, selection of materials, or construction methods should be questioned. In many cases the in-kind replacement of the original structural element or materials is not practical or possible. It is good practice to involve a bridge designer or to assign a structural engineer to work closely with the underwater inspection and maintenance teams.

Maintenance and repair of bridge substructures located below the waterline have been hampered by the following factors:

- Tendency not to be overly concerned with unseen maintenance problems.
- Lack of as-built plans or updated plans showing revisions and repairs.
- Changed channel conditions.
- Limited experience with underwater investigation by maintenance personnel.
- Limited experience with underwater repairs, and uncertainty over proper procedure or materials to be utilized in making repairs.
- Lack of proper maintenance during life of structure.
- Inability of supervisor to supervise or inspect underwater work in progress or completed work.
- Absence of major failures resulting from poor underwater maintenance.

A prerequisite of the maintenance or repair of an underwater structure is an understanding of what has caused the present condition. Usually there are several causes and effects, and the sequence in which the events occurred and the resultant conditions must be precisely determined.

Frequently, underwater damage or deterioration is related to design deficiencies or shortcomings. Reconstruction of original calculations may be required: plans may not be available for older bridges; and design calculations, soil test data, or construction specifications may be unavailable for newer bridges.

Construction deficiencies can also result in the need for maintenance and repair of underwater structures. Construction records are even more likely than design information to be unavailable. Sampling, testing, and analysis, along with an examination of obvious deficiencies, can aid in determining damage or deterioration resulting from improper construction materials or procedures. New borings and soil tests may be necessary.

Continuing degradation or deterioration may require an investigation process in order to fully understand the type of deterioration that is occurring, how and why it is occurring, and the rate at which it is taking place. Changed conditions may be a one-time or a continuing occurrence requiring maintenance or repair (e.g., increased loading on old bridges, change in salinity or other chemical environment, or shifted or continually shifting bottom configuration). Many older bridges were designed before the development of modern procedures for calculating flood intensity, duration, and frequency. Under some conditions tidal flood levels, surges, and currents can exceed almost any design specification. Monitoring change or the rate of change of conditions can be effective methods in the investigative process. Inspections, measurements, sampling, and tests on a continuing basis at appropriate intervals can aid deciding on the types of repairs to be selected.

The combinations of conditions and causes are too numerous to describe herein every type of condition and the required maintenance or repair. There is also a wide range of materials and procedures available for corrective measures; choosing the appropriate materials and procedures is not always easy or obvious. Table 8 lists, according to the nature of the problem and the types of materials to be repaired, some of the repairs and preventive measures currently performed under water and in the splash zone. Many state manuals on maintenance and repair methods are available; e.g., Florida's *Manual for Bridge Maintenance Planning and Repair Methods* (*15*).

There are fewer options available for underwater maintenance and repair procedures than for work above water; there is also less certainty that the underwater work will be completed satisfactorily. Cleaning, which is essential to concrete repair, is more difficult under water; and construction work below the waterline is slow and must be carried out on a smaller scale and therefore is more expensive. Repair decisions on alternative methods entail weighing risks and costs, thus requiring expert engineering knowledge, experience, and judgment.

TABLE 8
REPAIRS AND PREVENTIVE MEASURES

TYPE OF REPAIRS (UNDERWATER AND IN SPLASH ZONE)		NATURE OF PROBLEM												
		SCOUR	DETERIORATION			DAMAGE (STRUCTURAL)			STRUCTURAL FAILURE			FOUND. DISTRESS		
			CONC.	STEEL	TIMBER	CONC.	STEEL	TIMBER	CONC.	STEEL	TIMBER	CONC.	STEEL	TIMBER
REPLACEMENT OF MATERIAL		●												
SHEET PILING		●												
TRAINING WORKS		●												
MODIFICATION OF THE STRUCTURE		●							●	●	●	●	●	●
EPOXY INJECTIONS			●			●								
QUICK SETTING CEMENT			●			●								
EPOXY MORTAR			●			●								
PLACING CONCRETE UNDERWATER	UNDERWATER BUCKET		●			●			●			●		
	TREMIE CONCRETE		●	●	●	●	●	●	●	●	●	●		
	PREPACKED CONCRETE		●			●			●			●		
	PUMPED CONCRETE		●			●			●			●		
	BAGGED CONCRETE		●			●			●			●		
PROTECTIVE COATINGS				●			●							
CATHODIC PROTECTION			●	●			●							
SPLICING NEW STEEL SECTIONS				●			●			●				
PILE JACKETS			●	●	●	●	●	●	●	●	●			
WOOD TREATMENT					●									
FLEXIBLE AND RIGID BARRIERS			●	●	●									
STUBBING METHOD								●			●			
OIL DRUM METHOD						●	●	●			●			

SCOUR

Prevention of Problems

Measures to prevent the undermining of a bridge substructure should begin before the design phase with the selection of the site. Bridge piers across a body of water should be located, whenever possible, where there are minimal or no scouring currents. It is not desirable to locate a pier immediately downstream from a sharp bend in a waterway. Straight alignments, right-angled crossings, high-bank approaches, and narrow channels are desirable features for bridge locations. However, with high-bank approaches, floodwater is essentially confined to the existing channel; therefore flood currents are faster than where floodwaters can overflow the channel. Piers located in deep, fast-moving water will be subject to more scour than piers in wider, slow-moving streams.

To prevent undermining caused by scouring of the foundations of piers and abutments, the bottom of the footing should be located at an adequate depth below the existing stream bed (*16*). Stream beds of fine sand or silt are more susceptible to deep scouring, but piers founded on piles fairly deep into gravel stream beds have also failed as a result of scouring during major floods.

The most effective method for preventing scour is to design the underwater structure so as to minimize the effects of scour. The design should include longer piles, deeper footings, reduced water velocity in the channel (if possible), protective riprap (*17*), sheet piling, and training structures (Figures 13 and 14). Frequent inspections are also useful for early detection of scour, which can facilitate repairs and help prevent further damage (*2*).

Maintenance

Once scour has been detected, the cause of the scour should be determined, and, if possible, design changes and corrections should be made (Figures 15 and 16). If the cause of the scour can be identified and corrected, such as a change in the alignment of a stream, an inadequate waterway, or the presence of debris, the repairs made to scoured areas are much more likely to be successful (Figures 17 and 18). At locations where the process cannot be halted, continuous inspection and maintenance, particularly after major storms or floods, are necessary.

Determining the most effective solution to a scour problem is difficult. In some cases, certain remedial work could actually be detrimental to the structure or the channel (see Figure 19). Experts should be consulted before undertaking the solution of a serious maintenance problem (*18*).

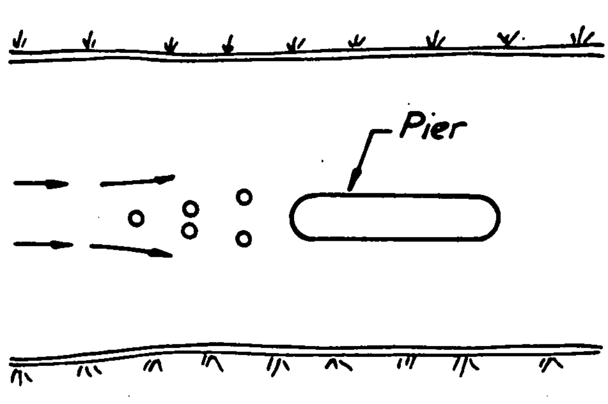

FIGURE 13 Scour reduction: piles placed upstream of pier.

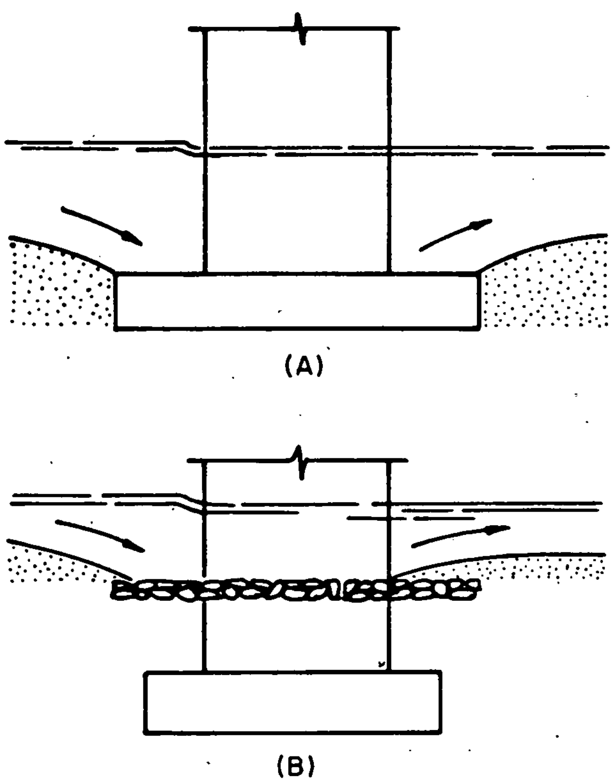

FIGURE 14 Scour reduction: *A*, wide footings; *B*, rock aprons beneath the bed level.

Repairs

Repair of damage caused by channel scour may be as simple as the replacement of displaced material, or it may involve redesign of the footing, construction of training works or sheet piling, or other modifications of the structure or channel (*6*). Current environmental policies may preclude altering stream alignments.

Replacement of Material

At sites where soil erosion has occurred because of stream or tidal action, it is common practice to place rock or riprap material in the void or to protect the replaced soil with riprap, bagged concrete riprap, or grouted or wire-enclosed rock. In some cases, material is dumped over the side of the bridge; however, at many sites, material is barged to the site. The placement of the material is checked either from the surface or by divers.

The velocity of flow, site material, and direction of the current are critical factors in selecting the replacement materials. The size of the riprap used is critical (*19–21*); it is

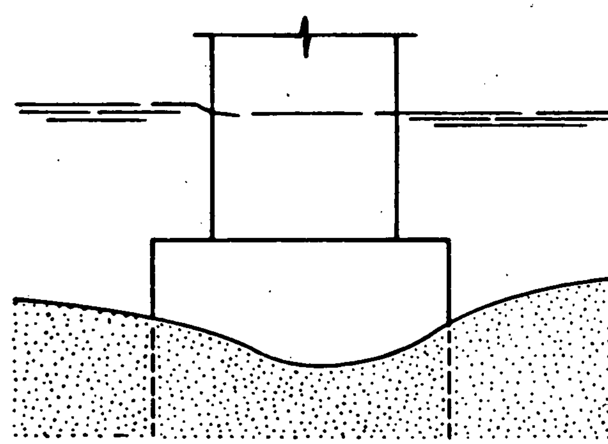

FIGURE 15 Projecting foundation will tend to increase scour.

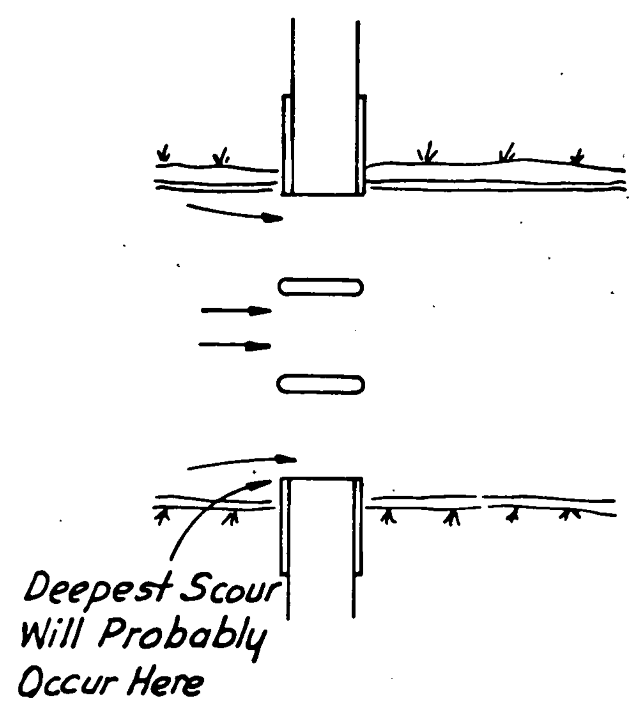

FIGURE 16 Scour caused by protruding abutments.

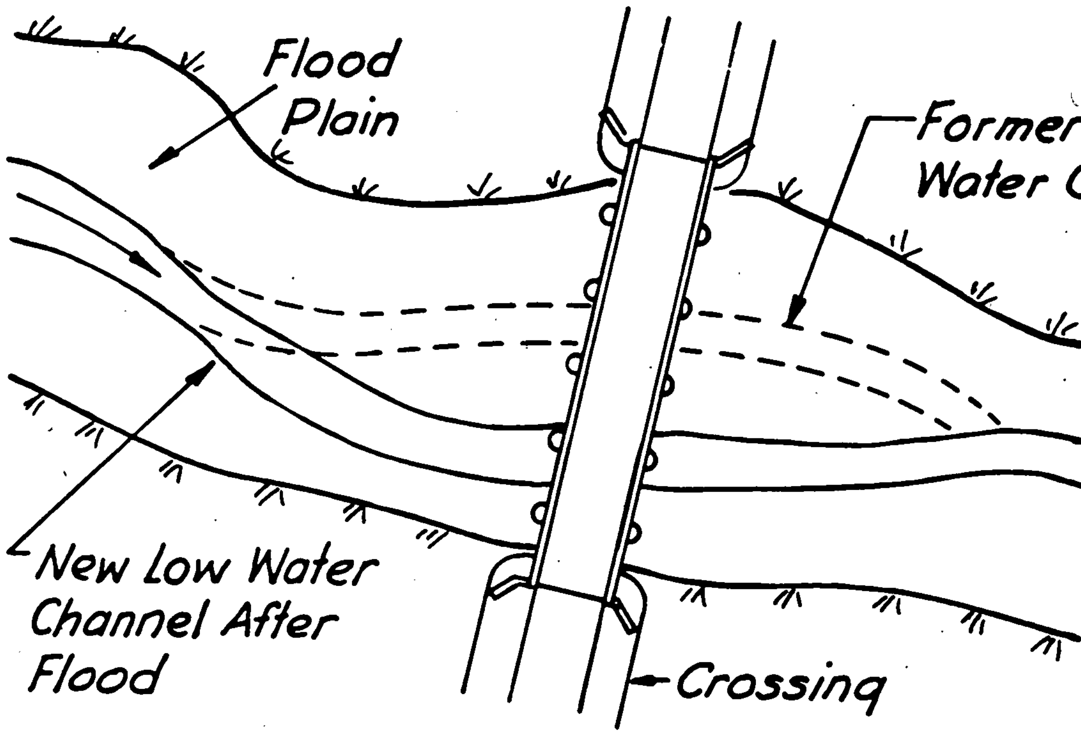

FIGURE 17 Channel change.

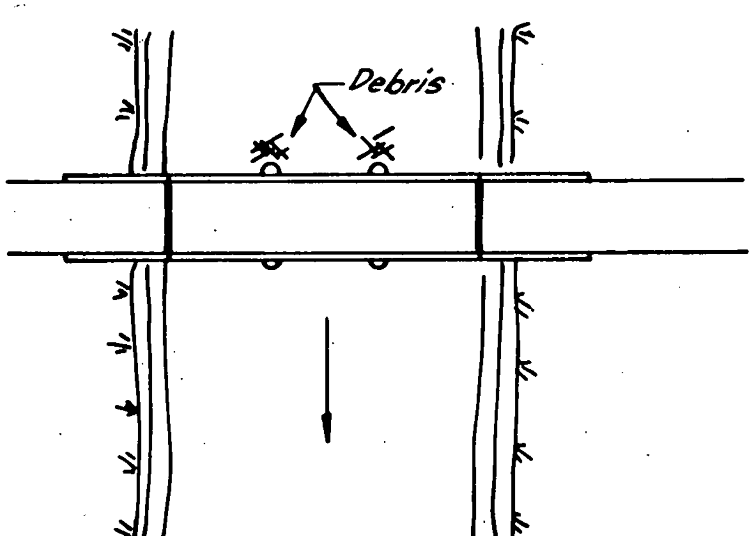

FIGURE 18 Scour caused by debris.

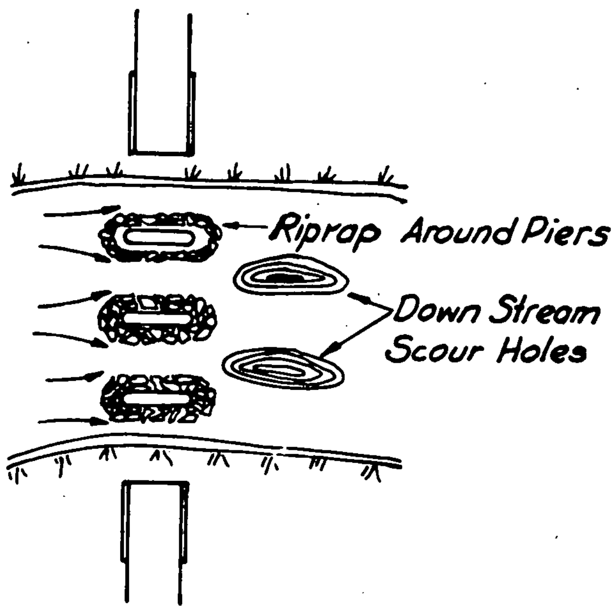

FIGURE 19 Loose riprap placed at piers to prevent local scour may be detrimental to the channel.

common practice to rely on past experience and the availability of local material.

Improperly placed riprap may not protect the footing or pier and can cause scour at adjoining piers. If material has been removed from beneath a spread footing, simple replacement of the material, even along with riprap, may not be satisfactory. Sometimes large volumes of concrete must be placed under water to protect foundations.

Sheet Piling

Piers and abutments may be protected or repaired by placing sheet piling to keep material in place or to prevent further scour. Sheet piling should be driven to a depth where rock or nonerodible soil conditions exist (Figure 20). A major disadvantage of using sheet piling is the overhead clearance required for driving.

Training Works

Spur dikes, jetties, deflectors, and other devices may be constructed to direct water away from a fill, bridge pier, or abutment (*22*); however, these devices may cause erosion damage on adjacent property if designed or constructed improperly. Correctly designed and constructed training works are helpful in controlling scour and erosion (Figure 21).

Modification of the Structure

If supporting material has been removed from under a large area of the footing, consideration should be given to redesigning the foundation, including filling the void with concrete. In some cases, the footing may be extended by using sheet piling as forms for the extension and as stay-in-place protection against further scour. If scour has exposed supporting piles (Figure 22), it may be necessary, particularly if they are short, to drive supplemental piles that are a part of the extended footing.

CONCRETE ELEMENTS

Prevention of Problems

Problems with concrete durability under water are often associated with the chemical processes in a marine environment, chemical reaction within the concrete mass, and corrosion of the reinforcing steel. Deterioration of concrete is most severe in a tropical marine environment. Physical erosion of concrete below the waterline may be caused by particles carried by flowing water (abrasion), pitting resulting from cavities forming and collapsing in water flowing at high velocities, or disintegration resulting from chemical attacks (*23*).

Selecting aggregates and cement that do not react with each other or with water is the first step in the prevention of problems with concrete durability. Sulfate-resisting portland cement should be used, especially in tropical waters. The cement content must be high, and the water-cement ratio low. Aggregates should be free of chlorides. Adequate thickness of concrete cover for steel should be specified and strictly enforced during construction. A suitable surface treatment may be specified. It is advisable to apply a protective coating to underwater piles before driving. A 1980 publication by the American Concrete Institute (ACI) contains an excellent bibliography on concrete behavior in a marine environment (*24*).

If corrosion of the reinforcing steel is anticipated, epoxy coating can be used. Reinforcing bars are initially heated to 150° F (66° C) in the shop, blast-cleaned (by wheel abrader) to white metal, and heated to 450° F (232° C). Epoxy powder (single component) is electrostatically charged and blown onto grounded bars. The powdered epoxy resin should be approved for coating bars to be used in reinforced concrete construction. Curing takes place through heat activation; no

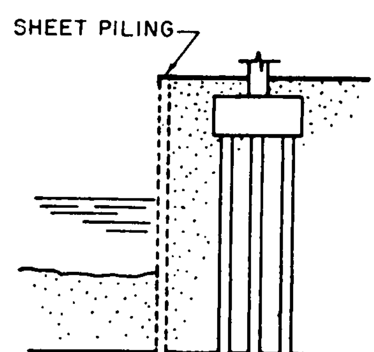

FIGURE 20 Foundation protection using sheet piling.

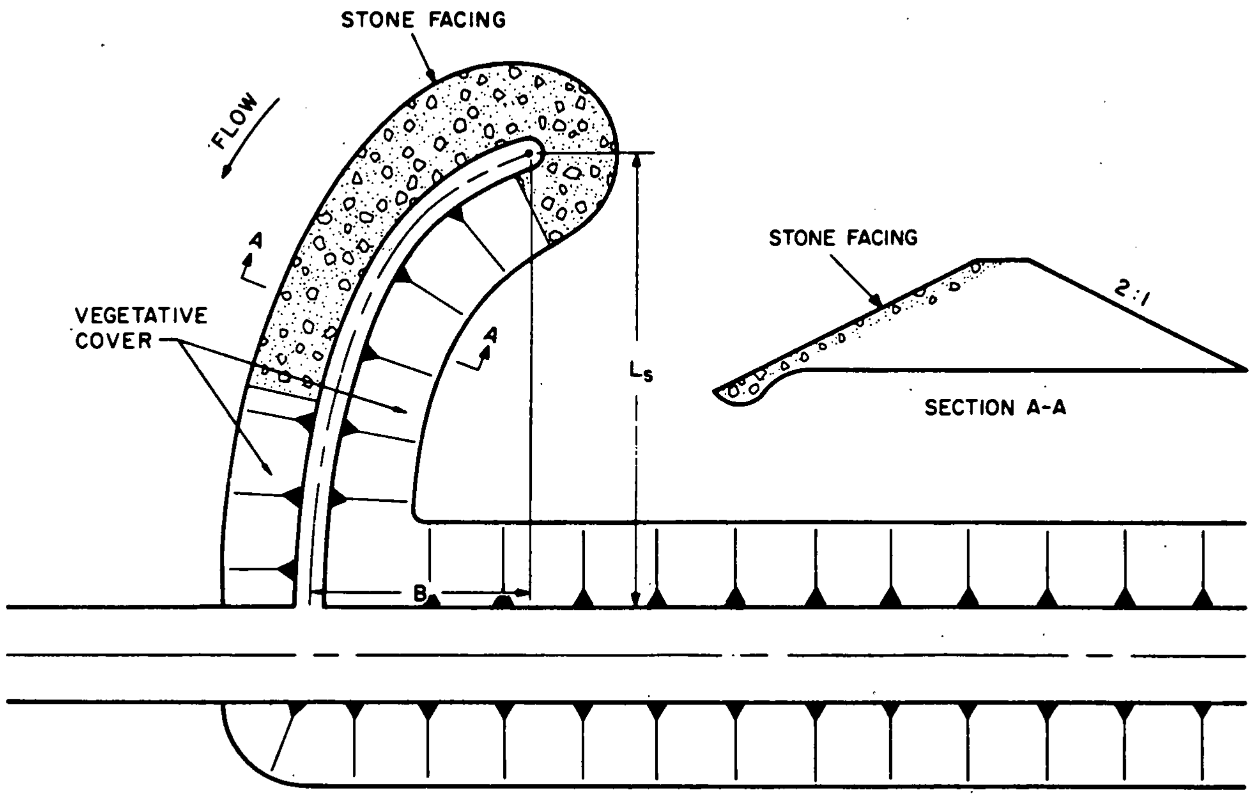

FIGURE 21 Spur dike.

catalyst or second component is needed. An application normally results in a thickness of 8 ± 2 mils (0.2 ± 0.05 mm), although specifications requiring 10 ± 2 mils (0.25 ± 0.05 mm) have been met. The bars are allowed to cool to 250° F (121° C) and kept at this temperature for about 1 hr. An electrical device is used to scan the surfaces for holidays; if any are found, which rarely happens, touch-up is done by hand. Fabricated bars can be coated in the same manner; however, the bars are usually coated before fabrication with no cracking or flaking occurring at bends after fabrication, even on hairpin bends. The cut ends of the bars are dabbed with liquid epoxy (two-component). Nylon slings should be used in handling coated bars. In the field, a maximum of 2 percent total scratched bar surface area is generally accepted without touch-up. Conventional, coated accessories for positioning bars (chairs, etc.) should be used. FHWA regulations currently do not permit the use of galvanized bars in lieu of epoxy coating because the zinc given off by the bars during corrosive attacks exerts almost as much pressure against the concrete (causing cracks and spalls) as the rusting action. The Owen Steel Company (Columbia, S.C.) reports that it has developed hot-rolled, nickel-coated steel reinforcing that retards corrosion.

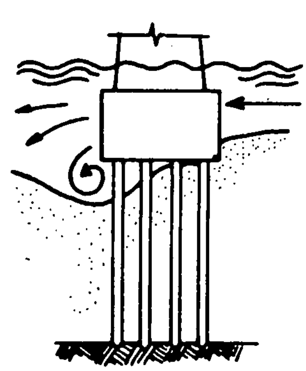

FIGURE 22 Scour-exposed supporting piles.

Care must be taken to avoid construction damage or errors when concrete is poured within dewatered cofferdams as well as when it is poured under water. Correct concrete placement methods, good forms (*25*), and well-trained work crews are essential. Specifications should include limiting the temperature of concrete at the time of placement, as high temperatures within the plastic concrete must be avoided (*26*).

Concrete should be uniform (*27, 28*); if poured in the dry and if several hours or more elapse between the bonding of successive lifts, the contact surface of the old concrete should be clean and damp. Foreign materials and laitance layers can be removed using wet sandblasting or high-pressure water jets. The occurrence of laitance layers is one of the deficiencies most often encountered by inspectors in underwater portions of bridge substructures. Movement of the formwork should be prevented during the setting of concrete. The forms should not be removed prematurely, and pieces of steel should not be left protruding from the finished concrete. It is recommended that the work be inspected immediately after placement of the concrete. Concrete should be protected from the motion of water until it has been in place at least 4 and preferably 10 days; forms left in place provide this protection (*29*).

The most effective procedure for the prevention of deterioration of precast concrete piles is consideration of the problem during design, fabrication, and construction. The designer should conduct a study on construction costs and the required maintenance costs during the anticipated life of the piles. It is recommended that, when installation of prestressed concrete piles is indicated, the following measures to minimize maintenance be considered in the design and construction (*30*):

1. Use ASTM Type III cement; Type II or V cement should be used in alkali soils and seawater.
2. Provide 2.5 in. (63 mm) clear cover for prestressing steel.
3. Use epoxy coating for reinforcing steel or use cathodic protection.
4. Handle properly to avoid cracking; do not overdrive.
5. Use protective coating (bituminous or epoxy).
6. Ensure that lifting rings do not protrude from concrete surface.
7. Inspect all piles thoroughly after installation is complete.

Maintenance

Once concrete structural members deteriorate, there are few methods available to halt the process. Cathodic protection can reduce corrosion of reinforcing steel; however, concrete may continue to spall as a result of the initial corrosion. Zinc anodes can be attached to the reinforcing steel in concrete piles. The procedure for clamping anodes to the exposed reinforcing steel is given in Appendix E (Item No. 844). Emergency or temporary repairs can be performed by clamping timber or steel members to the weak structural element.

Repairs

Most repairs to concrete substructures involve sealing cracks, patching, depositing concrete or grout to fill cavities, and encasing reinforced concrete members such as piers or piles. The basic steps in any underwater concrete repair work include:

1. Remove all marine growth (seaweed, barnacles etc.).
2. Remove all deteriorated concrete.
3. Restore reinforcing steel to original condition.
4. Seal, by injection, any cracks in the remaining concrete.
5. Replace concrete.
6. Apply protective surface treatment.

The amount of preparatory work required depends on site conditions and the extent of damage. In warm, tropical waters, marine growth appears and flourishes much more quickly than in cooler waters. Wire brushes, scrapers, chisels, pneumatic tools, sandblasting, and high-pressure water jets are used for preparing the surface.

A model of a pier showing locations of cracks, spalls, and other deficiencies is shown on Figure 23.

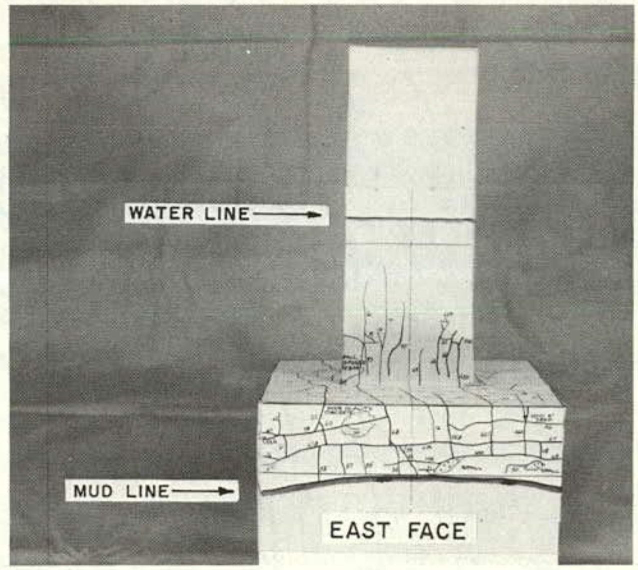

FIGURE 23 Pier model showing concrete deficiencies.

Sealing and Repairing Cracks by Epoxy Injections

Cracks that have adversely affected the strength of a structural member can be successfully repaired with epoxy injections (*31*). In above-water epoxy injections, the crack is

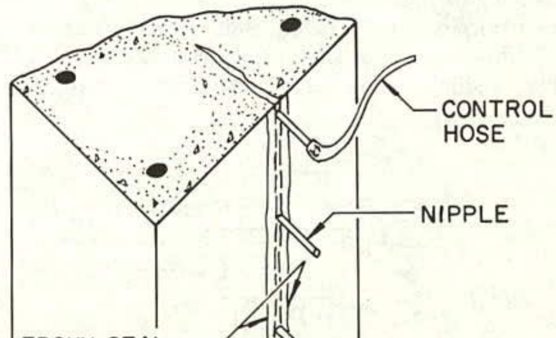

FIGURE 24 Repairing cracks by epoxy injections.

sealed on the outside using epoxy or tape, and vent ports (nipples) are inserted at regular intervals to ensure full-depth penetration (Figure 24). A low-viscosity compound is used, usually with a simple hand-operated caulking gun (sophisticated pumps are also available). Injection begins at the lowest nipple until the injected material appears at the next higher nipple and so on; the injection is completed when the material in the control hose maintains a constant level.

Methods used by divers to perform underwater (down to 60 ft — 18 m) epoxy injections are similar to the method described above, except that the epoxy surface sealer takes 3 days to harden sufficiently to withstand injection pressure. (Sealing with tape is unreliable under water.) Epoxies for underwater use must be water-insensitive. Before the application of epoxy surface sealer, cleansing is necessary; high-pressure, clear-water blasting is usually adequate. If oil or other contaminants are present in the cracks, and the epoxy is used for restoring the strength of the cracked concrete pier or pile instead of for simply blocking the free entry of water in the crack, bonding will be improved if detergents or special chemicals are mixed with the blast water to clean the crack interiors. The irregular configuration of crack interiors is usually sufficient to hold the epoxy in place after hardening, even if the surfaces are contaminated.

After all cracks are prepared and sealed and the nipples positioned, the low-viscosity epoxy adhesive is injected under pressure into the crack network. A surface-mounted, positive-displacement pump is used to dispense the adhesive's two components to the submerged injection sites where the adhesive is mixed in the injection head as it is pressure-pumped into concrete. The injection pressure is controlled by the diver-technician, and is monitored by a submersible gauge mounted near the injection head. Ratio checks are made each hour to confirm the correct proportioning of the adhesive's resin and hardener components. Water temperatures must be above 40° F (4° C). The adhesive cures to full strength in about 7 days. If bond is required, cores should be taken from the repaired cracks to examine the quality of the bond. Cracks up to ¼-in. (6-mm) wide are sealed with pure (unfilled) epoxy resin. For wider cracks, the addition of fine aggregate is generally required for a more substantial filler material and improved economy.

Quick-Setting Cement

The placement of hand-packed, quick-setting cement on concrete structures is used for the underwater patching of small spalls or voids (*32, 33*). A quick-setting cement (5 to 10 min) is mixed with fresh water in small quantities and hand-packed by a diver. Quick-setting cements attain compressive strengths of up to 6,000 psi (41 MPa) and bond reasonably well to existing concrete surfaces, providing that the existing concrete is properly prepared (*34*).

The use of quick-setting cement is not recommended for areas requiring large repairs. A disadvantage is that this material sets so fast that the diver has only a short time in which to get it to the repair site and place it. Some contractors have devised various methods of conveying the mixture from the surface to the diver at the repair site, including a rope pulley system with two buckets or a PVC pipe through which small, softball-sized portions of mix are dropped down to the diver. When a PVC pipe is used, holes must be drilled in the pipe to allow for displacement of the water in the pipe, which permits rapid descent of the material.

Epoxy Mortar

Another material frequently used for patching small spalls or voids on concrete underwater structures is epoxy mortar (*32, 35*). Epoxy mortar is composed of one part neat epoxy binder (two-component epoxy-resin system meeting the requirements of ASTM C881, Type III, Grade 3, Class C) and one part oven-dry silica sand aggregate (Grade 20-30) by loose volume, thoroughly mixed using mechanical mixing devices recommended by the epoxy manufacturer. Care should be exercised to ensure that the sand is kept free of moisture. The epoxy binder should be moisture-insensitive. The cured epoxy mortar should have a compressive strength of 6,300 psi (43 MPa) minimum at 28 days, 75° F (24° C) cure [in accordance with ASTM C109 (Modified)].

Surface preparation and work should be performed in accordance with the applicable requirements of the ACI Standard Specifications for Repairing Concrete with Epoxy Mortars (ACI Specification 503. 4-79) and the manufacturer's recommendations. The epoxy mortar, in the form of a putty, can be applied by hand (using gloves). This is an advantage when repairs are performed in turbid waters with poor visibility.

Underwater Placement of Concrete

Sometimes fairly large volumes of concrete must be placed under water within forms, caissons, or cofferdams or to protect foundations against damage or scour. To prevent the washing away of the cement from the concrete, concrete should not be placed in running water nor allowed to fall through water. Concrete should not be placed in water with a temperature under 35° F (2° C).

Underwater placement of concrete requires workable concrete with slumps as high as 8 in. (200 mm) and cement contents of up to 650 lb per yd^3 (390 kg/m^3) of cement. Aggregate should be free of fines or other materials that might cause excessive laitance (*29*). A considerable temperature rise occurs in large placements of rich concrete.

There are several basic methods of placing concrete under water: underwater bucket, tremie, prepacked concrete (preplaced aggregate), pumped concrete, and bagged concrete.

Underwater Bucket Concrete contained in special top-covered buckets with drop-bottom or roller gate openings, which can be opened from above water, is lowered into the water and then allowed to flow out. Subsequent buckets are guided to the previously placed concrete; the gate should sink into contact with the previously placed concrete to prevent fall of concrete through water. If air is used to open the bucket, the air should discharge through a line to the surface to prevent disturbance (*36, 37*).

Tremie A pipe (tremie), which is topped with a concrete-receiving funnel (hopper) and plugged at its discharge end to keep it sealed until gravity-filled with concrete or grout, is used in this method. In order to prevent water or air from entering the pipe, the tremie pipe must be immersed in the newly placed concrete or grout at all times and the pipe and hopper kept filled so that the seal is not broken. When more than one tremie pipe is required because of excessive lateral travel, care must be taken to keep the hoppers filled (*38*). (In the pumped concrete method, the manifold takes care of this problem.) Placing concrete by means of the tremie method has been described in publications of the American Concrete Institute (*36, 37, 39*). Many contractors favor the tremie method and request authorization to substitute this method for pumping because specialized equipment is not required.

Prepacked Concrete Prepacked concrete is prepared by filling forms with coarse aggregates packed around vertical pipes through which grout is slowly pumped from the bottom up, displacing water and filling the voids in the aggregate. The coarse aggregate should be carefully selected and should meet the requirements for prepacked concrete. The void ratio should range from 38 to 48 percent. The grout is a slurry mix of fine sand, portland cement, mixing water, a pozzolanic material to lower mixing-water requirements, and an agent designed to increase fluidity and inhibit early stiffening. The forms must be watertight (*40*), vented only at the top, so that the travel of the grout can be controlled. Lack of effective venting will create back pressure, resulting in voids in the concrete fill. The grout should be pumped from the lowest point in the forms and proceed upward. Grout pipes should be placed laterally at no more than 5 ft (1.5 m) on centers, and the grout should be kept at a uniform level. A positive head of at least 4 ft (1.2 m) above the level of outlets must be maintained in the grout pipes until the forms have been filled and the grout has set. The placing of grout should be a smooth, uninterrupted operation.

The prepacked concrete method of placing concrete has been described in previous publications (*36, 37, 41, 42*). Special equipment and techniques are required for this method, and the use of proper procedures results in concrete of excellent quality. The method is an advantage in situations where concrete placing is difficult; e.g., in underpinning. It has also been used successfully in cases where placing by the tremie or underwater bucket method was also suitable. However, if not performed carefully and rigorously, defective work will result and probably will be undetected.

Pumped Concrete In most cases, the method of filling the forms by pumping is more desirable than other methods because it is less dependent on the need for highly skilled workmen. Concrete and/or grout can be pumped into the form from the bottom or by inserting the fill pipe or hose into the form from the top. If inserted in the top of the form, the discharge end must be lowered until the bottom of the form is reached before any concrete or grout is pumped into place. If possible, the pump hose should be temporarily plugged at the discharge end to keep it sealed until filled with concrete. As the level of concrete or grout rises in the forms, the fill pipe must be slowly raised while keeping the discharge end immersed in the grout or concrete. Kinking of the hose or other causes of sudden surges should be avoided because sand pockets can result. Placing the concrete or grout through a single hose is acceptable if the mix does not have to travel more than 3 to 4 ft (0.9 to 1.2 m) laterally or funnel through small openings; however, it is preferable to use multiple discharge hoses or pipes connected by a manifold at the pump. Forms should be filled to overflowing, the concrete or grout allowed to settle for about 20 min, and the forms refilled to overflowing. It is recommended that aluminum alloy line not be used for the delivery of concrete. Placing of concrete with pumps has been described in previous publications (*36, 43, 44*).

Bagged Concrete Jute (or mesh polyethylene) sacks partly filled with concrete can be used both in shallow and relatively deep water. The concrete should have normal mix proportions for underwater work and should be mixed fairly dry with a low water-cement ratio. The bags should be carefully placed by divers and laid to bond so that the whole mass is interlocked. Bagged concrete can be very useful for protecting structures from physical damage and from the effects of scour at locations where flowing water cannot be avoided and at other difficult locations (*37*).

Reinforced Concrete Pile Jacket

When a concrete pile has deteriorated to the point that the structural integrity of the pile is in question, it can be encased with a concrete jacket reinforced with epoxy-coated bars (*32*). All cracked and unsound concrete should be removed. The pile surface should be clean and free of oil, grease, dirt, or other foreign materials that could prevent proper bonding. Exposed reinforcing steel should be sandblasted to near-white metal and then epoxy-coated. Reinforcing steel (epoxy-coated) cages should be placed around piles. The forms should be treated with an approved form-release agent before placing concrete and dewatered, the concrete placed, and the forms left in place for a minimum of 72 hr. Details for this type of concrete pile jacket are given in Appendix E (Item No. 838).

Integral Pile Jacket

Deteriorated concrete piles can be encased with a fiberglass form filled with epoxy grout, cement grout, or seal concrete. Construction methods, details, and applicability for six types of integral pile jackets, as developed by the Florida DOT, are given in Appendix E (Item No. 839).

STEEL ELEMENTS

Prevention of Problems

Various methods are currently used to prevent the corrosion of steel piling in seawater, including application of protective coatings, cathodic protection, encasement of the steel in concrete, or a combination of these procedures.

Protective Coatings

Protective coatings are intended to act as a barrier in separating the steel surface from the corrosive environment. Before pilings are placed in the corrosive environment, protective coatings are applied in accordance with strict specifications. Numerous types of coatings, which are used both alone and in various combinations, have been produced. The development of suitable coatings for long-term protection of steel in seawater has been slow; many of the coating systems are new and long-term test data are not available. Coatings in use today are of two types: metallic and nonmetallic.

Metallic Coatings Several studies have been conducted to determine the corrosion-protection capability of metallic coatings for steel piles. The materials tested include flame-sprayed zinc and flame-sprayed aluminum. In a test conducted by the U.S. Naval Civil Engineering Laboratory, flame-sprayed zinc was found to provide fairly good protection (except in the splash zone) to steel piles. The poor performance in the splash zone may be the result of the splashing water causing erosion of the protective corrosion film formed on the surface of the metal. Similar tests with flame-sprayed aluminum showed it to be superior to flame-sprayed zinc in protecting steel from corrosion in seawater.

Nonmetallic Coatings The nonmetallic coatings are of two types: organic and inorganic. The early nonmetallic coatings for steel piling were generally coal tar or asphalt. Neither of these proved successful in seawater because of penetration of the coatings by fouling organisms. Coal-tar epoxy coatings have been applied to pilings since 1955 and are proving to be more durable than ordinary coal tars.

Other nonmetallic coatings, including vinyl, rubber, phenolic, Saran, mica-filled asphalt emulsion, epoxy, urethane, polyester-glass flake, and furan are being tested on steel pilings by the U.S. Naval Civil Engineering Laboratory, the National Bureau of Standards, and the Coastal Engineering Research Center. The results of partially completed tests indicate that such coatings as Saran, phenolic mastic, coal-tar epoxy, epoxy, flame-sprayed aluminum, or zinc top coated with Saran, vinyl, epoxy, or furan may effectively protect steel in seawater for 15 yr or more provided that severe conditions, such as sand abrasion, are not involved.

Surface Preparation Surface preparation of steel is of primary importance when applying a protective coating for steel piling. Sandblasting the surface or pickling to remove scale and rust are the generally accepted methods of surface preparation. Solvent, hand or power-tool, and flame cleaning may be used to prepare steel pile surfaces for coating; however, these methods are more limited in use and effectiveness than are "near white blast cleaning" (*45*) and pickling. After sandblasting and before application of the coating, it is essential that any oil on the sandblasted surface be removed by solvent washing (*46*) in order to establish a firm bond of the coating to the steel. A floating collar can be used to isolate the work area and minimize the amount of solvent washing required.

Application Specially formulated primer coatings should be applied to bare metal surfaces before other coatings are applied. For maximum performance, primers should have the following characteristics:

- High specific adhesion, permitting good performance on clean sandblasted metal;
- High chemical resistance;
- Good wetting properties to fill and penetrate instead of bridging crevices, pits, and pores;
- High solids for coverage and good protection to sharp edges and corners;
- Good spray properties or minimum drag in brush applications;
- Compatibility with the generic types of topcoats;
- Adequate amounts of inhibitive pigments;
- Quick drying ability; and
- Weatherability (in the event that finish coats are not to be applied for 3 to 6 months).

Although the above characteristics are desirable, it may be difficult to obtain all of them in any one primer.

Inorganic primers that are cured after application, such as zinc-lead silicate for steel, are said to have a long and proven record, either top coated or alone, in the prevention of corrosion of marine structures. Epoxy coatings do not require primer; a one-coat application of the epoxy material [minimum thickness of ⅛ in. (3 mm)] has been shown to be adequate. Epoxy [thickness of ⅛ to ¼ in. (3 to 6 mm)] must be applied by hand (protected by rubber gloves) when applied under water; heavy hand pressure is required to force out trapped air and water bubbles. An excellent procedure for preparing a specification for splash-zone epoxy coating was published in 1980 (*47*).

Cathodic Protection

Cathodic protection is an electrochemical method that is effective in preventing corrosion of new or existing steel piling located in seawater, freshwater, or soil by making the metal surface cathodic with respect to its environment (*37*, *48*). This is accomplished by forcing direct electric current to flow to the metal surface. There are two basic methods of applying cathodic protection: the galvanic anode system and the impressed current system (*49*). Numerous variations of these two procedures exist.

The galvanic anode system utilizes anodes, usually made of magnesium, aluminum, or zinc, that are located adjacent to the piles or directly connected to them. Because of the difference in potential between the anode and the pile to be protected, a battery (corrosion cell) is created and current flows from the anode to the pile. The anode is sacrificed to protect the cathodic metal (pile). If required, the anodes may be replaced periodically. The method for the attachment of large zinc or aluminum anodes to steel H piles below water is given in Appendix E (Item No. 845).

The impressed current cathodic protection system utilizes anodes made of high-silicon cast iron or graphite that are energized by an external DC power source. The anodes are installed in the electrolyte and are connected to the positive terminal of the DC source. The negative terminal of the DC source is then wired to the pile that is to be protected. This method is also known as "rectifier type," because the power source is almost always a rectifier unit.

The decision on which type of cathodic protection system to use is often difficult to make. Although economic considerations may often be the determining factor, at times such variable conditions as cathodic interference or lack of power may take precedence. The galvanic anode system is usually used in lower resistivity electrolytes, whereas the impressed current system can be used in almost any resistivity environment. The particular problems associated with seawater applications as compared with underground or freshwater applications are usually a result of the greater current requirements. In underground or freshwater applications, the current required for protection is usually in the range of 1 to 3 mA per ft^2 (11 to 32 mA/m^2); in seawater, the current requirement is usually 5 to 10 mA per ft^2 (54 to 108 mA/m^2) of exposed area. Fortunately, because seawater is a very low resistivity environment, low voltage is required to deliver the current.

Before a decision can be reached on which type of cathodic protection system to use, a complete engineering and economic analysis of the problem must be made. Listed below are some of the advantages and disadvantages of the two types of systems:

Galvanic Anode System

Advantages

- No external power source is required.
- No further adjustment is required after proper current drain is determined.
- Installation is simple.
- Danger of cathodic interference is minimal.
- Negligible maintenance is required during the life of the anode.
- Current can be evenly distributed over a long structure.
- Overprotection at drainage points is minimized.
- System costs are usually easy to estimate.

Disadvantages

- Current output is limited.
- Anodes cannot be economically used in many high resistivity media.
- An excessive number of anodes and amount of material may be required to protect a large structure.

Impressed Current System

Advantages

- System can be designed over a wide range of applied voltage.
- System can be designed for small or large current requirements.
- An extensive area of metal can be protected by one installation.
- Applied voltage and current output can be varied over a wide range to meet changing conditions.
- Current drain can be read easily at the rectifier.

Disadvantages

- System must be carefully designed to avoid cathodic interference current from other structures.
- System is subject to power outages.
- Electrical inspection and maintenance are required.
- Estimation of costs is complex because of the numerous possible variations in design.

Concrete Jacket

Another method used to protect steel piles on an existing marine structure from corrosion, abrasion, or impact is to encase or jacket the steel in concrete. If the weight and bulk of the concrete jacket are not objectionable and the jacket is properly constructed, economical and satisfactory protection can be provided.

For effective protection of steel piles from corrosion in a marine environment, the concrete should have the following characteristics: good quality, high strength, relative impermeability, good bonding properties, adequate thickness, and proper placement and curing. Rich mixes with low water/cement ratios are desirable. Mixtures of 7.5 bags of cement per yd^3 of concrete (420 kg/m^3) and 3.5 to 5 gal of water per bag of cement (water-cement ratio 0.47:0.67) should provide the quality of concrete desired. In areas where freezing and thawing exist, entrained air is recommended to prevent concrete deterioration. The use of Type II cement with a tricalcium aluminate content of less than 8 percent is highly recommended for jackets in an environment of warm seawater.

Concrete jackets can cause accelerated corrosion on a steel pile where both concrete and water are in contact with the steel, because a corrosion cell develops between the steel in the water and the steel in the concrete. These concentrated corrosive cells will occur just below the bottom of the concrete jacket. The rate of corrosion is greatest if the jacket ends in the water just below the mean low-water elevation. Steel piles with concrete jackets that extend down to the mud line are also subject to the same type of corrosion, but at a much lower rate. Therefore it is recommended that concrete jackets extend well into the mud line. If this is economically or structurally infeasible, a cathodic protection system in combination with the concrete jacket should be considered.

Various forming systems can be used successfully for jacketing steel piles with concrete. Some of the forms currently in use are nylon fabric, fiber glass, timber, steel aluminum, fiber, or a combination of these materials. The details of encasing steel H piles, above and below water, with a fiberglass (stay-in-place) form filled with portland cement grout are given in Appendix E (Item No. 840). Jacketing work is conducted under water and on the splash zone. Conditions at the site (current, visibility, wave action, etc.) should be considered before selecting the type of form to be used. Rigid forms are preferred to nonrigid forms (e.g., nylon bags), because nonrigid forms are more difficult to work with and bulges and out of plumbness can be caused by improper positioning, unbalanced placement of concrete, and water currents. Form materials should have the following properties: adequate strength, adequate rigidity, surface smoothness, and economy (considering the initial cost and number of reuses).

Where environmental conditions are aggressive, it is desirable to leave the forms in place to protect the jacket concrete. For example, stay-in-place timber forms will insulate concrete and inhibit freezing and thawing. Also chemical reaction between the concrete and its environment will be inhibited because the forms prevent circulation of the environment in contact with the concrete; the resilient timber tends to reduce abrasion of the concrete surface caused by debris, suspended sediments, or ice action. However, a significant disadvantage of any stay-in-place rigid type of form is that it precludes inspection of the concrete surface.

Filling the forms for concrete jackets constructed under water can be accomplished by (a) pumping through a special fitting at the bottom; (b) using a tremie inserted through the top of the form, which is gradually withdrawn as the concrete level rises; or (c) using prepacked concrete.

Maintenance

When steel piles are found to be in a state of deterioration and the loss of a section is such that the structural function of the piles is not impaired, the deterioration process can be halted by the proper application of protective coatings or the use of cathodic protection methods. However, if the loss of section is such that strengthening of the piles is required, splicing new steel sections across the deteriorated areas or encasing the steel in concrete should be considered.

Repairs

Repairs to steel piles involve strengthening the pile by splicing new steel sections, using concrete jackets, or a combination of both procedures.

Splicing New Steel Sections

Pile surfaces must be free of marine growth, oil, grease, dirt, and corrosion. Rolled steel sections or plates can be run alongside and past the deteriorated area and spliced into the sound areas of the pile. Bolting or welding will hold the spliced members in place. The method for strenthening steel H piles by bolting a rolled section to the weakened area is given in Appendix E (Item No. 837).

Arc welding has become an accepted procedure in underwater construction, salvage, and repair operations. The technique, termed "self-consuming," has enabled the fabrication of stronger welded joints, and has greatly reduced the time required for training divers for underwater welding. Underwater welds made on mild steel plate under test conditions at several naval facilities have consistently developed over 80 percent of the tensile strength and 50 percent of the ductility of similar welds made in air. The reduction in ductility is caused by hardening due to the drastic quenching action of the surrounding water *(50)*. Several companies have produced structural-quality welds by means of special equipment and procedures that create a small, dry atmosphere in which the welding is performed. However, the personnel and equipment for this process are expensive.

Gas welding under water is not considered to be a feasible procedure (Commercial Diving Center, Wilmington, California, *personal communication*). Although arc welding and gas cutting are common underwater techniques, electric shock is an ever present hazard; only through the careful application of established procedures can this hazard be minimized *(51)*.

Concrete Jacket

The principles of concrete encasement or jackets for steel piles are basically those described above in the section on the prevention of problems.

WOOD ELEMENTS

Prevention of Problems

As there is no wood that is immune to marine-borer attack, the designer should select the type of wood and the method of protection most appropriate for the conditions existing at the intended piling installation *(30, 48, 52)*. Two general protective methods are used to eliminate or reduce the attack of marine-borers: protective treatments of timber and installation of flexible barriers.

Protective Treatments

The impregnation of selected preservative chemicals under pressures as high as 200 psi (1.4 MPa) is the basic protective treatment for wood piling. Timber piles are placed into hermetically sealed, cylindrical retorts and then immersed in the preservative chemical. The pressure forces the preservatives deep into the wood to help ensure long-lasting protection. The range of pressure required for treatment according to type of wood is given below.

	Min. Pressure		*Max. Pressure*	
	(psi)	*kPa*	*(psi)*	*kPa*
Southern Pine	125	850	200	1400
Pacific Douglas Fir	75	500	150	1000
Oak	150	1000	200	1400
Larch	75	500	150	1000

The life of the treated piles is affected by the thoroughness of the treatment, the care used in avoiding damage to the treated shell during handling and installation, and the severity of borer attack. The treatment must be thorough, the penetration as deep as possible, and the retention high to achieve satisfactory results in heavily infested waters. The piling should be dried before treatment to ensure the highest retention possible. It is best to treat piles by the full-cell process "to refusal"; i.e., to force into the piles as much of the preservative as possible without using treatments that can cause serious damage to the wood. Maximum protection against marine borers is obtained when as much preservative as is practical is injected into the piles.

For maximum effectiveness the preservative should be matched to the borers expected to be present. As discussed in Chapter 3, creosote is highly effective against all borers except *Limnoria tripunctata*. In addition to its own destructive activity, the marine borer *Limnoria tripunctata* can expose the untreated areas of a pile to attck by the borer *Teredo* by destroying the protective creosote layer. The larvae of the *Teredo* do not settle on timber that is well protected with creosote; however, mature *Teredo* can penetrate the creosote layer of a pile via a firmly attached, untreated dapped piece of wood, brace, or strut.

Research by the U.S. Navy Civil Engineering Laboratory (NCEL) on improved preservatives for marine piles indicates that three types of combination treatments are effective:

1. A compound toxic to *Limnoria* is dissolved in creosote, which is toxic to *Teredo*.
2. A compound toxic to *Limnoria* and a compound toxic to *Teredo* are dissolved in an inert solvent.
3. A water-soluble compound, which is toxic to *Limnoria* and becomes insoluble in the wood after impregnation, is used first; after drying, the wood is given a conventional creosote treatment.

The third combination treatment described above is called a dual treatment; because of economic considerations, it is the only treatment adopted by the wood-preserving industry. Dual treatment as specified by the American Wood Preservers Bureau Standard MP-1 (AWPB-MP-1) requires: (a) the application of no less than 1.0 lb per ft^3 (16 kg/m^3) retention of ammoniacal copper arsenate or chromated copper arsenate (CCA) and (b) the application of no less than 20 lb per ft^3 (320 kg/m^3) retention of creosote.

Research on preservative treatments at the Forest Products Laboratory, Madison, Wisconsin, indicates that a reduction from the present standard of 1.0 lb per ft^3 (16 kg/m^3) salt in the dual treatment is possible without a great reduction in marine-borer resistance. For example, panels protected with a dual treatment of 0.60 lb per ft^3 (9.6 kg/m^3) of CCA and 20 lb/ft^3 of marine-grade creosote have remained free from marine-borer attack after 78 months of exposure at Key West, Florida. Wood can be expected to lose 5 percent of its strength and to undergo about a 15 percent increase in brittleness for every 1.0 lb per ft^3 (16 kg/m^3) of salt retention. The pile design should allow for this occurrence. The NCEL has contracted with the Department of Forest Products, Oregon State University, to evaluate the effect of salt retention on the energy-absorbing capacity of wood.

A successful protective treatment will make the wood resistant to attack by the various marine borers, be economically feasible, and fulfill federal and state environmental regulations. The William F. Clapp Laboratories, Inc., is conducting an investigation both in the laboratory and in the natural environment that involves the addition of chemical toxicants to creosote before impregnation of the wood.

Flexible Barriers

The prevention of damage to timber piling caused by the attack of marine borers can also be achieved by encasing the piling in a protective jacket. The jacket or barrier must tightly fit the general contour of the pile. The purpose of the jacket is to create a lethal environment by eliminating dissolved oxygen in the water within the barrier. This is often referred to as the "stagnation principle." The installation of a flexible barrier system is not recommended in areas where timber piling will be subjected to the abrasive action of ice or other objects.

Polyvinyl Chloride (PVC) Sections of 30-mil (0.76-mm) PVC sheathing are prepared on land and then fitted around the piling *in situ* and tightened into position, with the encasement usually extending from a point below the mud line up to above the level of the highest anticipated tide. An underjacket of 6-mil (0.15-mm) polyethylene is incorporated into the wrap, as creosote softens PVC and can result in damage to the wrap. An aluminum alloy band with an intertidal seal is installed at the extreme points of the tidal zone; i.e., 8 ft (2.4 m) above the mean high-water elevation and 2 ft (0.6 m) below low-water elevation. The balance of the wrap is secured with aluminum alloy nails.

PVC sheathing has demonstrated resistance to impact by floating objects such as log rafts, free-floating logs, empty oil drums, and crates and by moderate ice action. PVC has been used within a temperature range of 9° to 100° F (−13° to 38° C).

A study by the Naval Civil Engineering Laboratory at Port Hueneme, California, has shown the feasibility of using a PVC barrier plus a metal shoe on timber fender piling. The metal shoe is a metal cylinder or similar metal armor installed over the PVC barrier at the tidal zone to prevent mechanical damage to the PVC. The installation of a camel system is recommended for preventing scouring of the hulls of ships caused by the metal shoes.

Rigid Polyvinyl Chloride Rigid split tube PVC material [thickness of 60 mil (1.52 mm)] is thermally shaped in such a manner that it can be opened longitudinally and snapped around a pile *in situ* to produce a snug fit. It is then nailed and/or banded with aluminum or copper-nickel alloy materials.

Heat-Shrink Polyethylene Applied to Timber Piling Engineering personnel at the Port of Los Angeles have developed a unit for applying 20-mil (0.51-mm) polyethylene by heat shrinking directly onto the pile before it is driven. The unit consists of an annular windscreen enclosing a ring of propane-fired ceramic burners. The polyethylene is applied in 10.5-ft (3.2-m) sections; as the unit passes over the polyethylene film, it shrinks circumferentially and tight against the pile and at the same time makes a heat seal at the overlap portion. This results in a one-piece continuous film of polyethylene [20 mil (0.51 m)] tightly shrunk to the pile. About 5 to 7 ft (1.5 to 2.1 m) is left uncovered at each end so that the pile may be handled without damaging the film. After driving, all areas of the pile immersed in seawater are protected with the polyethylene.

Metallic Various metallic barriers such as copper, copper-zinc, and copper-nickel alloys have been used for many years as an effective barrier against marine-borer infestation. The mechanical difficulties of application and the cost of material have made it expensive to use metal sheathing.

Maintenance

In general, once marine borers are ensconced in timber structures, they continue their activity until all involved material is destroyed. Certain natural processes, such as radical changes in salinity, oxygen, or temperature, will deter the deterioration, but will never completely eliminate a well-developed community of borers. Halting the damage caused by marine borers, resulting from improper procedures during the selection of materials for the structure or from an environmental change in the body of water in which the structure is located, involves methodology similar to that currently available for the prevention of destruction by marine borers. Halting the process of deterioration assumes that the structural value of the involved member remains, and thus procedures such as the installation of barriers (described above in the section on prevention of problems) are viable alternatives.

Bearing piles with a reduction of up to 15 percent in cross-sectional areas may be jacketed with a flexible wrap. Local conditions may require adjustment of this percentage. For example, the inspection policy at the Port of Los Angeles originally required the wrapping of piles with a 10 percent reduction in section. However, recent improvements in the quality of the harbor water has resulted in increased dissolved oxygen levels and a concomitant increase in marine-borer damage. Therefore, the protection policy has been revised: all piles are wrapped as soon as practicable and inspections are conducted regularly to verify the integrity of the protected piles.

NAVFAC Specifications TSM-B10A recommend the installation of a flexible barrier system on bearing piles that have lost 10 to 15 percent of their cross-sectional area. A minimum of an additional 5 percent reduction in cross-sectional area can be assumed to occur between inspection and installation of a flexible barrier as a result of progressive deterioration. In many harbors, a 5 percent reduction in area will progress to almost 10 percent within 1 yr.

Pile damage and strength loss can also be arrested by placing fill around piles damaged by borers. A suitable retainer for holding the fill in place must be constructed. Riprap appears to provide protection, probably because the oxygen content of the water is reduced. In certain cases, where localized cavities exist in piles, grouting and application of metal patches are effective maintenance techniques.

Repairs

Inspections detect not only the presence of borers, but also the extent of the damage to submerged members. If the damage has progressed to a point where structural capability is threatened or lacking, economical methods of maintenance to arrest deterioration are of questionable value. A decision must be made whether to pursue the more economical alternative of installing a barrier system on structurally sufficient piles, even though periodic inspections will create a costly ongoing maintenance program, or to specify a more costly, but practically maintenance-free installation, such as pile replacement or structural rehabilitation. Two factors are critical in the resolution of this situation: the rate of borer activity and the time frame for project implementation. If a maintenance program is implemented immediately after detection of borer attack, damage can be halted. If, however, delays occur in project implementation and borer infestation is high, the amount of deterioration at the time of detection may increase substantially by the time the work is performed. Unfortunately, projects involving large repairs rarely are implemented quickly. Therefore, maintenance engineers should monitor submerged structures on a regular basis to be aware of any changes within the structures and the rate at which the changes are occurring.

Replacement of timber piles should generally be considered only if the pile to be replaced is easily accessible. The decision should be based on economic and structural factors. It is possible for the costs of the materials and labor required for replacement of a pile to exceed the costs of in-place rehabilitation procedures.

Strength restoration is normally required when a pile has lost 15 to 50 percent of its cross-sectional area. When 50 percent or more of the cross-sectional area of a pile has been destroyed, the repair procedure involves cutting out the damaged area and replacing it with a sound section. Several techniques employed to restore strength to piling by methods other than replacement of the severely damaged pile are described below. Numerous other techniques are available; however, the application of any technique will depend on suitability at a given location and the overall economic considerations.

Stubbing Method

This procedure consists of exposing the pile at the mud line below the area of deterioration and removing the damaged area. A pin is driven into the exposed sound stump and a lightweight tube housing reinforcement bars is attached to the stump and cap. Concrete is pumped into the tube and allowed to harden; then the bottom and top tube attachments are removed. The loads are transmitted from the cap to the sound pile stub in the mud line by the new, reinforced-concrete pile section.

Oil-Drum Method

This procedure is used in splicing stubbed piles or replacing the major portion of the length of the piles. When splicing stubbed piles, the damaged section of a pile is removed and replaced with a treated wood pile section. A 50-gal (190-L) steel oil drum with a hole the size of the pile cut in the bottom is fitted around the joint and filled with concrete. A variation of this method is to place the drum around the old stump and add drums in chain sequence as required. Reinforcing can be installed, if required, and the molds, consisting of oil drums, are filled with tremie concrete. The pile is normally wrapped with polyethylene before placing concrete in order to get a tight oxygen-free seal adjacent to the pile surface. The Port of Oakland has successfully used this procedure as a standard method of repair for a number of years.

Concrete Jacket

This procedure is used when 20 percent or more of the pile cross section has been damaged or lost. A fabric "sock" is installed as a mold around the length of a damaged pile, reinforcing mesh or rods are placed around the pile inside the sock, and the sock is pumped full of concrete. This process has been used successfully even on piling that has been subjected to considerable lateral bending. Careful control and inspection, especially on battered piles, is required to ensure correct placement of the pumped or tremie concrete and to verify that water saturation has not resulted in separation of cement and aggregate in the mix.

Another relatively new material being used to make forms that are to remain in place is glass-reinforced polyester resin. These forms are light and easy to handle, but have enough rigidity to maintain shape and location and to control the proximity of the form to the pile and the reinforcing steel. Another advantage of these forms is that in contrast to the other methods described above, they provide a watertight surface that prevents the intrusion of chlorides through exposed concrete.

Precast Shotcrete

Prefabricated 3-in. (76-mm) thick concrete half-cylinders with projected reinforcing mesh on the sides and ends of each modular unit have been used successfully by the Port of Long Beach for the protection of wood piles. The split cylinders are placed around the piles above the water line and the projecting reinforcing mesh twisted to make a complete enclosure. End and side joints are shotcreted and the completed unit lowered into the water. A second section is placed on the first section and the process continued until a completed encasement is jetted several feet below the mud line; the annular space is then filled with concrete grout.

CHAPTER SIX

CONCLUSIONS AND RESEARCH NEEDS

CONCLUSIONS

Inspection

Although there have been few catastrophic failures of bridges, aging of structures, increased loads, and an apparent increase in major storms in some areas all must be taken into consideration in the planning of underwater inspections of bridge substructures. Many problems associated with bridge substructures are the result of lack of maintenance. To ensure a proper maintenance program for below-the-water portions of bridge substructures, periodic underwater inspections by qualified personnel are essential. All deficiencies must be reported and evaluated, and action taken for immediate repair.

The quality of inspection under water should be equal to the quality of inspection above water. Underwater inspection differs from inspection above water in that more hazards are involved; the inspector's mobility, visibility, and physical endurance are affected; and obtaining samples is more difficult. Inspections must be well-planned; structure plans, qualified inspectors, correct equipment, and detailed work plans are essential. Procedures should be organized and systematic. Checklists are helpful to ensure that important items are not overlooked. The planning for underwater inspection should include consideration of the season, flow, depth, turbidity, materials, and type and condition of the structure. It is prudent practice to be aware of the condition of the underwater portions of bridges—at frequent intervals and during and after storms. Underwater investigations should be conducted after a major storm or flood to determine if damage has occurred.

Each state agency must evaluate its own underwater inspection needs and choose the best method for performing the inspections; methods include contracting with engineering firms and divers for all underwater inspections, using in-house dive teams, or using a combination of in-house and contract divers. Each procedure can provide for adequate inspections when the divers performing the work are qualified. However, the most effective procedure may be for an agency to have limited dive capability for routine, construction, and emergency situations supplemented with a contract for additional diving operations. The underwater inspection teams of the agencies contacted during preparation of this synthesis expressed much pride in their assignments and work performances.

Inspections must be conducted by experienced, competent divers. The underwater inspectors must be knowledgeable about the design and construction of the structure and the type of problems that might develop with normal service in a specific environment. They must have considerable knowledge of the proper use of diving equipment, safety requirements, communication techniques, and diving operations. Safe procedures for diving operations have been developed by the U.S. Navy, OSHA, and others. Employers of divers should develop manuals of safe procedures for distribution at dive locations. The person responsible for the inspection should be a licensed engineer. The supervisor of underwater bridge inspection should be capable of recognizing problems, evaluating the effects on the member or structure, and preparing a record of findings to be reviewed by others. The importance of inspectors being qualified both as divers and as bridge inspectors is currently recognized by several state agencies. However, there is some disagreement concerning which ability should be primary. Some divers believe that they can be easily trained to be inspectors, whereas some agencies have indicated that young, healthy bridge engineers and inspectors can better be trained as responsible divers.

Underwater damage or deterioration can be identified by several methods of detection, including: visual inspection (the primary method); tactile examination, and settlement or loss of alignment of the structure. In some cases, more sophisticated instruments are required for the detection of underwater flaws, damage, or deterioration; these include echo sounders, ultrasonic thickness gauges, computerized tomography, and closed-circuit underwater television. Nondestructive testing techniques and sampling of underwater structural members should be coordinated with the inspection effort.

Cleaning marine growth from the underwater portions of bridge substructures is usually required to facilitate inspections. The amount of cleaning necessary depends on the amount of growth and the type of inspection being made. Cleaning of surfaces under water can be accomplished with diver's knives, hand tools, scrapers, power chippers, grinders and brushes, and sandblasting and water jets. High-pressure water blasters must be used carefully to avoid damage to the structure and injury to the operator or others.

After deterioration or distress has been detected, it is necessary to determine the basic cause of the problem in order to evaluate the need for repair and select a satisfactory repair procedure.

The problems most often encountered are scour, collision damage, construction damage, concrete spalling, steel corrosion, deterioration of wood, and abrasion (erosion) of structure members. Structures with foundations subject to scour should be inspected immediately after storms that cause flooding and strong currents. Damage to bridge substructures can result from improper procedures or accidents during construction. Underwater inspections should be conducted during and at the end of the construction phase. After each inspection, the structure plan should be updated to reflect any changes noted during the inspection. Inspection after completion can aid in determining compliance with contract specifications.

Maintenance and Repair

Once below-the-waterline deficiencies of structural members have been detected and repairs recommended, the preparation of repair plans and specifications should be expedited and repairs performed as soon as possible. Defective conditions progressively deteriorate with time and repairs become more expensive. If repair work is delayed, the actual cost of the repair can increase substantially over that estimated at the time of detection.

Underwater construction repair and maintenance is more difficult than work above water; a worker's ability to function is restricted, visibility is impaired, the selection of materials may be limited, and work methods must be modified. Careful examination by experienced divers is essential for an accurate assessment of the underwater damage in order to select effective repair procedures. It is essential that the contractor and craftsmen be specially qualified for underwater work. Supervisors and foremen should have experience with the type of work to be performed under water. Some agencies require a dry run above water to check fit. Other agencies have arranged for shallow-pool underwater demonstrations to check the ability of workers to perform the desired work.

Competent workmanship is essential. To provide adequate durability for below-the-waterline concrete construction and repairs, high-quality, dense, impermeable concrete must be used. Some agencies specify the use of epoxy-coated reinforcing not only for those submerged reinforced concrete members, but for the entire structure when it is located in a marine environment.

A thorough inspection should be conducted at the completion of underwater repairs. As-built plans should be recorded; such details as forms or sheet piling left in place should be noted on the plans.

RESEARCH NEEDS

Research is currently being conducted under NCHRP Project 10-16, "Assessment of Deficiencies and Preservation of Bridge Substructures Below the Waterline." The objectives of this study are (a) to develop improved methodology for evaluating the effects of below-the-waterline deficiencies on the structural capacity of the structure and (b) to develop solutions to specific deterioration problems found in bridge substructures below the water surface and in the splash zone. It is expected that this research will be completed late in 1982. Additional ongoing and recommended research programs are listed in Tables 9 and 10.

TABLE 9
PERTINENT RESEARCH AND DEVELOPMENT PROGRAMS (*13*)

Country	Participants	Title	Objective
France	CNEXO	Ocean Structures Behavior	A variety of programs concerning safety, maintenance and performance of steel and concrete structures.
Norway	Univ. of Thondheim	Electrical Resistivity of Concrete in the Ocean	To investigate the electrical resistivity of concrete exposed to the ocean environment.
	SINTEF and DNV	Corrosion Fatigue Offshore	To determine fatigue properties of structural steel at different cathodic polarization levels.
	DNV	Concrete Structure Fatigue	To investigate parameters believed to affect the fatigue strength of concrete in the marine environment.
United Kingdon	The Welding Institute	Hyperbaric Welding	Evaluate hyperbaric arc welding procedures and measure properties of the results.
	DOE and Industry	Concrete in the Oceans	Obtain fundamental data on concrete in the marine environment.
	DOE, DNV, ABS, and Industry	Exxon Ocean Test Structure	To improve the understanding of wave forces on offshore structures.
	Building Research Station	Foundations of Offshore Structures	Improve the safety and economy of offshore structure foundations.
	DOE and a number of research organizations	Offshore Structures Fluid Loading Advisory Group (OSFLAG)	Ten separate programs directed towards understanding of wind, wave and current loading on fixed and floating offshore structures.
	DOE and Academic Institutions	Buckling Research	To test and improve the prediction methods used to check the buckling stability of single members of offshore structures.
	DOE, Ministry of Defense and Baxter, Woodhouse & Taylor	Diving Equipment	To develop an alternate to hot water heating and to reclaim helium in a push/pull breathing unit.
	DOE, Industrial Firms and the European Coal and Steel Community	United Kingdom Offshore Steels Research Program (UKOSRP)	A major program ($8.9 million) of fatigue and fracture studies which also includes participation of four European countries. Includes a series of related programs involving stress analysis, corrosion fatigue, brittle fracture studies and full-scale fatigue tests on welded joints.
	University of Glasgow	Dynamics of Offshore Structures	A study of vibration and damping in offshore structures to assist in design of vibration analysis monitoring systems.
	Wimpey Laboratories Ltd.	Strain Gage Application to Deep Water Structures	To study strain gage and installation procedures for instrumenting deep water structures.
	Taylor Woodrow Construction Ltd.	Steel Corrosion in Concrete-Detection	To develop permanently-embedded and surface-mounted half-cells to monitor the potential of steel embedded in concrete.
	Ward, Ashcroft and Parkman	Instrumentation of Submerged Concrete	To ascertain the behavior of mass concrete under static hydraulic loading in order to develop methods of remote sensing.
	Structural Monitoring Ltd.	Integrity Monitoring System	To develop an integrity monitoring system using the principles of vibration analysis.

TABLE 9 *continued*

Country	Participants	Title	Objective
United Kingdom (cont.)	Strongwork Diving (International) Ltd.	Advanced Deep Water Inspection	To develop remote access devices capable of providing definitive information regarding physical damage, corrosion loss and fatigue cracking on deep water structures.
	Unit Inspection	Acoustic Emission Monitoring	To evaluate acoustic emission techniques for the detection and monitoring of fatigue in offshore structures.
United States	Shell Oil Co.	Vibration Analysis	To determine the fundamental periods and damping on four jacket-type platforms (program completed 1976).
	Keith, Feibusch, Associates, Engineers and 13 Oil companies	Vibration Analysis	To determine the effectiveness of vibration analysis techniques on three fixed platforms in the Gulf of Mexico.
	University of New Hampshire and USGS	Untethered Remote Controlled Vehicle	To develop an untethered remote controlled vehicle which would ultimately be capable of conducting inspections of pipelines and structures.
	USGS	Vibration Monitoring	To determine the feasibility and limitations of the vibration monitoring technique and to produce a bread-board equipment package.
	USGS and USN	Acoustic Emission Monitoring	Same as above but for acoustic emission monitoring.
	USGS	Dynamic Property Prediction	To predict and analyze the dynamic properties of offshore platforms for use during design.
	USGS and USN	Cavitating Jet	To develop a more efficient method of removing marine growth.
	USGS	Acoustic Emission	To determine if fatigue cracking can be differentiated from stress corrosion cracking.
	Petroleum Companies	Exxon Model Platform	To measure the response of a platform to various measured ambient conditions.

Inspection

New equipment or improved use of existing equipment is needed to solve the continuing problems in communication between scuba divers and the surface. Improved cleaning and sampling equipment should be developed or existing equipment modified for underwater use. The development of diver platforms to provide a secure work surface and reference to the surface is necessary. Platforms should be light and portable. The use of CT should be tested for a range of underwater work. This system can be programmed to produce video or printout only when the section or material varies.

It is suggested that agencies review their own experiences with underwater structures in various streams under various conditions. Some inspection and repair techniques can be generally employed; however, much of the underwater deterioration may be the result of specific materials in precise locations, e.g., a pier design that provides good service except in a specific current situation. Manuals can be provided, for example, for patching concrete or repairing wood or steel, but many underwater problems necessitate custom solutions.

Maintenance and Repair

Steel

Although copper-bearing steel is somewhat more resistant to corrosion than is ordinary carbon steel, it does not have a long life in marine environments if no other protection is provided. Research is required to develop a steel that is more resistant to corrosion than that available today.

Coatings

Research on coating protection for steel and concrete materials located below the waterline is needed. Most of the testing of epoxy compounds has been carried out by manufacturers. There have been problems with adhesion, thickness, and workability, and unanswered questions concerning durability, compatibility, and strength. Setting time has also been a problem. Because of the large number of epoxy materials available, it is impossible for each agency to carry out complete testing.

TABLE 10
RECOMMENDED TECHNOLOGICAL RESEARCH AND DEVELOPMENT PROGRAMS (*13*)

Classification	Title	Objective
Immediate	Operator/Surveyor Qualifications	Determine the need for diver NDT qualifications. If a need exists, establish minimal qualifications standards.
	Instrumentation Standards/ Qualifications	Establish minimal acceptance and performance standards for NDT instrumentation. Evaluate present techniques with regards to accuracy of data in low temperatures/ high pressure environment.
	Cleaning	Assess present structure cleaning techniques to evolve more expeditious, safer techniques via remote controlled vehicles or by employing new cleaning concepts. Define cleaning standards for NDT.
	Positioning	Develop a navigation system which would rapidly and reliably guide and locate the diver, RCV, etc., to the test site on the extremities of a steel and concrete structure, and within the interior of a steel structure.
	Mechanical Manipulation	Design alternatives to hand-held NDT devices which could be deployed by mechanical manipulators.
	Remote Controlled Vehicles	Define the state-of-the-art in RCV application and problems in underwater inspection. Define development criteria required to optimize this technique as a visual inspection and NDT capability.
	Corrosion Potential Monitoring	Conduct design review, field test and operationally evaluate systems for remote corrosion potential monitoring.
Long Term	Structural Monitoring	Field test and evaluate present structural monitoring techniques to substantiate state-of-the-art and define potential limits of these systems in satisfying inspection requirements.
	Testing Unclean Structures	Develop NDT techniques that can detect corrosion, cracking and internal flaws without requiring prior cleaning of structure.

Cathodic Protection

The use of cathodic protection for reinforced concrete structures is currently receiving attention. Cathodic protection designs differ considerably, depending on the coating, the configuration of the structure, the environment, and the presence of other structures. For reinforced concrete, a major problem is difficulty in ensuring electrical continuity through the reinforcing while providing a low-resistance path for the electric current. More effective methods of cathodic protection will require research and development.

Wood Treatment

The dual-treatment method is currently recommended by the American Wood-Preservers' Association to prevent marine-borer infestation of timber piles. However, dual treatment consists of two pressure treatments, which is time-consuming and expensive; in addition, dual treatment embrittles wood. Thus the development of a more effective treatment against marine borers is recommended.

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APPENDIX A

DIVE TEAM JOB DESCRIPTIONS (NORTH CAROLINA)

BRIDGE SPECIAL INSPECTION SUPERVISOR

DESCRIPTION OF WORK

The employee in this class directs a Statewide program of special bridge safety inspections including underwater inspections, mechanical inspections of drawbridges, and inspections utilizing nondestructive test devices.

Work includes the supervision of several two-man inspection teams, the scheduling of inspections, providing for the training of inspectors, establishing special inspection procedures, reviewing inspection reports, and establishing and maintaining a quality control program for inspections. Work is performed under the general supervision of the Statewide inspection supervisor and is reviewed through evaluation of the quality of the special inspection program and the quantity of inspections performed.

EXAMPLE OF DUTIES PERFORMED

Supervises and participates in the underwater inspection, mechanical inspection, and inspection of bridges requiring special nondestructive equipment or methods.

Establishes procedures for inspections and modifies procedures to increase program efficiency.

Develops and presents safety or inspection procedure training sessions.

Evaluates testing equipment or methods to determine their effectiveness and suitability for use.

Establishes inspection schedules and sets priorities.

Provides on-the-job training to individual inspectors.

Reviews bridge inspection reports for accuracy and completeness.

Reviews applications, interviews applicants, and selects new employees.

Performs related duties as required.

RECRUITMENT STANDARDS

Knowledges, Skills, and Abilities

Considerable knowledge of bridge inspection principles, techniques, procedures, and equipment.

Considerable knowledge of bridge construction materials.

Considerable knowledge of bridge design and construction, and maintenance requirements and procedures.

Working knowledge of safety requirements for divers.

Skill in the use and care of scuba equipment.

Ability to supervise, train, and coordinate the work of subordinate inspectors.

Ability to review and evaluate program efficiency.

Ability to perform work while exposed to varying climatic conditions or reduced visibility underwater.

Physical ability to climb bridge superstructures and dive for extended periods of time.

Minimum Education and Experience

Graduation from a four-year college or university with a major in civil engineering and one year of experience in the design, construction, or inspection of major concrete or steel structures; or graduation from a two-year technical institute with a degree in civil engineering technology and five years of experience in the inspection, construction, design, or maintenance of major concrete or steel structures, including two years in the inspection, construction, design, or maintenance of bridges; or an equivalent combination of education and experience.

Necessary Special Requirement

Certification as a scuba diver by a national diver certification association (agency).

BRIDGE UNDERWATER INSPECTOR I

DESCRIPTION OF WORK

Employees in this class function as members of underwater bridge safety inspection teams.

Employees conduct indepth inspections of all structures classified as bridges on the N. C. Highway System that require underwater investigation. In addition, they perform inspections of bridge substructure and superstructure above water. Work is performed under the technical supervision of an Underwater Bridge Inspector II, and is reviewed and evaluated in terms of the thoroughness of the inspections.

EXAMPLES OF DUTIES PERFORMED

Inspects sub and superstructures for evidences of deterioration due to wear, erosion, material loss, metal fatigue, ionization, and age.

Measures, interprets, and evaluates degree of material loss; converts these losses into percentages.

Conducts non-destructive tests, interprets and evaluates results, and documents findings.

Climbs ladders, scaffolds and overhanging structures to measure internal and external alignments, clearances, approaches, and all signs of structural distress such as movement, rotation, fatigue, and warping of support members.

Conducts underwater investigations to detect evidences of damage due to water flow, floating debris, changes in flow rate, shifts in river or channel bed, and to measure effects or adequacy of cathodic protection.

Conducts underwater inspections of cofferdams.

Takes soundings of water depth to determine adequacy of embedment of support piers and bulkheads.

Inspects alignment and wear on drawbridge shafts and gears.

Writes field notes, draws diagrams and sketches, and takes photographs to document inspections.

Performs related duties as required.

RECRUITMENT STANDARDS

Knowledges, Skills, and Abilities

Working knowledge of bridge inspection principles, techniques, procedures, and equipment.

Working knowledge of bridge construction and maintenance material characteristics.

Working knowledge of bridge designs and construction, or maintenance principles and procedures.

Working knowledge of safety requirements for divers.

Skill in the use and care of scuba gear.

Ability to perform required work while exposed to varying climatic conditions and varying degrees of underwater visability.

Physical ability to climb bridge superstructures and dive for extended periods of time.

Ability to read and interpret engineering and construction drawings.

Minimum Education and Experience

Graduation from a two-year technical institute with a degree in civil engineering technology or a closely related curriculum, and two years of experience in the inspection, construction, design, or maintenance of major steel or concrete structures, preferably including one year of experience in the inspection, maintenance, design, or construction of bridges; or equivalent combination of education and experience.

Necessary Special Requirement

Certification as a scuba diver by a national diver certification association (agency).

BRIDGE UNDERWATER INSPECTOR II

DESCRIPTION OF WORK

Employees in this class supervise and participate in conducting underwater and regular safety inspection of bridges.

Employees serve as squad leaders in conducting indepth inspections of all structures classified as bridges on the N. C. Highway System that require underwater investigation. In addition, employees serve as squad leaders in the inspection of bridge substructures and superstructures. Work involves establishing priorities, planning and scheduling inspections, determining the most appropriate inspection procedures, and selecting appropriate test equipment. Work also involves performing all the duties of the Underwater Bridge Inspector I along with the responsibility for training new inspectors assigned to the squad. Work is performed under the general supervision of the special inspections section chief and is reviewed and evaluated in terms of completeness and accuracy of inspections.

EXAMPLES OF DUTIES PERFORMED

Supervises and participates in conducting indepth inspections of assigned bridges that require underwater investigations.

Supervises and participates in the inspection of bridge sub and superstructures for evidences of structural distress such as rotation, fatigue, warping of support member and scour.

Dives to inspect substructures for evidences of deterioration due to scour, erosion, material fatigue, age, ionization, and shifts in water flow rates or stream, channel, or river beds.

Conducts underwater investigations to evaluate effects or adequacy of cathodic protections, and to determine extent of structural damage due to floating debris or from collisions with marine vessels.

Conducts nondestructive tests; interprets and evaluates results; documents findings.

Supervises and participates in the mechanical inspection of drawbridges.

Supervises and participates in diver proficiency training exercises.

Climbs ladders, scaffolds, and overhanging bridge structures to measure internal and external alignment, clearances, approaches, and geometric symmetry of openings and approaches.

Determines inspection priorities, techniques, procedures, and equipment.

Compiles data and prepares reports on completed inspections.

Performs related duties as required.

RECRUITMENT STANDARDS

Knowledges, Skills, and Abilities

Working knowledge of bridge inspection principles, techniques, procedures, and equipment.

Working knowledge of bridge construction and maintenance material characteristics.

Working knowledge of bridge designs and construction or maintenance principles and procedures.

Working knowledge of safety requirements for divers.

Ability to perform required work while exposed to varying climatic conditions and varying degrees of underwater visability.

Physical ability to climb bridge superstructures and dive for extended periods of time.

Ability to read and interpret engineering and construction drawings and other related data.

Minimum Education and Experience

Graduation from a two-year technical institute with a degree in civil engineering technology or a closely related curriculum, and three years of experience in the inspection, construction, design, or maintenance of major steel or concrete structures, including one year of experience in the inspection, maintenance, design, or construction of bridges; or an equivalent combination of education and experience.

Necessary Special Requirement

Certification as a scuba diver by a national diver certification association (agency).

APPENDIX B

PROPOSAL—UNDERWATER INSPECTIONS—ANNUAL CONTRACT (LOUISIANA)

PROPOSAL - UNDERWATER

INSPECTIONS - ANNUAL CONTRACT

A contract will be let on an annual basis for the underwater diving/inspection needs of the Louisiana Department of Highways.

The inspections shall be in accordance with:

A. Standard specifications of Louisiana Department of Highways roads and bridges.

B. Louisiana Bridge Inspection - Inspection check list (underwater investigation)

The times of work shall be between 8:00 a.m. and 4:00 p.m. Monday through Friday, excluding state holidays, except in emergency situations.

The following information will be supplied to the contractor at least two weeks prior to each underwater inspection, except in emergency situations:

1. Bridge nomenclature

   (A) Dist. _____ Parish_____________ Route____________
   (B) Bridge type____________________
   (C) Structure No. _______________ Name_______________
   (D) Waterway Name
   (E) Between City_______________ To City_____________

2. Description of items to be inspected
   (A) Underwater only
   (B) Plans available____________and Insp. items marked
   (C) Number of concrete piers___________
   (D) Number of concrete bents___________ pile__________
   (E) Number of timber bents___________ pile__________
   (F) Fender system timber_______________steel__________
   (G) Scour Location at pier____________or bents_________
   (H) Water depth at piers____________or bents_________
   (I) Surrounding area water depths

3. LDH estimate of items of work to be performed in inspection.

4. Other items which may be required at our request.

5. LDH estimate of field working days to complete inspection.

6. The name and address of the LDH engineer in charge of the inspection. The LDH engineer in charge or his representative shall be present at the work site during the inspection.

The contractor shall be paid only for the items of work actually performed during the inspection. The contractor shall perform only those items of work as directed and approved by the LDH engineer in charge. At the completion of each inspection, the contractor shall submit an itemized invoice to the LDH engineer in charge for his approval. Upon approval of the LDH engineer in charge, the invoice will be forwarded to LDH Headquarters for payment.

Bidders shall submit bids for the following items of work:

1. Diver inspection team, to include all support equipment, (excluding motor vessel and work barge), personnel, materials, supplies, expenses, meals, lodging and mileage to complete one diving team for water depths not to exceed 50 feet on inland waters and western rivers of Louisiana.

   8 hour daily rate_________

2. Same as "1" above except for water depths not to exceed 100 feet.

   8 hour daily rate_________

3. Same as "1" above except for water depths not to exceed 150 feet.

   8 hour daily rate_________

4. Motor vessel of at least 30 feet in length and work barge at least 20 by 30 feet. Motor vessel to have sufficient HP to handle barge on any waters of state of Louisiana, including all operators, deckhands, fuel, supplies, etc.

   8 hour daily rate_________

5. Formal report, two typed copies of report. Report to include sketches of all structural elements described in contract and descriptions of deficiencies. Report to include at least five 5"X 7" color photographs. lump_____________

6. Additional color photographs 5"X 7" each _____________

7. Extra charge for two-way communication between diver and surface
per 8 hour day____________

8. Extra charge for diver actuated depth reading device with ± 5% accuracy
per day____________

9. Extra charge for underwater burning, including all required equipment and supplies
per 8 hour day____________

10. Extra charge for underwater welding, including all required equipment and supplies
per 8 hour day____________

11. Extra charge for water jet cleaning, including all required equipment and supplies
per 8 hour day____________

12. Extra charge for closed circuit television, between diver and surface
per 8 hour day____________

13. Extra charge for video tapes each____________

14. Extra charge for pneumatic chain saw
per 8 hour day____________

15. Extra charge for pneumatic drill
per 8 hour day____________

16. Extra charge for pneumatic hammer
per 8 hour day____________

17. Extra charge for pneumatic impact wrench
per 8 hour day____________

18. Extra charge for pneumatic buffer
per 8 hour day____________

19. Extra charge for pneumatic grinder
per 8 hour day____________

20. Extra charge for pneumatic chipper
per 8 hour day____________

21. Extra charge for air compressor (150 CFM min.)
per 8 hour day____________

All overtime will be compensated at double the regular rate and will be performed only upon authority of the LDH engineer in charge.

Failure to bid on any item will result in rejection of bid. The low bid will be determined in the following manner:

Sum item 1, 2, 3 divided by 3 = ____________

Sum item 4 through 21 = ____________

Grand Total Bid = ____________

APPENDIX C

PROCEDURES FOR INSPECTING UNDERWATER SEALS, FOOTINGS, AND PILES (NORTH CAROLINA)

North Carolina's Procedures for Inspecting
Underwater Seals, Footings, and Piles

I. General preparation and safety procedures

A. Preparation

1. Review plans (and specs) of seals and footings, excavation sections, water conditions, and bridge and pile data

2. Review previous inspection reports

3. Ensure that necessary inspection equipment is working properly and is inventoried in vehicle

B. Safety Procedures

1. Practice basic safety procedures as instructed by certifying agency

2. Have divers descend slowly in case of poor visibility and sharp objects along descent path or on bottom

3. Take precautions in severe currents

a. Attach safety line on upstream side of bent or piles for divers' use underwater. DO NOT use safety line when visibility is poor unless line is completely taut.

b. Stretch safety line across stream 50 yards downstream in rivers up to 300 feet wide.

c. In tidal areas attach 100 feet of rope with ring buoy on stern of boat. Tie boat to bent or piles.

d. Man a safety boat downstream of current.

e. Have divers return to bent or piles to protect themselves from boat traffic.

II. Inspection

A. Use masonry hammer, probing rod, rule, scraper, diver's tools, caliper, increment borer, marker

B. Cofferdams

1. Inspect area at sheeting

A minimum of two divers will perform inspection. Each diver inspects half the perimeter of the cofferdam sheeting at base of excavation. Each diver keeps in touch with sheeting with hands or feet and moves along the cofferdam while inspecting the base of excavation from the sheeting to as far as it is possible to reach.

The diver should look for any clay, mud, or silt buildup in all corners or between base of excavation and sheet piling throughout cofferdam. The base of each sheet piling should be examined to ensure that sheeting is driven all the way down (this is important in cases of shallow excavation depth). Check for any loose, large rocks that might be leaning against sheeting.

2. Inspect excavation base

Divers will look for mud, clay, silt, any loose rock, or other loose, hard foundation material. Surface should be clean of loose material. Divers will also describe geometric features and contour of surface, which can be specified as level, stepped, or serrated. A rock surface should be left rough.

Surface should be inspected for material description such as sound rock, decomposed rock, or firm clay. If surface is not sound rock, a sample of material is taken. Because specifications call for surface to be cut to firm surface, diver should be sure foundation material is what designer expected.

3. Inspecting corners and all corrugations of sheeting from natural ground to base of foundation for any earth inclusions must also be done.

4. Inspecting near center

   When inspecting cofferdam up to 20 feet wide, at base of excavation near center, one diver keeps one hand on the sheeting while the other hand guides the other diver out near the center. The second diver inspects cofferdam while being guided and moved completely around it by the first diver.

   When inspecting cofferdams over 20 feet wide, divers first use the method for those up to 20 feet wide and then place a rope with weight on one end along the bottom to complete inspection. This is done as one diver carries the weighted rope and stations it near center of cofferdam wall, while other diver carries other end of rope and holds on bottom at opposite wall. First diver can then proceed on each side of rope, which is used as a guideline. Rope can be moved to a second location if inspection cannot be completed at first location.

C. Seals

1. Make layout of seal

   Number with crayon the interior corrugations on each face of seal and record.

   Measure distance from interior corrugation to edge of footing on all seal sides at each corner of footing. This will establish the position of the footing onto seal.

   Measure height of seal from mudline at all four corners and record (report drawings are made from this information).

2. Inspect for condition of concrete

   Inspect for soundness and appearance and take photographs when possible.

   Inspect for spalls; measure their width, length, and height; and locate them on layout drawing.

   Inspect for cracks and measure size, length, and depth. Record crack location at designated corrugation number by recording the distance from top of seal to the crack within that corrugation. If crack runs from one corrugation to another, record all new crack data to correspond with a different corrugation number.

   Use a surveyer's chain for probing to determine an approximate crack depth.

   A final inspection will show crack sizes, lengths, depths, and locations in each corrugation number on all sides of seal. Scale crack depths on the plan view for the report to show relation to footing.

D. Footings

<u>Spread Footings</u>

1. Inspect for scour near footing upstream or adjacent to footing, measure size of scour (width x length x depth), and document location

2. Inspect for scour or soft material under footing

   Survey perimeter of footing. Use probing rod and rule. Station footing from upstream end to downstream end at 2-inch increments. At these stations measure water depth, height from bottom of footing to mudline, and depth of scour from edge of footing to point under footing where bearing is established.

   Take photographs of bottom of footing showing scour at each station when possible. Measure from top of footing to waterline on upstream and downstream ends. Measure size of footing.

3. Inspect for condition of concrete

   Measure size of spalls (width x length x depth) and locations and sizes of cracks.

   Inspect for any exposed reinforcing steel and for soundness and appearance.

4. Inspect footings keyed into rock

Inspect for separation at base of footing and rock foundation. This condition could indicate foundation or substructure movement.

Inspect for voids between footing and rock foundations that could have been formed by trapped clay, silt, loose rock, or mud in concrete.

5. Inspect footings on seals for any separation at base of footing and seal

Pile Footings

1. Measure width, length, and height of footing if unknown

Measure size, number, and spacing of piles under footing if unknown

2. Inspect for scour at piling and record approximate depth

3. Inspect condition of concrete at sides, top, and bottom of footing. Measure size of spalls (width x length x depth) and crack sizes and locations

Inspect for any exposed reinforcing steel and inspect it for soundness and appearance.

Inspect condition of concrete where pile enters footing. Record any voids or cracks.

4. Inspect footing

If originally designed to be embedded in steam, this requires measurements of each exposed pile from bottom of footing to mudline. Take photographs of bottom of footing showing exposed pile when possible.

5. Inspect piles for soundness and section loss

6. Inspect for drift lodged between pilings

E. Piles

1. Two divers inspecting same pile

When poor visibility requires mask and light close to pile, divers can inspect on opposite sides of pile. After descending to mudline, divers can rotate to uninspected sides and ascend.

2. Divers inspecting piles adjacent to each other

Divers can choose to inspect one pile each as long as piles are adjacent. This will be more desirable in strong currents, when piles have areas to be cleaned, or in times of good visibility. Divers are to concentrate on inspecting faces of each pile.

Concrete Piles

1. Inspect condition of concrete

Take photographs when possible. Measure width, length, and height of spalls.

Inspect for any exposed reinforcing steel or cables and for soundness and appearance.

Inspect for cracks and measure size, length, and location for future inspections. If a crack is spalling on each edge, record actual crack size which is measured deeper than the spalled surface. Crack length should be measured from waterline to end of crack underwater. If crack extends above waterline and has not been previously recorded, measure and record. If a crack does not start at waterline, locate crack with reference to it.

Bent number, pile number, and face number are required when recording location of cracks. Direction of numbering bents is from south to north or from east to west, numbering of piles is from left to right and of pile faces is counterclockwise.

Take close-up photographs of cracks when possible.

2. Inspect for scour at base of piling and record approximate depth

3. Inspect concrete when marine growth covers pile

Clean random areas of pile from waterline to mudline. The number of areas will depend on condition of concrete, visibility, water depth, and type of growth. This should be determined in the field.

Inspect those areas that are already clean, which in most cases are located at the mudline.

Steel Piles

1. Inspect condition of steel

   Inspect paint or epoxy coating.

   Inspect for rust. Light rust is a loose rust formation staining steel or beginning to show through paint by pitting paint surface. Moderate rust is a looser rust formation beginning to scale or flake. These areas are discernible with no appreciable loss in steel (1/16 inch and less surface pitting). Severe rust is a heavy rust scale or heavy pitting of metal surface (1/8 inch and larger pits). Section loss of steel should be recorded in this condition.

   For piles with severe rust, it is recommended that a complete pass up and down the piles be made to determine the worst areas of deterioration. Scrape one or two areas to determine section loss.

   Locate those areas of section loss and record remaining thickness of flange and web. Inspect the most vulnerable area at waterline where air and moisture cause rust. Inspect at mudline where abrasion causes section loss. Take close-up photographs of some deteriorated areas when possible.

   Scrape rust flakes off worst areas and bare metal. Then measure section loss with calipers and rule. Record the remaining section and locate for future inspections.

2. Inspect steel piles with marine growth

   Clean random areas of pile from waterline to mudline. The number of areas will depend on condition of steel, visibility, water depth, and type of growth. These should be determined in the field. Inspect areas at the mudline that are already clean.

3. Inspect for scour at base of piling and record depth

4. Inspect closely for loss where pile enters concrete jacket under water if steel pile is incased in concrete at waterline

5. Inspect connections if angle cross bracing extends underwater

Timber Piles

1. Inspect for condition of timber

   Inspect for soundness. Core pile underwater when necessary and record remaining pile section. Plug hole with treated plugs after inspection. When decay is found, remove unsound material and determine the remaining cross section.

   Inspect for marine life attack. Wood immersed in seawater is subject to biological deterioration. A variety of marine borers can cause loss of wood volume and a corresponding decrease in strength. The two divisions of destructive organisms are the molluscan borers and the crustacean borers.

   a. Molluscan borer. The Teredo, commonly called the shipworm, is an internal borer that leaves little external evidence of its destructive activity. Visible evidence of infestation is found in the form of either surface pinholes or tunnels exposed by the destruction or removal of surface wood. These borers attack anywhere below the tidal zone and bore tunnels as large as half an inch in diameter and 30 inches long into side pilings.

      When alive the only visible sign of the animal is the two slender posterior siphons that extend above the wood surface. When anything disturbs the Teredo, the siphons are withdrawn inside the tunnel.

      Where damage is detected, only an extremely rough estimate of piling strength can be made. Core samples can be effective in determining the presence of Teredo borers but obviously only if the inspector is lucky enough to intersect a tunnel.

      The inspector should list the locations and extent of damage and indicate where it is feasible to exterminate the infestation and strengthen the member of it is necessary to replace it immediately.

Teredos generally enter poorly impregnated creosoted piles, cracks or splints, bolt holes not properly covered, uncreosoted bracing timber, the cut ends of creosoted bracing timbers, and piles.

b. Crustacean borer. The most commonly encountered crustacean borer is the Limnoria or wood louse. Limnoria is a small, lobster-like animal that gouges and erodes the wood surface. It is active principally in the intertidal zone. It bores into the surface of the wood to a shallow depth.

Wave action, abrasion, and floating debris break down the thin shell of wood outside the borer's tunnel and cause limnoria to burrow deeper. The continuous burrowing results in a progressive destruction of the timber pile cross section that exhibits a characteristic hourglass shape between tide levels.

The remaining pile section is to be recorded at the areas of attack by Limnoria. A general attack can occur over an extended surface area and produce surface erosion.

2. Inspect for large crack and splints
3. Inspect for drift accumulated and any pile damage caused by drift and debris
4. Inspect piles protected by concrete jackets

   The concrete jackets should be inspected carefully for cracks or holes that would permit entrance of marine borers.
5. Inspect for unplugged holes
6. Inspect pile cross bracings and condition of connecting bolts
7. Inspect for any loss in pile section due to abrasion

III. Report

A. Drawings

1. Elevations showing dimensions and scour, cracks, unstable conditions, etc.
2. Sections showing degree of scour, spalling, etc., in terms of mudline and waterline
3. Plans showing inspection area, inspected section, spacing of piles and footings, areas of damage

B. Summary report from inspection data

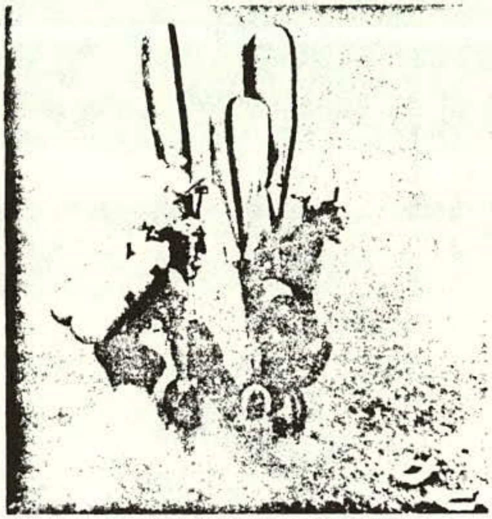
1. Describe general overall condition
2. Indicate best and worst conditions found

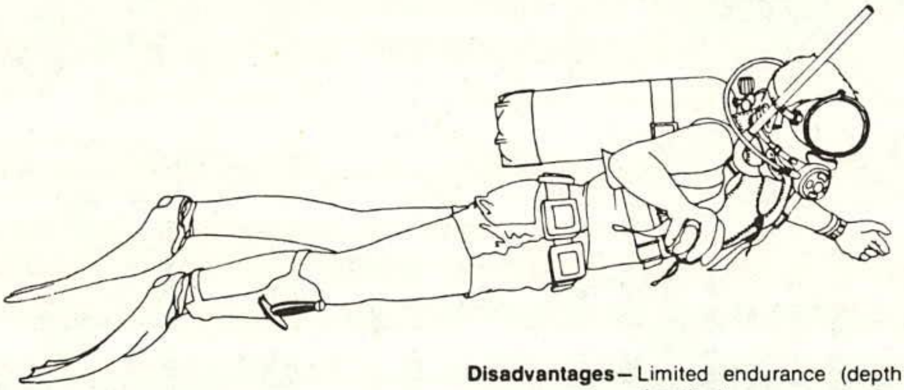
APPENDIX D

GENERAL CHARACTERISTICS OF DIVING EQUIPMENT (U.S. NAVY)

SCUBA

GENERAL CHARACTERISTICS


Open-Circuit SCUBA divers at work.



Minimum Equipment— Open-circuit SCUBA
Life preserver
Weight belt
Knife
Face mask
Swim fins

Principle Applications— Shallow water search
Inspection
Light repair and recovery
Clandestine operations

Advantages— Rapid deployment
Portability
Minimum support
Excellent horizontal and vertical mobility
Minimum bottom disturbances

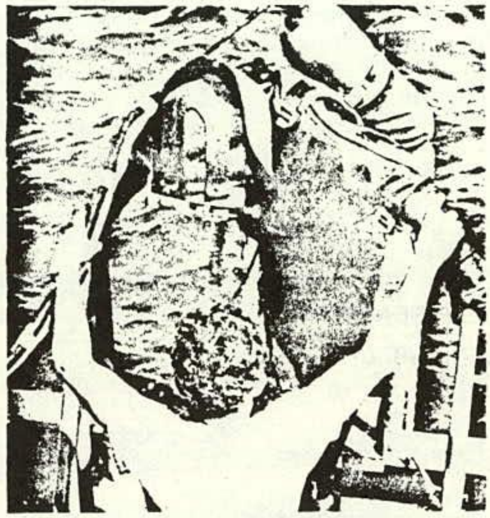
Disadvantages— Limited endurance (depth and duration)
Breathing resistance
Limited physical protection
Influenced by current
Lack of voice communication

Restrictions— Working limits—
Normal 60 feet/60 minutes
Maximum 130 feet/10 minutes
Current—1 knot maximum
Diving team—minimum 4 men

Operational Considerations— Buddy and standby diver required
Small boat required for diver recovery
Avoid use in areas of coral and jagged rock
Moderate to good visibility preferred
Ability to free ascend to surface required.

LIGHTWEIGHT DIVING

GENERAL CHARACTERISTICS



Diver using lightweight MK I diver's mask.

Minimum Equipment–
Diver's Mask USN MK 1 or Jack Browne mask
Wet suit
Weight belt
Knife
Swimfins or shoes
Surface umbilical

Principle Applications–
Shallow water search
Inspection and major ship repair
Light salvage

Advantages–
Unlimited by air supply
Good horizontal mobility
Voice and/or line pull communications
Fast deployment

Disadvantages–
Limited physical protection
Limited vertical mobility
Large support craft required

Restrictions–
Work limits–Jack Browne –
Normal 60 feet/60 minutes
Maximum 90 feet/30 minutes
Work limit—MK 1 without come home bottle
Maximum 60 feet
Work limit–MK 1 without open bell
Maximum 130 feet/10 minutes
Work limit–MK 1 with open bell
Maximum 190 feet/60 minutes
Current–2.5 knots max.

Operational Considerations–
Ability to free ascend to surface required, with exception noted in Para. 6.8.7.2.
Adequate air supply system
Standby diver required

DEEP-SEA DIVING
GENERAL CHARACTERISTICS

Minimum Equipment–
- Helmet and breastplate
- Diving dress
- Thermal underwear
- Weight belt
- Weighted shoes
- Knife
- Rubber cuffs and/or gloves
- Surface umbilical

Diver in MK V deep-sea diving outfit entering the water.

Principle Applications–
- Deep diving operations
- Heavy salvage and repair
- Underwater construction

Advantages–
- Unlimited by air supply
- Maximum physical and thermal protection
- Voice and line pull communication
- Variable buoyancy

Disadvantages–
- Slow deployment
- Poor mobility
- Large support craft and surface crew

Restrictions–
- Work limits–
  - Normal 190 feet/40 minutes
  - Maximum 250 feet/90 minutes (Exceptional Exposure)
- Current–2.5 knots
- Diving team–minimum 6 men

Operational–Considerations–
- Adequate air supply system
- Stand-by diver required
- Medical officer and recompression chamber required below 170 feet
- Exceptional exposures require approval of Commanding Officer or higher authority.

APPENDIX E

SELECTED REPAIR AND MAINTENANCE ITEMS—FLORIDA DOT (*15*)

STATE OF FLORIDA DEPARTMENT OF TRANSPORTATION BRIDGE REPAIR MANUAL	ITEM NO. 837	Page 1 of 2
	UNIT: Each	

ITEM NAME: Steel H Pile Repair

DESCRIPTION: Reinforcing deteriorated steel H pile by bolting steel channel to weakened section.

APPLICATION: This repair method is used to increase the structural strength of a deteriorated section of H pile. This method of repair is applicable when pile replacement is not practical. Considered short term repair unless pile is jacketed.

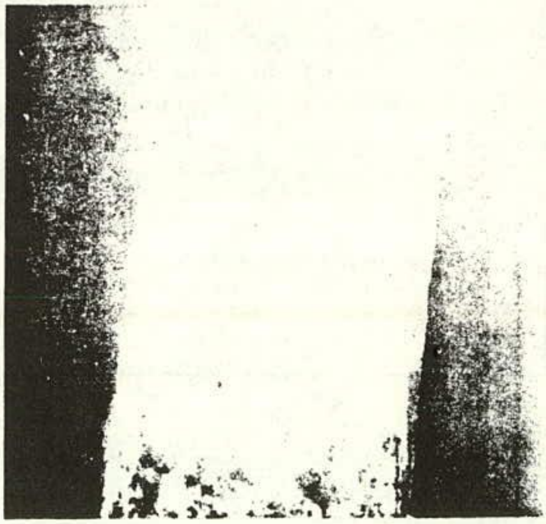
TRAFFIC CONTROL AND SAFETY: Refer to Manual on Uniform Traffic Control & Safe Practices.

MATERIALS:
3/4" Ø High strength bolts/nuts & washers - M.S. #962-2
Steel channel (pile size 2")--------------- M.S. #962
Self-curing inorganic zinc-rich coating --- APL
(if above water)

CONSTRUCTION METHOD:

1. Clean damaged pile.
2. Locate extreme limits of deteriorated section. Channel section shall be 18" longer than the distance between these limits.
3. Thoroughly clean area to which channel is to be bolted.
4. Clamp channel section in place against pile.
5. Locate and drill holes through channel and pile for high strength bolts.
6. Place bolts and secure.
7. Remove clamps.
8. If pile repair is above water, coat in accordance with Item No. 817. If underwater, protect with zinc anodes.

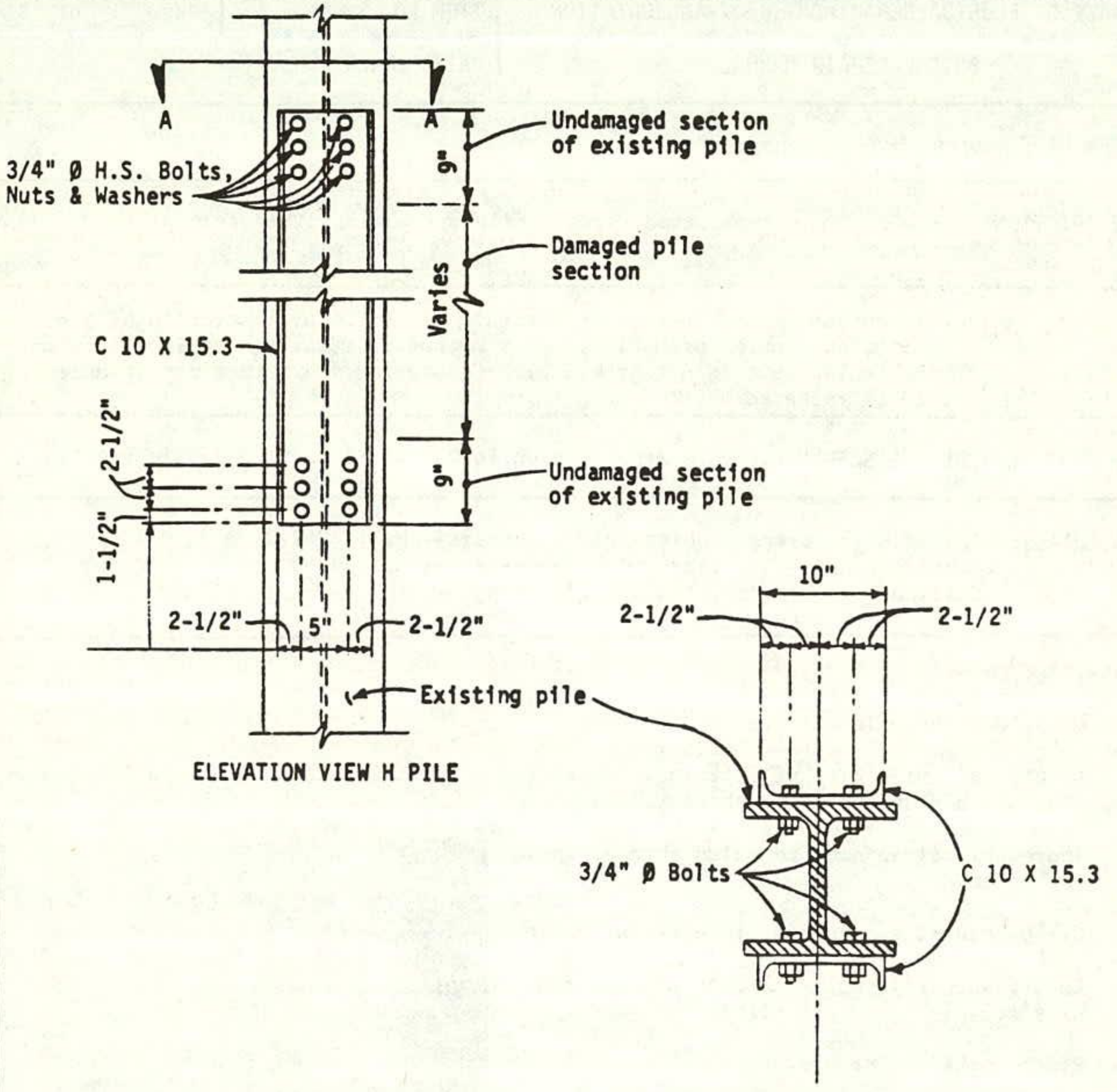
NOTE: For permanent repair, steel piles should be encased with a concrete jacket.



Damaged pile requiring reinforcement

STATE OF FLORIDA DEPARTMENT OF TRANSPORTATION	ITEM NO. 837	Page 2 of 2
BRIDGE REPAIR MANUAL	UNIT: Each	

ITEM NAME: Steel H Pile Repair



STATE OF FLORIDA DEPARTMENT OF TRANSPORTATION BRIDGE REPAIR MANUAL	ITEM NO. 838 UNIT: Each	Page 1 of 3

ITEM NAME: Concrete Pile Jacket (Reinforced)

DESCRIPTION: Encasement of concrete pile with a concrete jacket reinforced with epoxy coated rebars.

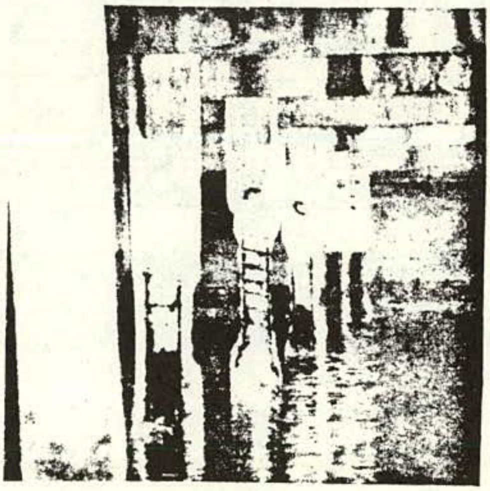
APPLICATION: This repair method should be used where a concrete pile has deteriorated to the point that structural integrity of the pile is in question.

TRAFFIC CONTROL AND SAFETY: Refer to Manual on Uniform Traffic Control & Safe Practices.

MATERIALS: Class III Concrete -------------- M.S. #354-3
Concrete Spacers
Reinforcing Steel (Epoxy Coated)- M.S. #931-1

CONSTRUCTION METHOD:

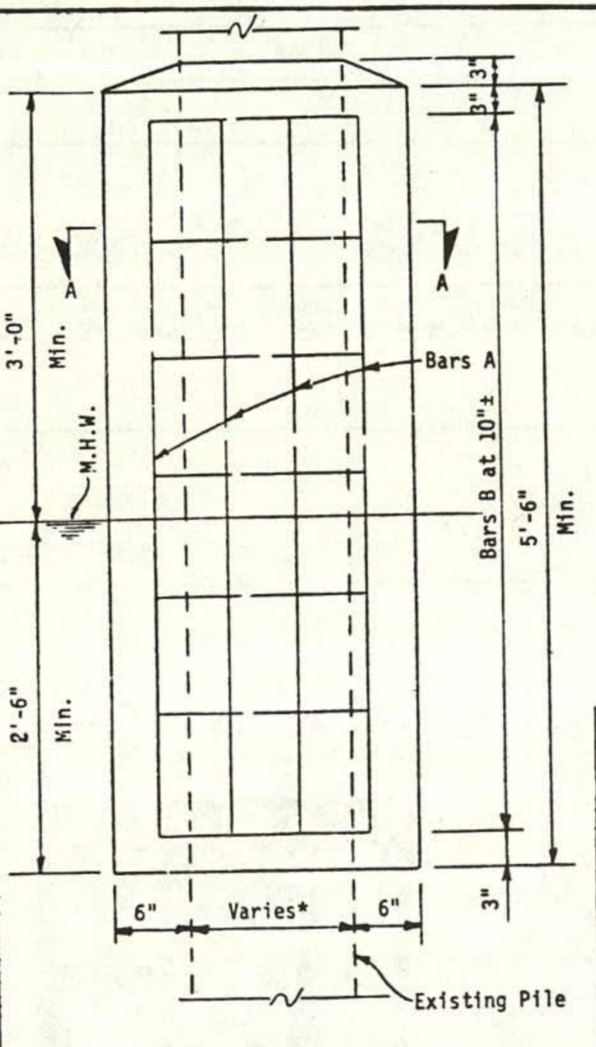
1. Remove all cracked and unsound concrete.
2. Clean pile surfaces of oil, grease, dirt and other foreign materials which would prevent proper bonding.
3. Sandblast exposed reinforcing steel to "near-white metal".
4. Place reinforcing steel cage around pile.
5. Set forms for concrete jacket. (Treat forms with an approved form release agent before placing concrete.)
6. Dewater forms and place concrete.
7. Leave forms in place for a minimum of 72 hours.



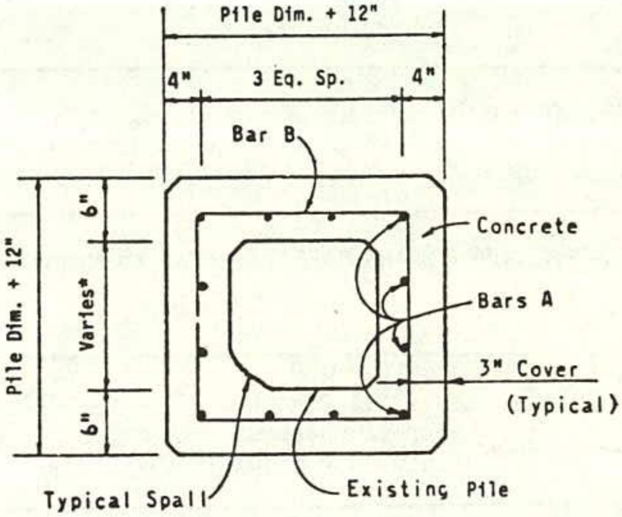
Typical condition where this repair method should be used.

STATE OF FLORIDA DEPARTMENT OF TRANSPORTATION BRIDGE REPAIR MANUAL	ITEM NO. 838	Page 2 of 3
	UNIT: Each	

ITEM NAME: Concrete Pile Jacket (Reinforced)



ELEVATION OF PILE

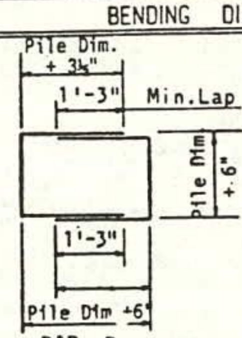


SECTION A-A

BILL OF REINFORCING STEEL

MARK	SIZE	NO. REQ'D.	LENGTH
A	5	12	Min. 5' - 0"
B	4	Min. 7	Varies

BENDING DIAGRAMS

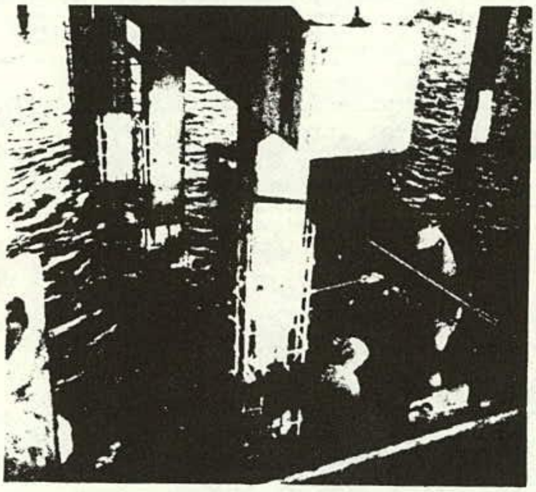


BAR B

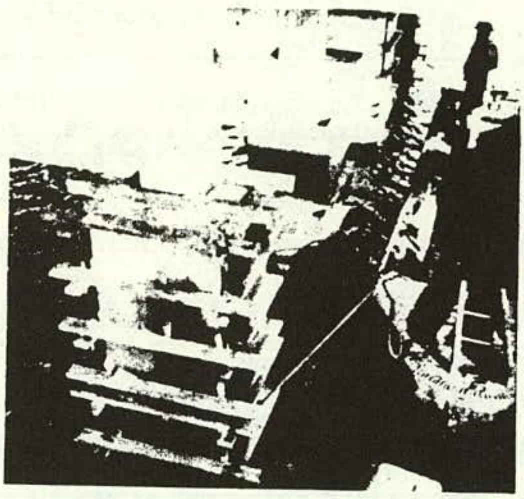
NOTE: All bar dimensions are out-to-out.

STATE OF FLORIDA DEPARTMENT OF TRANSPORTATION	ITEM NO. 838	Page 3 of 3
BRIDGE REPAIR MANUAL	UNIT: Each	

ITEM NAME: Concrete Pile Jacket (Reinforced)



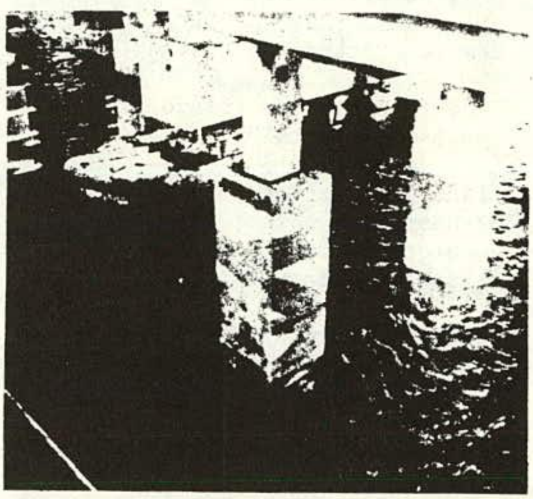
Placing epoxy coated reinforcing steel cage for pile jacket.



Forming arrangement for placing concrete.

*This measurement must be varied for size of pile. Jacket may be used on the following type and size piling.

Reinf. Conc. or Prestressed (14" Sq.)
Reinf. Conc. or Prestressed (18" Sq.)
Reinf. Conc. or Prestressed (20" Sq.)
Reinf. Conc. of Prestressed (24" Sq.)



Completed epoxy coated reinforced pile jacket.

STATE OF FLORIDA DEPARTMENT OF TRANSPORTATION BRIDGE REPAIR MANUAL	ITEM NO. 839	Page 1 of 5
	UNIT: Linear Foot	

ITEM NAME: Integral Pile Jacket (Conc.) - Type I, II, III, IV, V & VI

DESCRIPTION: Encasement of concrete piles with a fiberglass form filled with epoxy grout, cement grout or seal concrete between form and pile.

APPLICATION: Types I through IV are used to protect the pile from further deterioration. Types V and VI are used to restore structural integrity and protect the pile from further deterioration. See note on Page 2.

TRAFFIC CONTROL AND SAFETY: Refer to Manual on Uniform Traffic Control & Safe Practices.

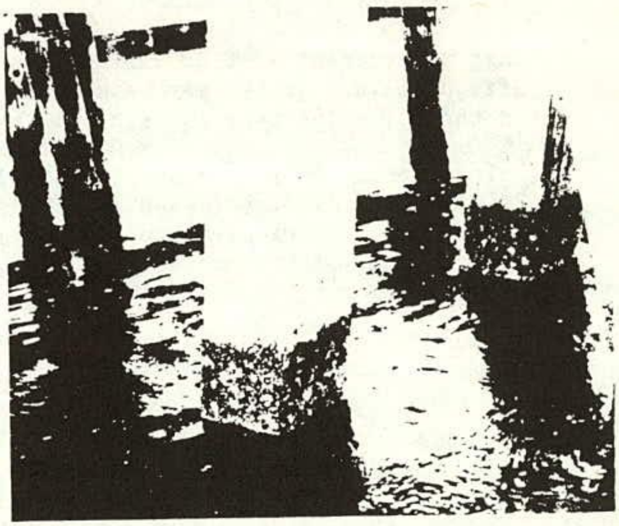
MATERIALS:

Material	Type	Specification
Epoxy bonding compound		APL
Fiberglass Forms	All types	M.S. #457-1
Epoxy Grout Filler	Type I & III	M.S. #926-2
Portland Cement Grout Filler	Type II & IV	M.S. #460-30
Class III Concrete Filler	Type V & VI	M.S. #345-3

CONSTRUCTION METHOD:

General for all Types:

1. Clean pile surfaces of oil, grease, dirt and other foreign materials which would prevent proper bonding.
2. Remove cracked and unsound concrete.
3. Sandblast exposed reinforcing steel to "near-white metal".
4. Place pile jacket form around pile. Standoffs of either form material or concrete blocks should be permanently attached to form or pile.
5. Seal interlocking joint with epoxy bonding compound and seal bottom of form against pile surface.
6. Place external bracing and bonding materials.
7. Dewater form.



Typical condition where Types I and III jacket should be used.

ITEM NAME: Integral Pile Jacket (Conc.) - Type I, II, III, IV, V & VI

8. Fill annulus between the pile and form with specified filler.

9. Remove external bracing and banding, and clean any filler material deposited on forms.

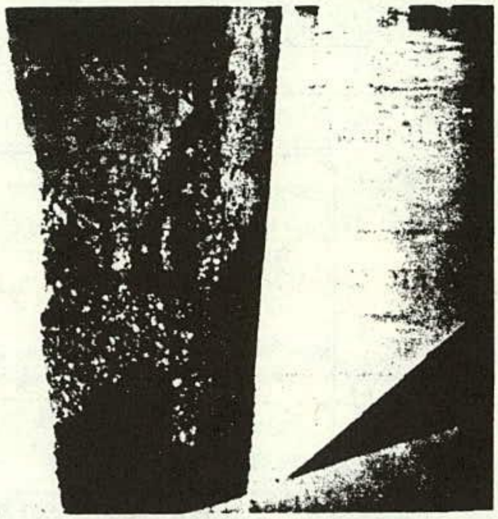
SPECIAL CONSTRUCTION METHODS

Prestressed Concrete Pile - In cases where prestressed strands have been exposed and deteriorated, they are to be removed and replaced with No. 4 reinforcing bars. A minimum of 12" of sound strand material should be used at each end of reinforcing bar for splice.

NOTE:

Type I, III and V are used when deterioration terminates at the water line or no more than one or two feet below.

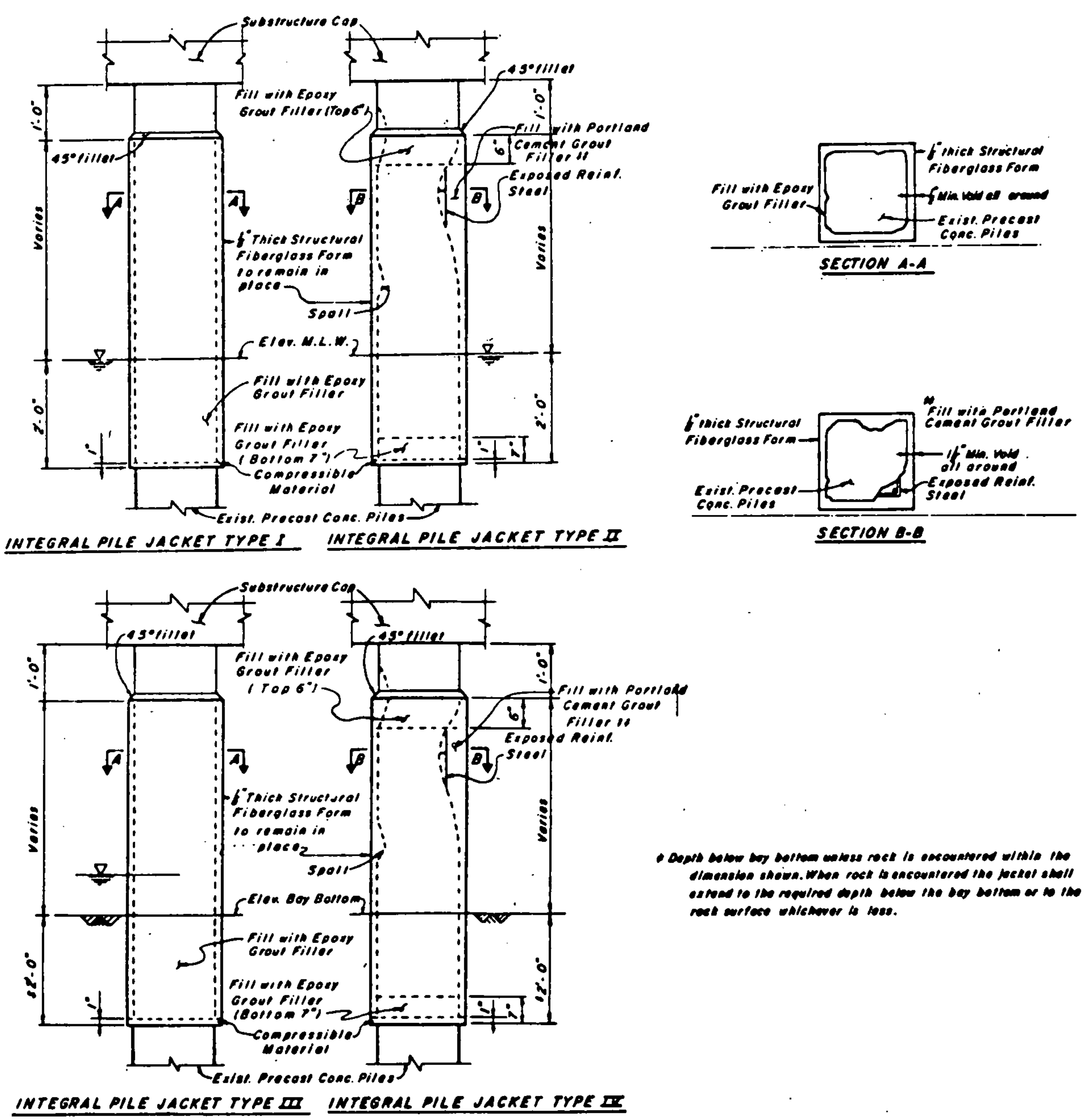
Type II, IV and VI are used when deterioration runs the full length of the pile.



Typical condition where Types II and IV jacket should be used.

Typical condition where Types V or VI jacket should be used.

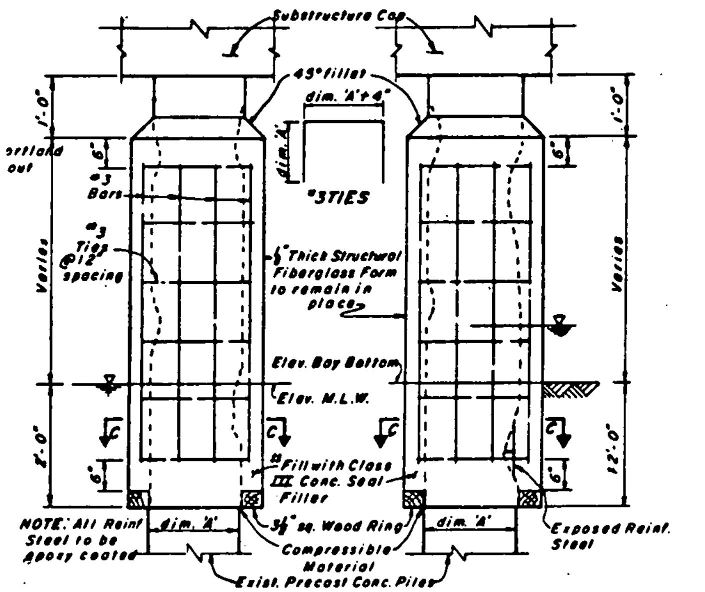
STATE OF FLORIDA DEPARTMENT OF TRANSPORTATION BRIDGE REPAIR MANUAL	ITEM NO. 839	Page 3 of 5
	UNIT: Linear Foot	
ITEM NAME: Integral Pile Jacket (Conc.) - Type I, II, III, IV, V & VI		



* Depth below bay bottom unless rock is encountered within the dimension shown. When rock is encountered the jacket shall extend to the required depth below the bay bottom or to the rock surface whichever is less.

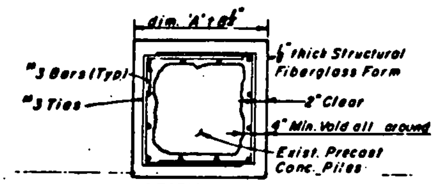
STATE OF FLORIDA DEPARTMENT OF TRANSPORTATION BRIDGE REPAIR MANUAL	ITEM NO. 839	Page 4 of 5
	UNIT: Linear Foot	

ITEM NAME: Integral Pile Jacket (Conc.) - Type I, II, III, IV, V & VI

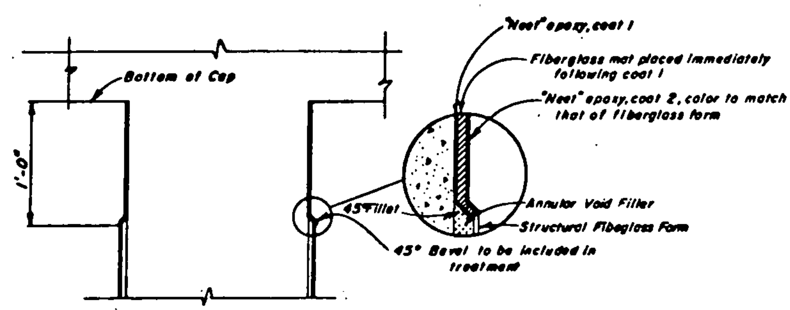


NOTE: An external band shall be drawn against the wood ring seal during placement of Seal Concrete

INTEGRAL PILE JACKET TYPE V   INTEGRAL PILE JACKET TYPE VI



SECTION C-C

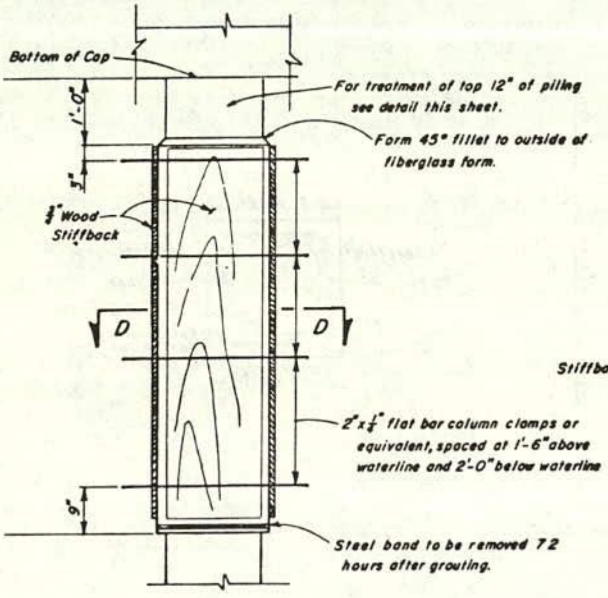


DETAIL OF STANDARD TREATMENT OF TOP 12" OF PILING

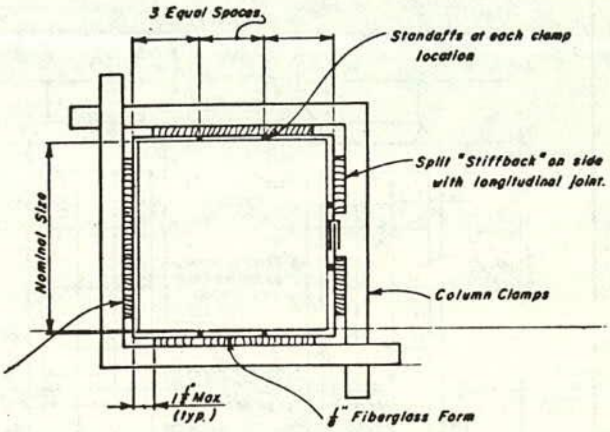
NOTE: The top 12" of piling shall be restored to the original lines with epoxy mortar

STATE OF FLORIDA DEPARTMENT OF TRANSPORTATION	ITEM NO. 839	Page 5 of 5
BRIDGE REPAIR MANUAL	UNIT: Linear Foot	

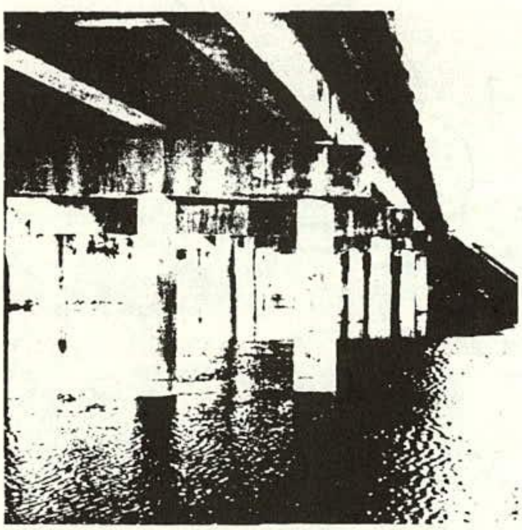
ITEM NAME: Integral Pile Jacket (Conc.) - Type I, II, III, IV, V & VI



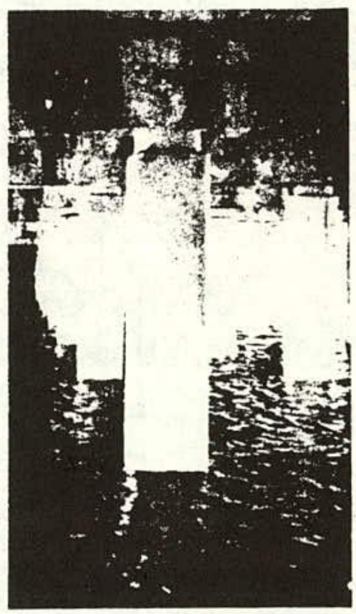
CONSTRUCTION METHOD DETAIL



SECTION D-D



Example of Integral Pile Jacket constructed on a round pile.



Example of Integral Pile Jacket constructed on a square pile.

STATE OF FLORIDA DEPARTMENT OF TRANSPORTATION BRIDGE REPAIR MANUAL	ITEM NO. 840	Page 1 of 3
	UNIT: Linear Foot	

ITEM NAME: Integral Pile Jacket - Steel

DESCRIPTION: Encasement of steel piles with a fiberglass form filled with Portland cement grout filler between form and pile.

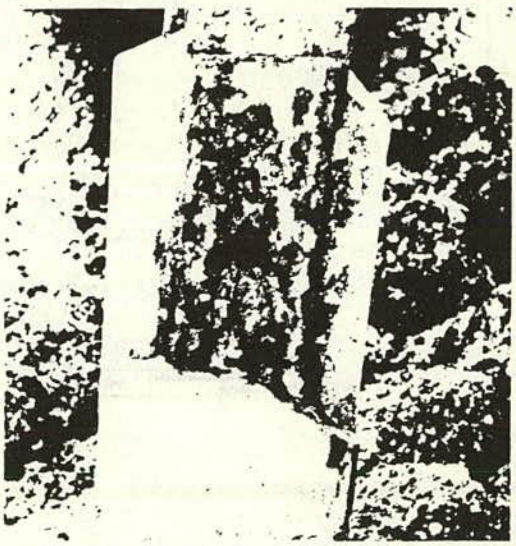
APPLICATION: Provides protection to steel piles above and below water. Not applicable where loss of section of the pile is such that reinforcement is required.

TRAFFIC CONTROL AND SAFETY: Refer to Manual on Uniform Traffic Control & Safe Practices.

MATERIALS:
Fiberglass Forms ------------- M.S. #457-1
Epoxy Grout Filler ----------- M.S. #926-2
Portland Cement Grout Filler - M.S. #460-30
Epoxy Bonding Compound ------- APL

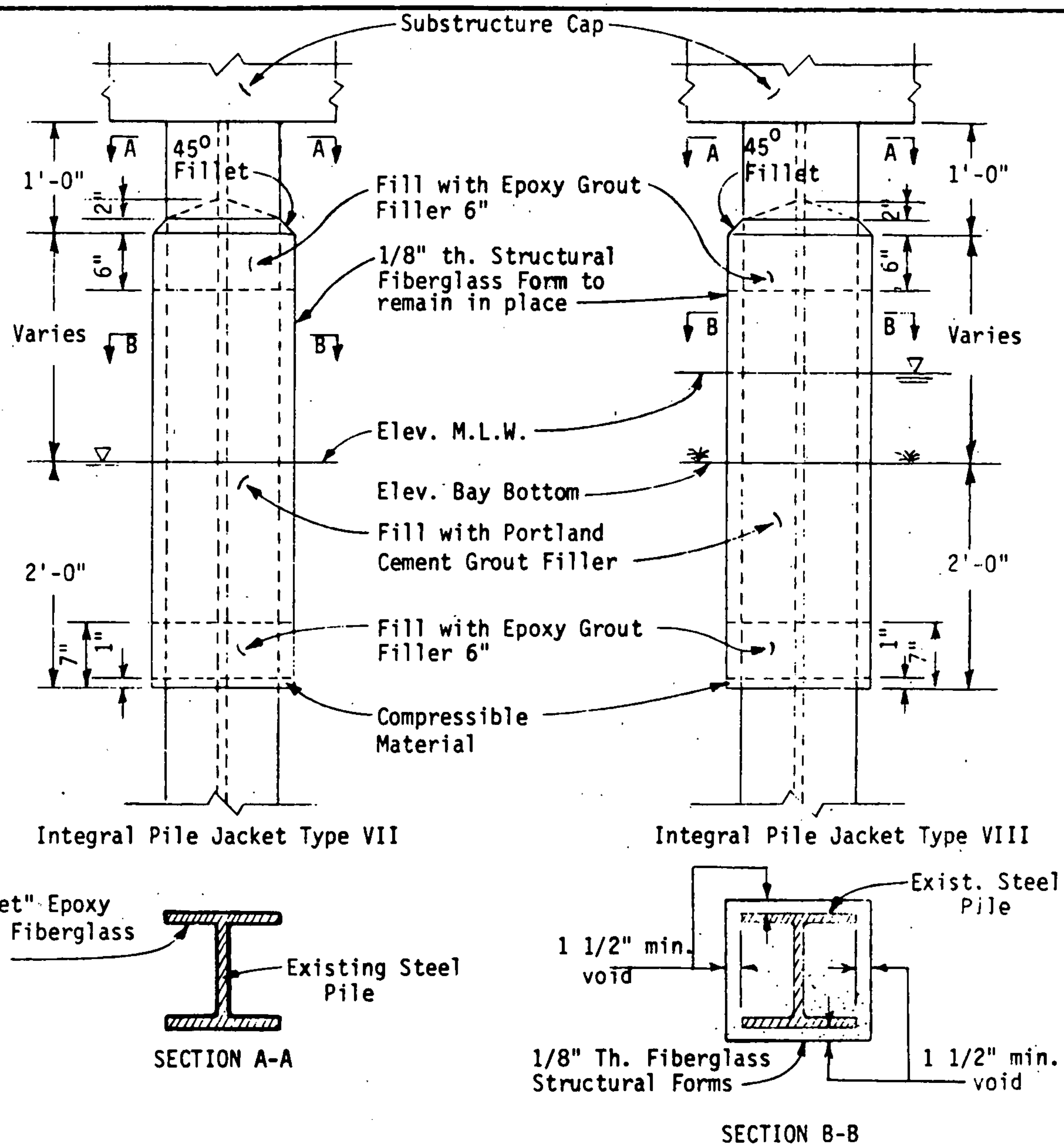
CONSTRUCTION METHOD:

1. Clean pile surfaces of oil, grease, dirt and corrosion by sandblasting to "near white metal".
2. Place pile jacket form around pile. Standoffs of form material should be permanently attached to form or pile.
3. Seal interlocking joint with epoxy bonding compound and seal bottom of form against pile surfaces.
4. Place external bracing and banding materials.
5. Dewater form.
6. Fill bottom six inches of form with epoxy grout filler.
7. Fill form to top 6" with Portland cement grout filler.
8. Fill to 6" with epoxy grout filler. Form fillet and slope grout to web of pile.
9. Remove external bracing and banding, and clean any filler material deposited on form.

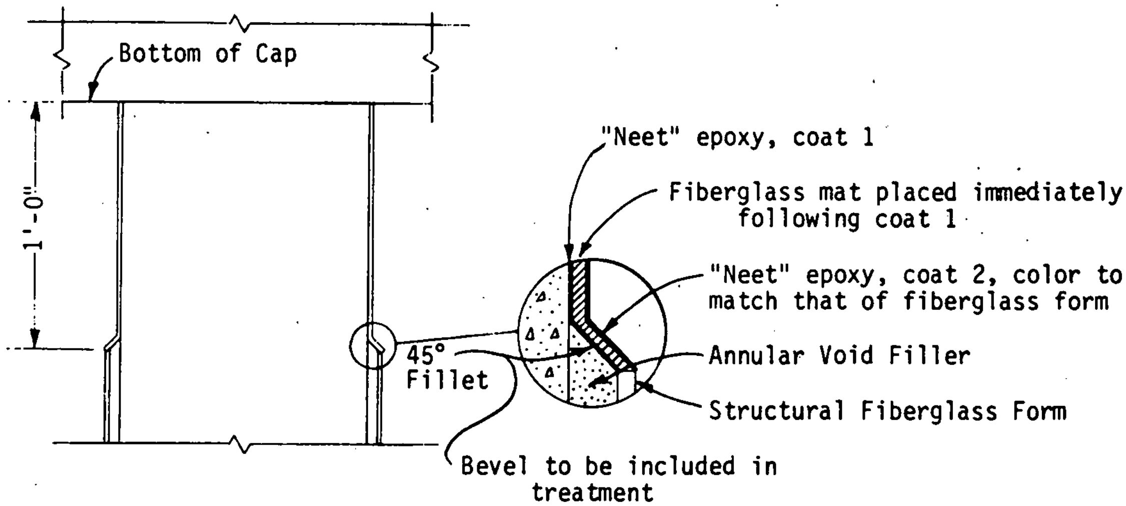


Typical condition where this repair method should be used.

STATE OF FLORIDA DEPARTMENT OF TRANSPORTATION BRIDGE REPAIR MANUAL	ITEM NO. 840	Page 2 of 3
	UNIT: Linear Foot	
ITEM NAME: Integral Pile Jacket - Type VII & VIII		



STATE OF FLORIDA DEPARTMENT OF TRANSPORTATION BRIDGE REPAIR MANUAL	ITEM NO. 840	Page 3 of 3
	UNIT: Linear Foot	
ITEM NAME: Integral Pile Jacket - Steel		



DETAIL OF STANDARD TREATMENT OF TOP 12" OF PILING

NOTE: The top 12" of piling shall be restored to the original lines with epoxy mortar.

STATE OF FLORIDA DEPARTMENT OF TRANSPORTATION BRIDGE REPAIR MANUAL	ITEM NO. 844	Page 1 of 3
	UNIT: Each Pile	

ITEM NAME: Cathodic Protection (Zinc Anodes - Small)

DESCRIPTION: Attachment of small zinc anodes to steel H piles or reinforced concrete piles below water by use of a clamping device.

APPLICATION: To abate corrosion of steel H piles or reinforced concrete piles located in salt or brackish water when less than 8 lineal feet of pile is exposed. Applicable for all sizes of steel and reinforced concrete piles.

TRAFFIC CONTROL AND SAFETY: Refer to Manual on Uniform Traffic Control & Safe Practices.

MATERIALS: Zinc Anodes - 4, 7 or 10 pound - M.S. #964

CONSTRUCTION METHOD:

<u>Steel H Pile</u>

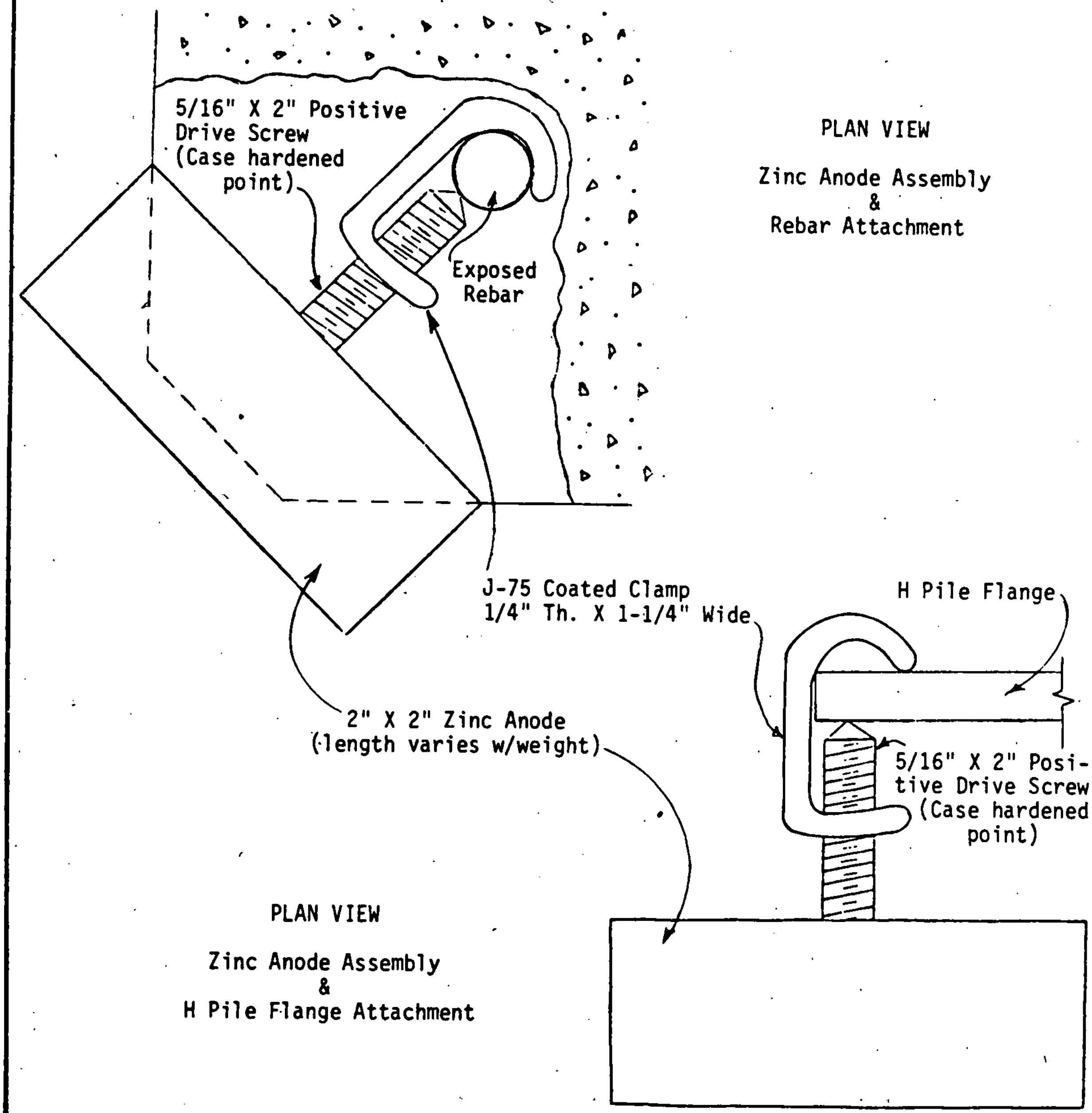
1. Clean area on steel large enough to accommodate the clamp and hardware.
2. Place two anodes on opposite flanges 12" below low water line and then alternate one anode on each flange every 18 inches to the mud line. If the pile has concrete jackets in the splash zone, place the first two anodes 6" below the jacket in the water. (See Drawings on Pages 2 & 3.)

<u>Reinforced Concrete Pile</u>

1. Clean area on exposed reinforcing bar large enough to accommodate the clamp and hardware.
2. Place one anode on exposed reinforcing bar for each six lineal feet of pile in contact with brackish or salt water.

NOTE: The normal application consists of using 7-pound anodes. The use of 4 or 10 pound anodes requires additional site testing. Less brackish water or fast moving sea water will affect the two-year life expectancy requiring a change in the size of the anode. Contact the Bridge Maintenance and Operations Engineer in Orlando for coordinating design changes.

STATE OF FLORIDA DEPARTMENT OF TRANSPORTATION BRIDGE REPAIR MANUAL	ITEM NO. 844	Page 2 of 3
	UNIT: Each Pile	
ITEM NAME: Cathodic Protection (Zinc Anodes - Small)		



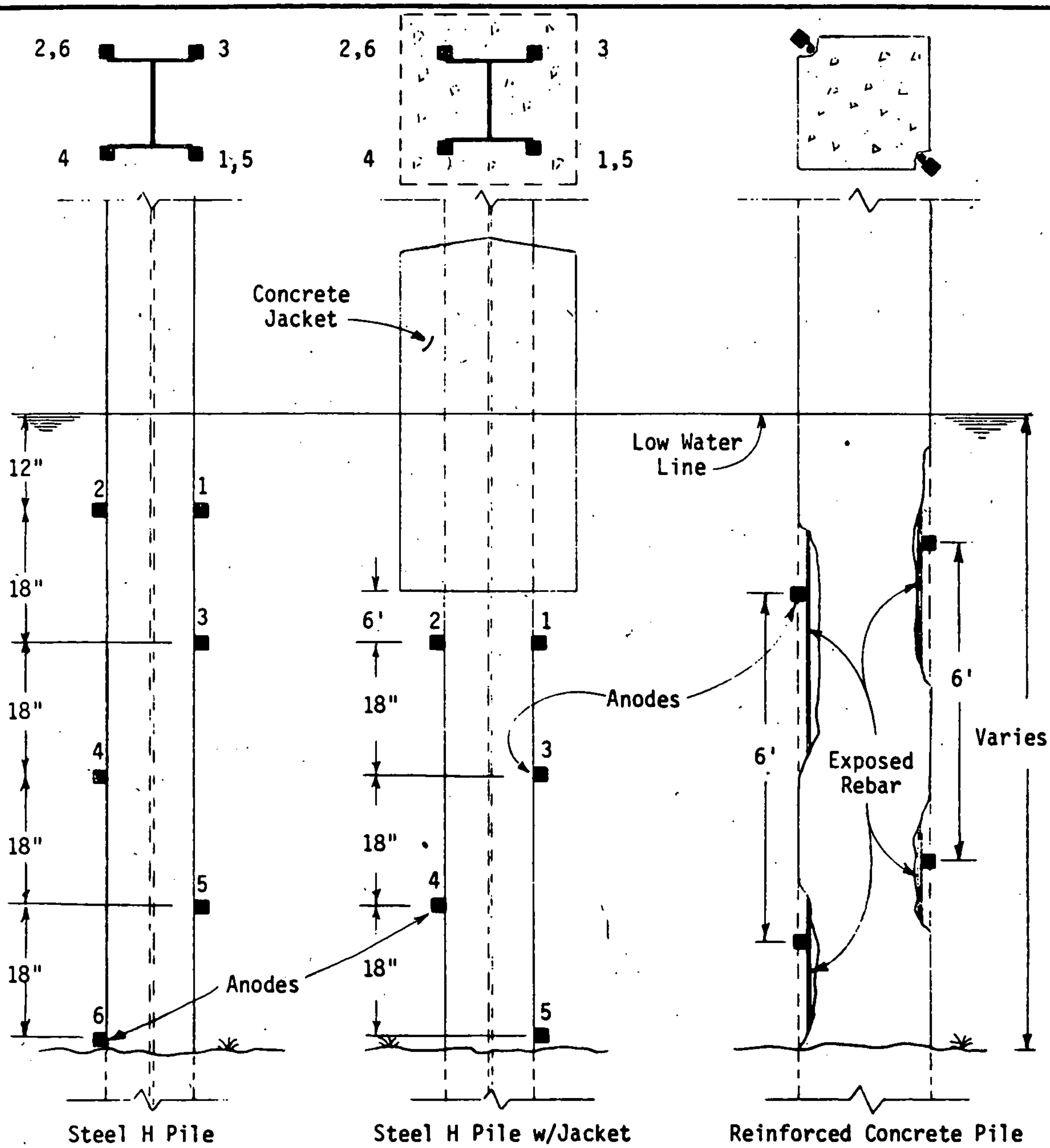
PLAN VIEW

Zinc Anode Assembly
&
Rebar Attachment

PLAN VIEW

Zinc Anode Assembly
&
H Pile Flange Attachment

STATE OF FLORIDA DEPARTMENT OF TRANSPORTATION BRIDGE REPAIR MANUAL	ITEM NO. 844	Page 3 of 3
	UNIT: Each Pile	
ITEM NAME: Cathodic Protection (Zinc Anodes - Small)		



STATE OF FLORIDA DEPARTMENT OF TRANSPORTATION BRIDGE REPAIR MANUAL	ITEM NO. 845	Page 1 of 3
	UNIT: Each	

ITEM NAME: Cathodic Protection (Zinc or Aluminum Anode - Large)

DESCRIPTION: Attachment of large zinc or aluminum anodes to steel H pile below water by use of a clamping device.

APPLICATION: To abate corrosion of steel H pile located in salt or brackish water when more than 8 lineal feet of pile is exposed. Applicable for 10", 12" and 14" piles.

TRAFFIC CONTROL AND SAFETY: Refer to Manual on Uniform Traffic Control & Safe Practices.

MATERIALS: 48 pound zinc anode w/clamp ----- M.S. #964
or
21 pound aluminum anode w/clamp - M.S. #964

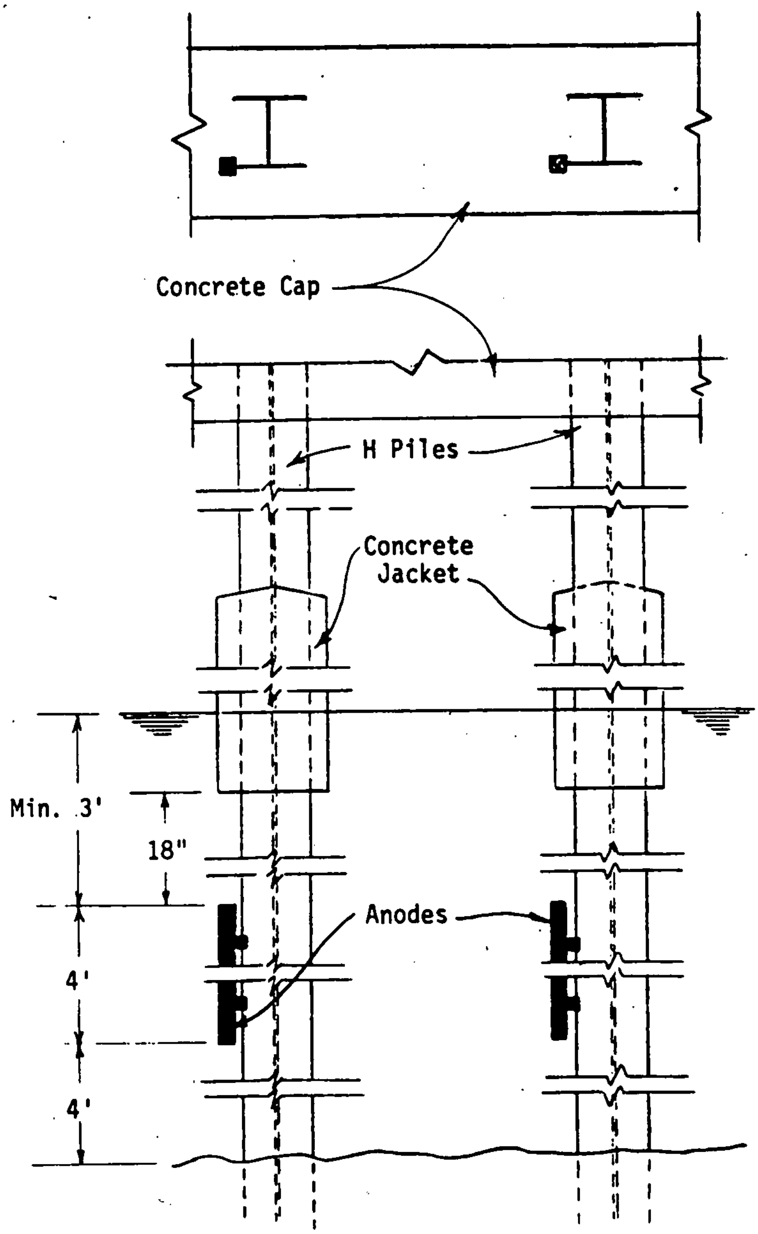
CONSTRUCTION METHOD:

NOTE: Zinc and aluminum anodes are comparable in efficiency, but both should never be used at the same site or installation.

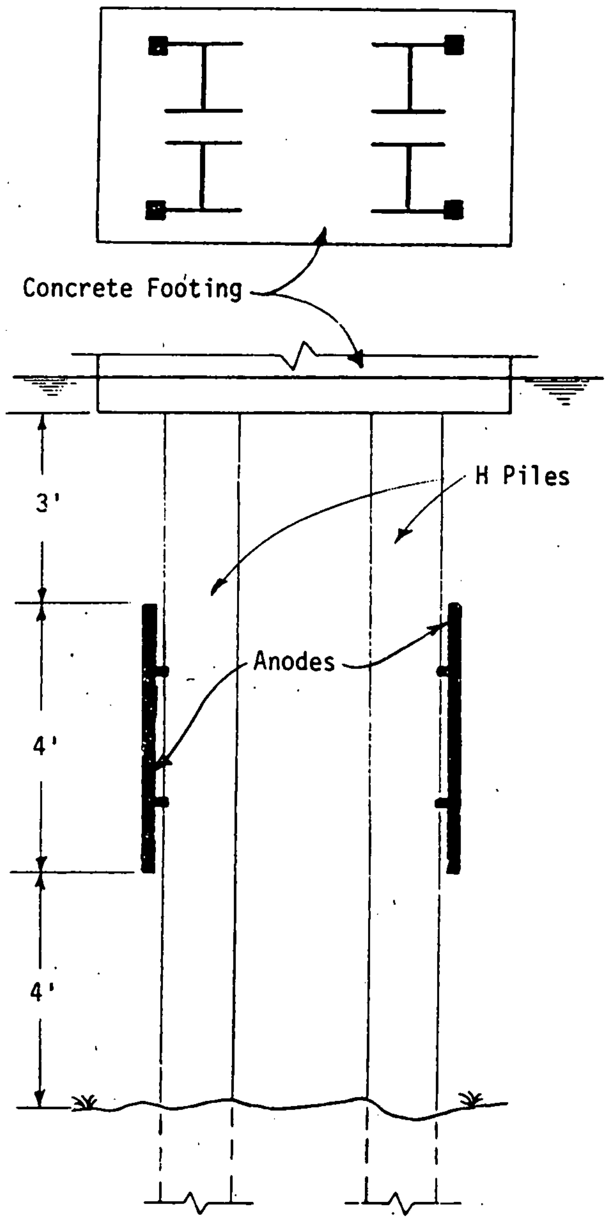
1. Anode should be placed approximately in the middle of the area to be protected. The top of the anode must always be below the low water line.
2. Clean area on the steel pile large enough to accommodate the clamps.
3. Tighten the two clamps on the anode to the flange of the pile. Positive contact between the clamp bolt and the steel pile is absolutely essential.

(See drawings on Pages 2 and 3 for applicable installations.)

STATE OF FLORIDA DEPARTMENT OF TRANSPORTATION BRIDGE REPAIR MANUAL	ITEM NO. 845	Page 2 of 3
	UNIT: Each	
ITEM NAME: Cathodic Protection (Zinc or Aluminum Anode - Large)		



STATE OF FLORIDA DEPARTMENT OF TRANSPORTATION BRIDGE REPAIR MANUAL	ITEM NO. 845	Page 3 of 3
	UNIT: Each	
ITEM NAME: Cathodic Protection (Zinc or Aluminum Anode - Large)		



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